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# IGC Newsletter

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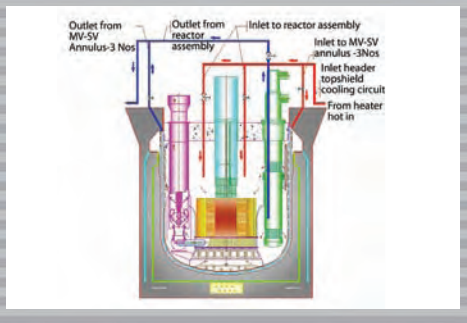
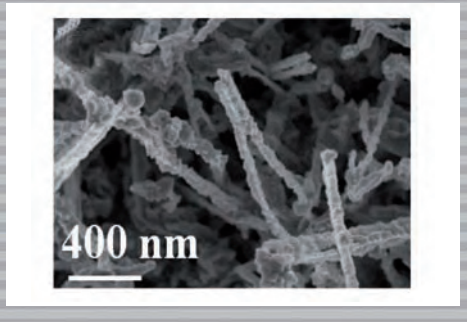
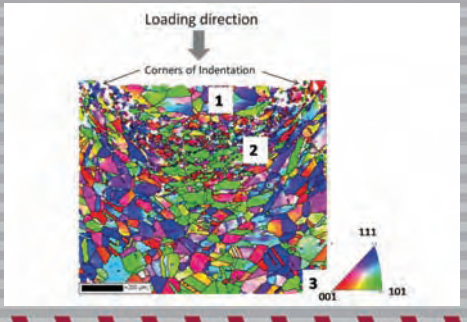



INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH
http://www.igcar.gov.in/lis/nl101/igc101.pdf

# From the Editor

## Dear Reader

It is my pleasant privilege to forward a copy of the latest issue of IGC Newsletter (Volume 101, July 2014, issue).

IGC Newsletter has been carrying a regular feature of interaction of young officers with eminent personalities. In this issue we are extremely happy to present the summary of the interaction with Dr. Baldev Raj, former Director, IGCAR, who is always passionate about discussing with youngsters, keen to motivate and encourage them to perform better.

In the first technical article Shri Babu and Dr. Murugan have shared their experience in the development of Extended Spark Type Leak Detector that detects any sodium leak in the main and safety vessel of PFBR.

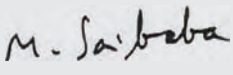
In the second technical article Shri Sudharshan and colleagues have described a preheating strategy devised for PFBR with both the primary sodium pumps in position and establishment of a mockup facility to simulate PFBR reactor assembly for confirming the preheating scheme.

In the young officer's forum, a study on the optical properties of II-V nitride nanostructures grown by chemical vapor deposition technique is described by Shri Kishore Kumar Madapu.

The work carried out in establishing an innovative and material non-invasive impression creep technique that enables to evaluate the creep deformation behavior of 316LN stainless steel and its weld joints has been elaborated by Shri Naveena in the young researcher's forum.

We are happy to share with you the awards, honours and distinctions earned by our colleagues. We look forward to your comments, continued guidance and support.

With my best wishes and personal regards,



(M. Sai Baba)
Chairman, Editorial Committee, IGC Newsletter
&
Associate Director, Resources Management Group

# Interaction with Dr. Baldev Raj


Young Officers with Dr. Baldev Raj, Dr. P. R. Vasudeva Rao, Director, IGCAR and colleagues of the Centre

**Can you share with us your experience regarding commissioning of Hot cells at Radiometallurgy Laboratory, IGCAR. Do you recollect any special knowledge you gained from this assignment?**

I was inspired by Homi Bhabha to join the Department, he was like a magnet, pulling me even in my dreams to join the Department and I was luckily accepted by the Department. I was about just twenty five years old, when the then Director, Late Shri N. Srinivasan assigned me the task of commissioning the hot cells and designated me as Group Leader of hot cells. I was elated for two reasons – one because this was the second largest project, next only to FBTR being pursued at our Centre at that time, and the other was that, the Director of the Centre placed confidence in such a young person. Shri N. Srinivasan wanted a young person to be fully independent both in terms of thinking and execution, which has been great for me throughout my life. The assignment was in the area of civil engineering, so I went back to him and said,

***Dr. Baldev Raj,*** *is currently Director, National Institute of Advanced Studies, Bangalore and President, Indian National Academy of Engineering, Former Director of Indira Gandhi Centre for Atomic Research, Kalpakkam, Department of Atomic Energy, Member, German National Academy of Sciences, International Nuclear Energy Academy, Fellow, The World Academy of Sciences, Fellow of all Engineering and Science Academies in India. His specializations include materials characterization, testing and evaluation using non-destructive evaluation methodologies, materials development and performance assessment and technology management. He has steered and mentored large, multi, cross-disciplinary and multi-institutional teams to earn for India an eminent and esteemed position in high technology domain of sustainable clean energy system through the sodium cooled fast reactors with closed fuel cycle. He has more than 970 publications in leading journals and books. He has co-authored and co-edited 70 books and special journal volumes. He has 6 Indian Standards and 26 patents to his credit. He is Editor-in-Chief of three series of books, NDE Science & Technology, Metallurgy & Materials and Corrosion Science & Technology. He has delivered more than 300 honour, plenary, keynote and invited talks in his fields of specialization. He has won many awards and honours, notable among them are Homi Bhabha Centenary Gold Medal, Indian Science Congress 2012, Homi Bhabha Lifetime Achievement Award, Indian Nuclear Society(2011), Indian National Science Academy Prize for Materials Science (2010), Portevin Lecture of International Institute of Welding (2011), Distinguished Alumni Award (2007) of Indian Institute of Science, Pandit Jawaharlal Nehru National Award from Department of Science & Technology, Government of Madhya Pradesh (2007), Padma Shri from Government of India (2006), Life Time Achievement Award of Indian Society for Nondestructive Testing (2004).These achievements establish him as an eminent and prolific researcher in domains of his expertise.*

" I am a gold medalist in Metallurgy and came to the Department to do research and you are asking me to do concrete, embedments, cells etc., would not a civil or mechanical engineer be more appropriate?". He replied in a single sentence, "This will be helpful to you". At that point of time, I did not realize that Shri N. Srinivasan himself had done the same by building the plutonium plant at BARC, being a chemical engineer. So the message was bold and clear that if he was asking me to do something, it meant that he was dreaming something for me. Then I took up the assignment. As a metallurgist, I was not good at reading civil drawings, but I had to read a big bundle each day as a part of my assignment. I approached my colleagues Shri P.V. Kumar, Shri K.V. KasiViswanthan and Shri P. Kalyanasundaram and told that "though I would like to pursue research, the Department has given me this responsibility, which I would like to pursue and you people have to support me". It was a management of equals at the age of twenty five. It was a small team with good understanding and all of us shared the work.
What I cherish the most is learning civil engineering and I soon started enjoying it. After a few years, I never felt a stranger to concepts in civil engineering. Another thing that I would like to mention is that the civil engineering team led by Shri C.R. Nagaraj was very strong. He was very particular that construction activities should never get delayed. He along with late Dr. Placid Rodriguez was able to convince some of the suppliers to ensure the supply of embedments thereby speeding up the activities. I can tell you that there are two ways to face any challenge: (i) give up and say, "I cannot meet the challenge" that means you are shutting down your career and your own confidence, or alternatively (ii) beat the challenge with your imagination and the support of your team.

Sir, extending this question to carbide fuel, how did you feel when the choice was made on carbide fuel. What was your personal reaction, because it was for the first time a reactor in the world had to go critical with this fuel?

At that time Shri N. Srinivasan asked three groups, Chemistry, Reactor Design and Metallurgy Groups to make studies independently. We were all competing with each other. Youngsters would discuss, but the seniors would not. Sometimes even the youngsters would not discuss because of the superiors' instructions to maintain secrecy. One thing that was converging was that the carbide fuel could not be used unless it was tested in an existing reactor like Cirus etc., Characteristics of the fuel with 70% plutonium is a well known devil, but what was intriguing was the plutonium in the form of a carbide. It was destiny that Dr. Raja Ramanna chose me through the then Director of the Centre, to make a presentation on behalf of the Centre to the Council, as to what should be the choice of the fuel. I said we had confidence based on the interpolation from the known literature, because there was some literature available on 20 and 30% Plutonium content carbide fuel. Mechanically speaking, the key factor lies in the control of the centre line temperature. Swelling would not pose a major issue, because as long as you stay below the break-away swelling, you can exactly identify how much swelling would happen upon irradiation. With a very good understanding of the basic feature that a linear heat rating of 250 watts/cm and a burn up of 25000 MW day or so is durable, we confidently went to the regulatory body with the proposal. It was accepted right away and we started working on the manufacturing of carbide fuel at BARC, which was successful. I also appreciate the extreme capability of the operating colleagues of FBTR with whom we were closely associated towards working out a regimen of raising the temperature from beginning till contact is made between the cladding and fuel, to avoid breakaway swelling. We had to establish complementary aspects of robust testing and evaluation of clad tubes with eddy current and ultrasonic tests to be acceptable to manufacturing and design professional at the highest level. Like the approach of Mahatma Gandhi (sustained selfless efforts directed to good cause), we had to convince Shri K Balaramamurthy, the then CE, NFC, regarding the specification of cladding tubes, and had to undertake innumerable trips to fine tune the specifications for acceptance and implementation. As far as I am concerned, the success of carbide fuel is attributed to the combined effort of BARC, IGCAR and NFC. In this process, it was remarkable that we had built a great team, confident to achieve something substantial. To be a leader doesn't mean that you have to do all things, instead you should drive to do, which nobody else could do. So we could thrust time in the younger years of the Centre, and also our younger years to do something which nobody has done. From the doubting eyes and minds of the world and our own colleagues, the extreme confidence in science and technology of the Fast Reactors emerged in India. That again is a message that "you challenge the challenge, you don't get challenged by the challenge" so it is a mindset of the same wording that would take you far.

Sir, how important is the role of mentor in young researchers' life?

To me it is extremely important to have a mentor even at this age. First I will tell you the definition of mentor. A mentor is a person who sees in you something which you cannot see for yourself, because we are all limited by our own perceptions. Sometimes the outsider's view is extremely important. A mentor has to be totally selfless. Your superior could have certain selfishness, because he is pursuing with you to complete the mission oriented programme, wherein you are a partner. Mentor is not a partner in your success. He is there to enhance your successes and either take you to the place where you want to go, or where he feels that you should go and starts a journey with you to take you there. Mentor has to be critical, has to take tough stands at times even while being extremely affectionate, even if it meant that he was totally wrong in supporting you. I had mentors who supported me in most of the difficult circumstances and never allowed me to lose my confidence. In life it is never a linear graph. We all have very high points, during which we feel we can challenge and do anything, and during certain other

times when we feel low for some reason and feel unable to accomplish the goals, that is when the mentors have a greater role to play.

Sir, coming to BARC Training School at IGCAR, you have mentored us. It was like a dream child for you. Now it has completed eight years. How do you feel looking back at the training school, do you feel the same excitement and thrill?

No, I feel a lot more excitement today, than at that time. Initially it was the joy of creation. When I initiated the Training School, it was pretty clear to my mind that, we have come to a stage, where without the input of the young people, this Centre would not be able to meet its aspirations. I was looking for leaders for certain programmes to push the mission. In a certain time period, we were not getting best of the people from the BARC Training School. I was convinced that we require the best people to pursue the difficult technology, of Fast Reactors. So I started thinking on how to get them? It came to my mind instantly that we should have our own Training School. Then we had to convince Dr. Anil Kakodkar the then Chairman, AEC and justify the need in various bodies. I am happy to have been able to accomplish my goal within a very short time as I was very clear and confident in my mission. Then finally when the IGCAR Training School was born, I was very happy because I thought that I have contributed towards providing quality human resources to the Centre in a sustained way. Joy of creation then and now the joy of achievement, I can see a few exemplary students, who would grow as leaders and also see much wider impact in the Centre. I realized that this influx is not complete and we needed to have a University. That also slowly emerged (HBNI) and I was a part of first committee to look into how this university should work. It worked out successfully, we attracted some good people. But to my mind if we ask, whether we have created a university eco-system, I would say no. Here your boss is a Ph.D. guide also. There is difference between a boss and professor. I took my Ph.D. from the Indian Institute of Science. The relation between the professor and a student is very unique. There needs to be a change in the mindset of the bosses when they are guiding to become professors and become bosses when the student is doing mission oriented job. I am happy that some of the my colleagues have been able to play the dual role effectively. My relation with people has remained very different from those who became my Ph.D. students. I like everybody who is my colleague but that relation is never the same to those who were my students. When I like someone, I tell them that you are like my Ph.D. student that is the maximum extent to which I can go.

First I would like to congratulate you for being appointed as the Director of NIAS. It is an institute that deals with sociology, humanities etc. We feel that youngsters are not realizing the importance of ecosystem or environment. Do you think it is high time to make these subjects mandatory in the curriculum of engineers?

First of all I am looking forward to go to NIAS. NIAS was born out of the vision of JRD Tata. Twenty six years before, he realized that the country's challenges would not be met unless humanities, social science, science, technology, policy, finance and diplomacy are combined. You see the vision of the great man. He started the institute and found a person like Dr. Raja Ramanna, to be its first Director. It has grown very well. This institute has been created only for the purpose of creating leaders. I invite all of you, to study the institute and meet some outstanding people. The whole idea there is to create leaders, as envisioned by JRD Tata, in all walks, be it government, public and private. Coming to personal perspective, you see the curriculum of Cambridge, Oxford, University of California, you can find an element of social science which would not make you specialist in environmental ecology but definitely would prepare your mind to the reality. You don't want to become an ornamental specialist, but you must interpret and plan your work within the context of what is the reality of the country and its sustainability. How do you get that? You cannot get it from newspapers or websites, but from somebody who would be engaged with you. He/she may engage you for two or three hours, that doesn't matter. But I think we all know that, a good teacher can transform you even in one lecture. Teachers have the ability to really touch you and give something which leads you to learn for yourself. We must think of meeting

outstanding people in humanities, social science and environmental science at IGCAR. For a Centre like IGCAR, at least 10 to 20% of the visitors should be musicians, doctors and environmentalists. It will change the fragrance of this Centre. I can provide the resources from NIAS. These outstanding persons can come and communicate to you and also stay in our campus for few days. You can also come to NIAS stay with us and communicate your perspective for enriching us.

Another important aspect to be successful, according to me is, to be comfortable in different domains. When I engage with the community around Kalpakkam, unless I am a social scientist by my liking is not necessarily by my degree, I would be a failure. When I have a responsibility of engaging with the school children, teachers, principals, I must be an educationist at my heart. I must be sensitive to their needs. I remember that whenever a Principal of our schools would join at Kalpakkam, they come and meet the Director. Normally I keep not less than an hour and the meeting would always end by saying that "Schools are very important for us which would make many people stay in Kalpakkam campus because education of their children is taken care of very well. You are a VIP and not just the Principal of the school, I will do everything, that you want, you will have access to me and I will also come and talk to the teachers and students, whenever I can".

Internalizing success is another secret to success. I am successful, if I feel successful and feel the impact of my life has been positive. You must get down to all the levels and don't ever shy away. Sometime we face very challenging times, sometimes it's a struggle and you are totally lost, because you don't understand the parameters. But I think, if you challenge yourself, you get into that, first of all you learn a lot, second thing, you work with people who feel that it is a good place to work, but that part we have missed in our curriculum.

How has been your journey from being the Director of IGCAR to Chairing R&D of the PSG Institutions and from there to take over as the Director of NIAS?

When I left Kalpakkam, I was very confident that IGCAR and BHAVINI have come to that stage of trajectory which could sustain excellence on its own. Fortunately I had two of my colleagues, who are more my friends, to steer the institutions. I have never tried to enquire about the well being of the Centre with anybody, but if some of my erstwhile acquaintances seek my advice, I would simply advise them to discuss with the present Director and also give my suggestions qualifying that "my way of working is like this". I went to Coimbatore, which is basically a very good educational institute. But if you look at the capacity to generate a discussion on cutting edge science and technology it is very difficult. Before deciding to go to Coimbatore, I got many an opportunity in other reputed intellectual systems. I was requested to take up the Homi Bhabha Chair, I could have continued that by sitting at IGCAR, BARC, IIT or somewhere. But I was very clear that my first journey or first innings was for my body and soul, more for body and less for soul. Second innings I wanted to make it only for my soul. I was very clear. I felt going to Coimbatore is my commitment to my soul. During my tenure at IGCAR, I had the opportunity to interact a lot with, children at the school level and under-graduates. I did go to colleges and universities but those were very little. Three years I spent interacting with the students, school children and teachers, school teachers getting to know the challenges and trying to contribute. My soul was better there as compared to my soul here. Coming to the innings at NIAS, which has tremendous opportunities, in current trajectories of the growth of the country; creating leaders, creating policy interventions and so on. It is another challenge and another opportunity which has come my way. You can be sure that I shall put my best of imagination and efforts, in the new assignment too.

After interacting with students, what do you feel about their expectations from an R&D Centre like IGCAR?

Young minds today do not consider the boundaries of India and the world. Those who are best want the best and are choosy. They get a number of opportunities, they come to me to choose the best and as a mentor, I interact and guide them. If they get convinced that they will get their best in IGCAR, then they will definitely join IGCAR. If you ask me, it is a common notion amongst educational institutes that IGCAR is one of the right places to work. Now the question is, is it the place to reach the highest aspirations of achievements, my mind would say no. Now how to change that, I would say we need to produce excellent scientific and technological work. Everybody is convinced that "Fast Reactor Fuel Cycle Facility" is a challenging technology. The moment the fast reactor goes critical and fuel cycle facility is established, it would be a great demonstration and iconic representation of how the *ab initio* science of this Centre can get converted into world class technology. We are on the path towards that, but as the Indira Gandhi Centre for Atomic Research, what are we doing in research? what are the iconic pieces of science we are pursuing to convince the world that we are endowed in terms of facility and power? Has our work been ever attracted with 1000 or 500 citations and is the world talking about our work? There are some examples, but not many. I would say that you along with the management have the responsibility to produce iconic science, even while we produce iconic technology. I am fully convinced that we can do it. In my own life in a humble way I got elected by all the academies of science, engineering, medicine, archeometallurgy and so on. You may think that my life was focused only on career, no it is not true, I have many other interests, I did many things and it certainly did not burden my life. It was very light and I enjoyed a lot. I could do only a little because I belong to the era of 60's and 70's of India, when India did not have the capacity to dream and capacity to realize. If you come to 2014, India is a very different country with different aspirations. So why not you achieve three times more than Baldev Raj. To my mind the answer should be yes and can tell with confidence that the system supports you,

as I have grown in the same system. Not only the system, but your mentor and eco-system will also support you. I believe that you must first internalize your vision, if you don't own your vision, who would own yours? Once you internalize your vision and start working towards it, you will definitely be successful. Many a times we have a vision given to us by the Centre. Your vision should be beyond science which you are doing immediately, it should connect the society, country and the world. I believe mind is a great machine.

Sir, you have seen both sides of the coin, research institution as well as educational institution, girls are equally performing as good as boys in educational institutions, but we don't find many women in the top positions in most of the research institution or hard core engineers?

This is a topic which I discussed passionately till last evening with two women who are at the cutting edge of performance. It is the family which becomes the most important parameter for a woman to be successful, than the outside world. You talk to all successful women, and you will learn that it is the family that has propelled them and not the organization. I am very sure that the women are not asking for a special favour. I am amazed by the way in which they meet their responsibility in the family as wife, mother, sister and so on, to their consciousness and stay at the cutting edge in the technology, while the men do one job and take pride. Women do two jobs and both are very important. Those women who come out of the threshold are extraordinary and can reach the pinnacles of success.

Sir, if we compare the R&D pursued by India twenty years ago and the research which is going on now, we are involved and contributing for one of the prestigious projects of the world, ITER, among the few countries. How do you think has the world's perception changed and when do you see the first electricity to be generated from fusion reactor?

Answer to the first question about Indian science, yes it has increased significantly by way of our involvement in certain projects and achieving within certain milestones. For example, you see our space, missile and atomic energy programmes, some of the industries competing very well with the cutting edge, some of the pharmaceutical and bio companies are emerging as leaders. The days when people use to talk of India as the land of snake charmers and elephant riders are gone, though snakes are still there, and so are the elephants. I was newly married and went to Denmark in 1974, many times I had to face the question on "what is India and how the Indians live". They thought Indians to be a separate species and realized after some time that Indians are much the same as them. Indians made a name as individual, even at that time and were known for their intellectual ability. As a country, India emerged stronger after 2000. Though we were working with low level technology, the impact was global for the first time. Till that time we were known in atomic energy, which had accomplished a lot. That was the beginning. After travelling for forty years, mostly related to domains of atomic energy, I can see several more domains. But if you see Indian professionals who have established themselves as intellectual work force in the US, be it science, technology, management or anything, question that comes to my mind is where are we? I think we still have a long way to go. Our country has to do more in many levels. Government has to put more money into research, industries have to contribute equally as that of the Government, as products and innovation come from equal participation of the industry and the Government. Then the more the aspiration of the individuals, who are part of the country, the more is the success. Many times I try to count how many Indians have made a difference in science and technology, say from 1900. There are many scientists and technologists but not many have made a difference, but even in smaller countries many have made a difference at individual level. According to me, there are two parameters that define the science of the country: (i)) average level of the science and technology of the country and (ii) what are the peaks? You cannot singly contribute to average level of science, it all depends on the policy and projects of the country but nobody stops you from creating individual peaks. Are we doing our job of creating individual peak?, that is the question you have to ask for yourself. But when you take up senior positions, you must start working towards raising the average level of science.

Can you share with us your experience during the Tsunami in 2004? It was totally unexpected and in scientific terminology it is called beyond design basis, how did you prepare yourself?

I was not prepared neither as an individual nor as the Director. It was a Sunday, I had just finished my tea and started reading the newspaper

and water started raising. As a senior person, I rushed to the hospital. I found dead bodies in the verandah, it shook me and I have never been shaken in my life like that. Then I met the Medical Superintendent and the doctors and instructed them to do their best to any one who comes for treatment and not to differentiate between residents of the township and the nearby villagers. The next thing that I did was to gave a ring to Dr. Anil Kakodkar that such a thing has happened and it was very severe. Then I visited all the facilities, our nuclear submarine reactor was there at that time, right in the sea. It was a great relief that all the facilities were safely shut down and there was no radiation leak.

When I looked at PFBR, my dream project for which I had worked all my life, it was under water with full of salt, sludge and sediments. Then we set up an emergency room in GSO and started working from there. The next day I noticed the greenery going away, the trees started shedding their leaves due to the large amount of salt deposited in their roots. It was like a horror movie, rather than a place which was beautiful to live. I knitted a team of 10-20 colleagues and started interacting with people. How do you console people who have lost their family member and those who have just escaped from death. The difference between death and life was just three centimeter, if water was three centimeter more you are dead and if it was a few centimeter less, then you are alive. Everybody would come with a lot of pain, agony and lot of requirements. There was pressure from parents and well wishers to leave the place, but your job was to retain them and continue the work. It was sort of sharing pain and being in the midst of the people who have suffered and do everything which you could do. I remember I never slept for ninety hours, maybe in between I might have winked but I never slept, I could not sleep because the shock was too much. Then we restored the township and everybody who had the credibility helped us. We were fortunate that it was a Sunday, because the hospital did not have too many patients and on any other working day the school children would have been wiped off. Even in extreme grief we did have some blessings. One more thing that we did was, god forbid tsunami comes to this place again, we would make sure that tsunami is mitigated. We involved all specialists to redesign the township, I believe that it was a mistake, because tsunami possibility in the township should have been perceived by me, even if others have not done it. My advice to all those who take up responsibilities is please don't go by what has been perceived by your predecessors. Take a fresh look at things, to summarise on the opportunities and threats around.

### What is your view on the current education system in India?

Our young students are very good. We are not in the learning mindset but still in the mindset of teaching. We have less emphasis on doing things with hands and more repetitive kind of things. Then coming to information technology, the data can be accessed easily. We don't have to really memorize a lot of things, which I did when I was a student. When I was a student, there used to be a question "What is melting point of this" or "What is thermal conductivity of that". That used to be question by itself and you get good marks if you are able to answer the same. Some of the teachers are still continuing this practice. But it has to be learning. Learning has to be both theoretical and practical. We have to change our systems. How much students can learn on their own and how much we can complement it with help of teachers and laboratories is what we should focus upon. Recently, I met our Honorable Minister for Human Resource Development, Ms. Smriti Irani, in a meeting at Goa. She is very conscious about the school education. Though we were discussing about IIT's, as it was the council meeting of IIT, she insisted on the need to introduce innovative laboratories in schools for the students to connect things or mess-up upon a few things, so as to expand their understanding of science. Our students are much valued throughout the world. We shouldn't change along the lines of the west. We should ask as to what is good in our schools which is not in the west and in spite of our not very robust education system and infrastructure, we are doing well. The teachers are very important and they should work with lot of commitments and should also have a sense of discipline and spirituality that makes us strong internally. But I strongly believe that transformation from teaching to learning is required.

### You have interacted with lot of international delegates, can you please share your experience?

By my nature and philosophy, I believe that we have to learn from many. I have never considered anybody to be on the pedestal or a single stream from whom I can learn. I also like the young people who are directly engaged with me, not necessarily under my influence as a mentor, my first advice is to experience from all over.

### What drives you?

My mother, who is not there physically with me now, had only one message for me that I should stay ethical in my life no matter what position I reach. Second thing that drives me is the internal enquiry, as destiny has given me lot of opportunities, am I using those opportunities for my selfishness or am I using it for others? Thirdly, to me it is very important that, before I die, this country should be in the lead of the best nations and infact better than them because we should create more quality and ethical society. I think ethics are failing everywhere in the world. As I said before, we have an element of spirituality and philosophy. We definitely can be a very progressed nation with better equity and ethics as compared to many other countries. I hope if God gives me sufficient number of years, I would like to see that kind of India. I am very positive in spite of so many negatives. I am not blind to negativities, I fully absorb them, feel very bad, sometimes cry over that and sometimes ignore them. But they are all there. I still feel we have sufficient amount of good people and opportunities. I have internalized my own commitment. If we have internalized our vision, we will find many good collaborators to work with. Sometimes a younger colleague drives you, sometimes

a senior mentor drives and sometimes the country drives you. As long as you are not selfish, you have a strong reason to be successful. The moment you are selfish, everything is gone.

Sir can you share with us your hobbies?

I love watching sports. I can spend twenty four hours in listening to music and I love reading. I read a lot and read all subjects right from philosophy, religion, biology, archeology, space, theoretical physics to computational methods.

Whom are you supporting in this FIFA world cup?

Emotionally, Brazil and technically Germany.

You have spent most of the time in research. How does madam (Mrs. Baldev Raj) react to this?

She is happy and unhappy at times. She is happy and convinced, when she sees that I am not doing anything for myself. It took a lot many years to prove her. Second thing is that, after I stepped down as Director, IGCAR, she had a hope that I would spend more time with her and the family. It has happened the other way round. Now I have less time than what I had when I was at Kalpakkam. But many a times we travel together and stay together. I think we understand each other because we fight quite a lot. Every fight makes us understand each other better.

When you demitted the offer of Director, IGCAR, we were all worried for two reasons. One is that we miss your leadership and mentorship. The other thing is the responsibility of maintaining what you have set for us. It is really a big challenge to us. You have set us the challenge and we would at times say, If Baldev Raj was there what he would say, it is like a sort of benchmarking ourselves in doing things.

I have the opportunity of keeping track of what you are doing, I feel you have filled the gap that was required in different domains.

Having seen a Centre like this in the Department of Atomic Energy, academic institutions and the policy making bodies in which you are a member, Sir, can you tell us if we are preparing the next generation to takeover?

We have excellent people in science and technology. But to be a leader we don't need only science and technology. To lead the people who are driven by the country or driven by internal desire of theirs, who are selfless, I would not be making a wrong statement if I say that, we have become more self-centric as the technologies have grown. That part really disturbs me. While the private world has fully realized that the young leadership is better than the seniors and senior must be kept in a loop of wisdom and contributing, in a government system we have still not come to terms that a person at the age of 45 can be a Director or a Chairman. And why not only the competence and the capability become the criteria? Homi Bhabha picked up very young people, gave them huge responsibilities and they came out with success. I have always preferred to see a scenario in this country that young people take the leadership role. But we have to choose those young people who are not self-driven and are only driven for the society.

The team:

*Ms. Vinita Daiya, Ms. Rimpi Dawar, Shri Suddhasattwa Ghosh, Shri Avik Kumar Saha, Ms. Diptimayee Samantaray and Ms. K.Saipriya*

# Development of Extended Spark Plug Type Leak Detector for PFBR

The main vessel of PFBR contains reactor components, which are immersed in sodium pool. In case of a sodium leak from the main vessel, sodium will be collected in the safety vessel and if sodium leaks from safety vessel, it will be collected in the reactor vault. For detecting the leak from the main vessel and the safety vessel, two diverse methods are used. One of which is extended spark plug leak detector (ESPLD) and the other is mutual inductance type leak detector (MILD). Two numbers of ESPLDs are used for the main vessel leak detection and one number is used for the safety vessel leak detection. ESPLD functions based on the excellent electrical conductivity of the sodium. Sensing end of the leak detector is located in nitrogen atmosphere at the bottom-most point inside the safety vessel where the leaked sodium gets collected in case of leak. The leaked sodium will short the center conductor and sheath of the mineral insulated cable and the electrical circuit will be completed to indicate sodium leak. The temperature near the sensor will be around 400°C. As per ASME code, a leak rate of 100 g/h of sodium should be detected in 250 hours in the inert atmosphere.

The schematic and a photograph of the image of active sensor portion are shown in Figure 1. The sensor consists of a central stainless steel needle tube which is insulated from the outer stainless steel tube by alumina. Sealing is achieved using vacuum brazing technique.

The overall dimensions of the sensor is 5 mm diameter and 49.5 mm length which are limited by the guide tube profile (O.D-10 mm and I.D-7 mm). The guide tube is welded on the inner wall of safety vessel, which will protect the sensor. The guide tube outer diameter is restricted to 10 mm to avoid interference of in-service inspection (ISI) vehicle movement. About 24 meters long mineral insulated cable of diameter 1.5 mm was laser welded with sensor and brought through a thin walled stainless steel tube of 4 mm outer diameter. The thin walled stainless steel tube protects

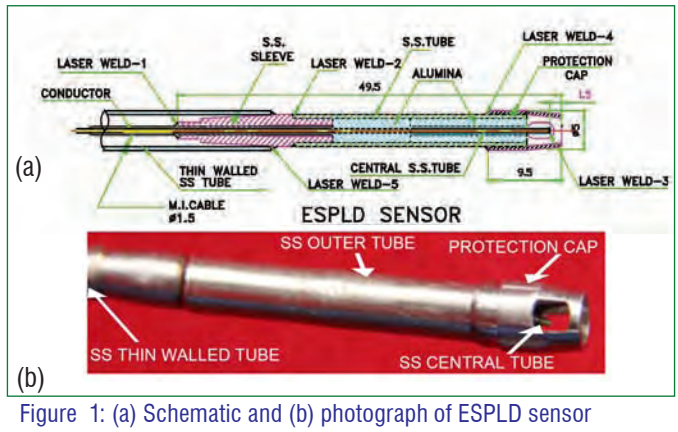



Figure 1: (a) Schematic and (b) photograph of ESPLD sensor

the mineral insulated cable and facilitates easy insertion / withdrawal in the guide tube. The active sensor tip portion was protected with a stainless steel protection cap to avoid damage of the sensor tip portion during insertion. Figure 2 shows the sensor with mineral insulated cable and stainless steel thin walled tube.

In the development of the ESPLD, five critical weld joints were required to be made. Due to the small size of the sensor, laser welding was the best option available. The sensor was required to be attached to a 24 meters long mineral insulated cable of 1.5 mm diameter. A fixture was designed and fabricated to restrict any relative movement between the mineral insulated cable and the sensor during welding, since the self weight of the cable would be sufficient to induce stresses and cause cracking in the laser welds. For defect-free circumferential laser welding, the gap between the core of the mineral insulated cable and the inner tube of the sensor should be within 15 $\mu$m, which made it necessary for the design and fabrication of fixtures to reduce the stainless steel core wire diameter precisely from 0.8 to 0.6 mm. The fixture components are shown in Figure 3.

The design and fabrication of the special fixtures and the laser welding were carried out as per the specifications. The 24 meters

Figure 2: Sensor with 24 meters long mineral insulated cable and stainless steel thin walled tube; stainless steel protection cap is shown in insert

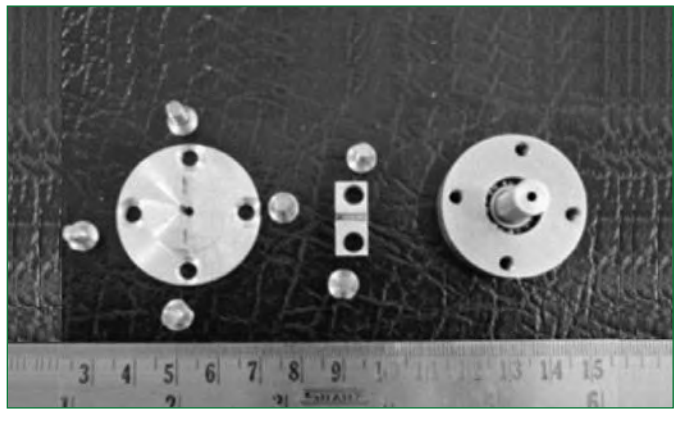


Figure 3: Machined components of fixture


Figure 4: Precision machining in lathe to reduce the wire diameter

long mineral insulated cable was held between the head stock and tail stock of a lathe, as shown in Figure 4 and the precision machining was successfully carried out to reduce the stainless steel core wire diameter to 0.6 mm. To optimize the welding parameters and for welding procedure qualification, three sets of mock up pieces were machined and welding parameters were standardized by conducting trials.

Solid state Nd:YAG laser with wavelength of 1064 nm was used for the laser welding. The focal length of the lens was 200 mm. A four axis CNC was used for precise positioning of the work piece. Purging gas outlet was placed at a distance of 10 mm from the work piece and at an angle of 45° to the horizontal. The CNC work station was programmed to rotate by a fixed angle in each step. In the time gap between each step, a single laser pulse was released for welding. Thus, the percentage overlap was controlled by the process of indexing in each step. Each joint has different dimensions and configuration. Welding procedure and parameters for each joint were optimized by conducting welding trials. The sheath wall thickness of the mineral insulated cable was 0.2 mm. To control the weld penetration depth and to avoid puncturing of the sheath of the mineral insulated cable, different pulse shapes were used.

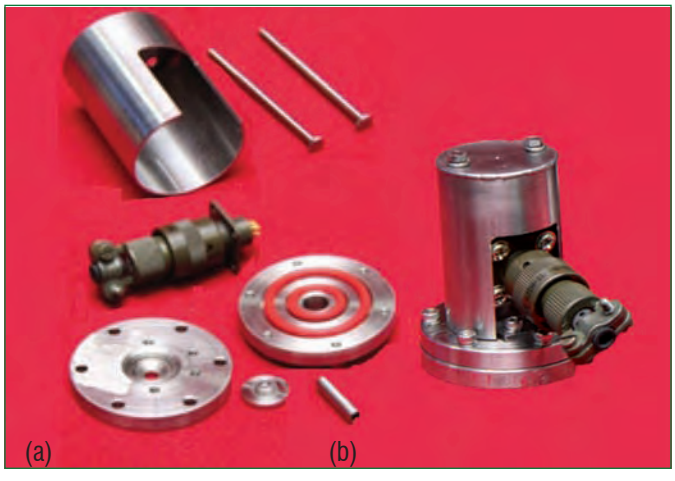



Figure 6: (a) Various parts and (b) assembly of sealing arrangement

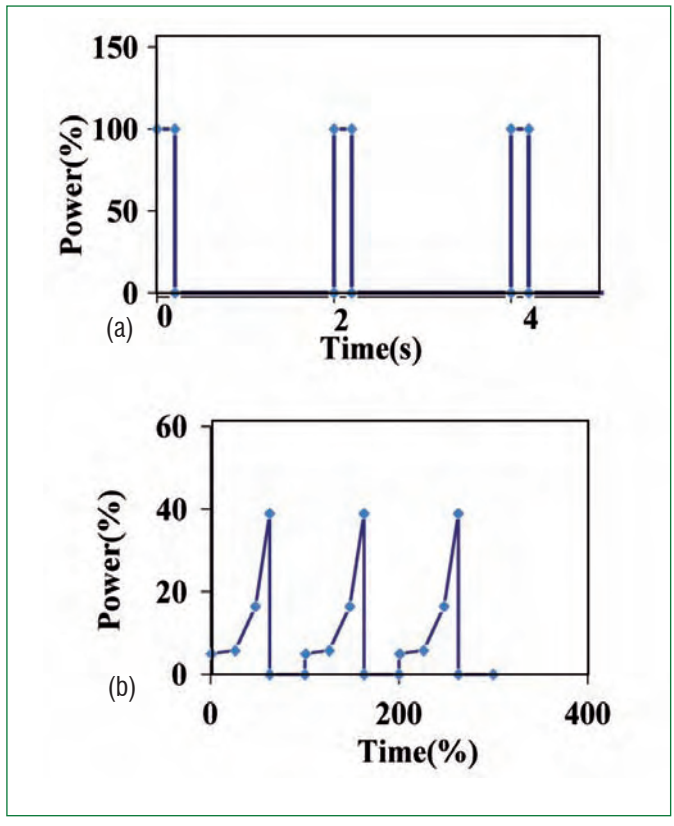



Figure 5: Pulse shape used (a) for sleeve to mineral insulated cable weld and (b) in the weld of stainless steel conductor to needle

Some of the pulse shapes employed are shown in Figure 5.

Weld parameters were standardized for each of the five joints with respect to average power, index angle, pulse duration, energy per pulse and weld off-set. The overlapping factor between two successive laser spots was kept as 85 to 94% in these joints. The welding procedure and parameters were qualified by liquid penetrant test and metallographic examination. Before welding the stainless steel core wire to the sensor inner tube, tape heaters were used to heat and remove any moisture from the mineral insulated cable. This has also improved the I.R. value of mineral insulated cable.

After insertion of sensor in the guide tube of PFBR, the leak tightness of the sensor should be ensured. Hence, a leak tight arrangement was also designed, for guide tube, capillary tube and mineral insulated cable. The parts of the sealing arrangements and the assembly are shown in Figure 6. The leak tight assembly will be welded after insertion of the sensor in the guide tube at PFBR site.

Thus ESPLD has been developed meeting the required stringent quality assurance requirements for use in PFBR.

*Reported by*
*B. Babu, Fast Reactor Technology Group and*
*S. Murugan, Metallurgy & Materials Group*

# Confirmation of PFBR Preheating Scheme Based on Scale Down Model Studies

Sodium has been the universal choice for the fast reactor coolant in view of several attractive thermal, physical and neutronic properties. However, a few disadvantages of using sodium need to be mentioned. The major one is its chemical reaction with air and water and another one is it remains in liquid state above ~98°C in atmospheric pressure condition. Hence, there is a need to maintain the temperature of its container and pipeline at the temperature of ~150°C with comfortable margin to avoid freezing. This is not of great concern during normal operating condition including shutdown state, due to availability of nuclear heat. However, this poses difficulties during initial sodium filling conditions as well as after sufficiently long shutdown conditions. Before filling sodium, all those metallic parts which will be in contact with the sodium, should be maintained above 150°C, so that there will not be any solidification particularly at some complicated locations. This is an important requirement before filling sodium in the vessels and piping. Ensuring that all parts have attained such threshold temperatures, calls for careful processes including analytical and numerical computations. Due to the complicated geometry with varying thickness of 0.4 mm (cladding of dummy core subassembly) and 0.8 mm (IHX tubes), 50 mm (flanges) and 150 mm (IHX tube sheet thickness), theoretical prediction needs confirmation preferably by realistic experimental mockup studies.

The internal components of reactor assembly are preheated by circulating nitrogen through a closed loop by blowers via bank of heaters, at a flow rate of 10 kg/s. Uniform heating of all the components to $150^{+30}_{-0}$ °C is a challenging task due to multiple flow paths that are complicated and parallel for heating fluid ($N_2$). It is proposed to rise temperature of nitrogen by maximum of 10 °C/day in order to uniformly heat the reactor internals, supported by thermal hydraulic and structural analyses.

Mockup facility is established on 1/13th scale down model of PFBR reactor assembly with all internals to confirm preheating strategy. Air flowing in open loop is used as preheating medium to simulate PFBR preheating scheme in the model. In this article we describe our study in devising the preheating strategy.

## PFBR Preheating Strategy

The hot nitrogen is supplied to the reactor assembly through the following inlet ducts (Figure 1):

- Opening for observation facility in small rotatable plug (300NB).
- Access opening to in-vessel transfer port in large rotatable plug (450NB).

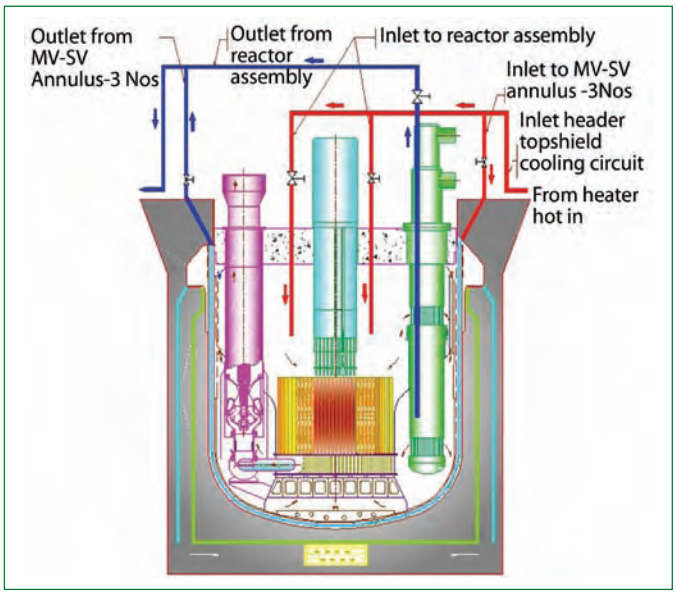



Figure 1: Flow of gas inside reactor assembly during preheating

- Three numbers of 250 NB ducts provided in the main vessel – safety vessel inter-space through the openings for ISI.

Nitrogen returns to the blower and electrical heater from the reactor assembly through the following outlet ducts:

- From the cold pool (EL 18500) through the opening for cold pool level detector in roof slab (450 NB)
- 3 Nos. of 250 NB ducts provided in the main vessel – safety vessel inter-space through the openings for ISI.

Determining the temperature evolution in the reactor assembly is challenging due to asymmetry in the location of inlets and outlets, differential concentration of steel mass in the reactor assembly and co-existence of thin and thick components at the same location. Gradual heating of the components is envisaged to achieve uniform temperature of the entire structure.

Detailed thermal hydraulic and structural analysis is carried out while arriving at the heating scheme. In order to gain further insight and to confirm the preheating scheme, experiments are carried out on 1/13th scale down model of reactor assembly, simulating the phenomena.

## Description of Scaled Reactor Assembly Model

Features of PFBR reactor assembly are incorporated in the model. The model simulates temperature and temperature rise rate; hence the scaling is applicable only for ratio of mass of steel in PFBR to mass of steel in model and rate of heating to the model is made same as that of PFBR. Flow fractions across various flow paths in reactor assembly internals are simulated in the model as close to PFBR.

Table 1: Dimensional details of scaled model with respect to PFBR

| Parameter | PFBR reactor assembly features | Model components features |
|---|---|---|
| Main vessel | OD-12.9 m, Thk-25 mm, Ht -13.2 m | OD-1000 mm, Thk-2 mm, Ht-1268 mm |
| Inner vessel Upper cylindrical shell | OD-12.2 m, Thk-15 mm, Ht- 3.8 mm | OD-800 mm, Thk-1mm, Ht- 419 |
| Inner vessel Lower cylindrical shell | OD-6350, Thk-15 mm, Ht-2024 mm | OD-422 , Thk-1 mm Ht-659 mm |
| Inner vessel overall height | 9114 mm | 670 mm |
| Top shield | OD-12.900 m Ht -1.800 m | OD-998 Ht-140 |
| IHX | OD-1850 , Ht-17.955 m flange OD-2520 mm | OD-108 mm Ht-985 mm flange OD-180 mm |
| Pump | OD-1850 mm, Ht-13867 mm Flange OD-1850 mm | OD-108 mm, Ht-890 mm Flange OD-180 mm |
| Grid plate | OD - 6800 mm Ht - 1000 mm | OD-469 mm, Ht-69 mm |
| Core support structure | OD-7830 mm,(UCP) Ht-1600 mm Thk. 30mm | OD-600 mm, Thk-2 mm, Ht-100 mm |
| Core | OD-3053, Ht-3530 mm | OD-400 mm, Ht - 355 mm |
| Safety vessel | ID-13.5 m Thk-15 mm Ht-12872 mm | OD-1140 mm, Thk-2 mm, Ht-1289 mm |

Some of the salient features for comparison of model with PFBR are given in Table 1. Process parameters for the model and PFBR are given in Table 2.

Major components of scale down model of reactor assembly are: i) safety vessel, ii) main vessel, iii) inner vessel, iv) grid plate, v) core support structure, vi) core, vii) top shield, viii) control plug, ix) primary sodium pump, x) intermediate heat exchanger and xi) decay heat exchanger.

## Preheating Mockup Facility

The preheating mockup facility for PFBR (Figure 2) consists of a blower which sucks air from atmosphere and drives through inlet manifold, a bellow connected at outlet of blower to accommodate thermal expansions and bypass valve connected to the inlet manifold to regulate the flow rate through the system. Metered amount of air flows through heaters and gets heated up to the desired temperature by heater control. Hot air enters the model with two inlets to hot pool locations of main vessel and three inlets to main vessel - safety vessel inter space. Air that comes out of the model through the outlet from cold pool location and three outlets

Table 2: Comparison of process parameters for the model and PFBR

| Component | Mass | | | Flow (kg/s) | | |
|---|---|---|---|---|---|---|
| | PFBR (ton) | Model (kg) | Scale ratio | PFBR (ton) | Model (kg) x $10^{-4}$ | Scale ratio |
| Core | 1125 | 400 | $13^3$ | 0.536 | 2.440 | $13^3$ |
| IHX | 46 | 20 | $13^3$ | 0.548 | 0.249 | $13^3$ |
| PSP stand pipe | ~40 ( below roof slab) | 18 | $13^3$ | 0.512 | 2.330 | $13^3$ |
| Cold pool annulus | - | - | - | 3.304 | 15.00 | $13^3$ |
| Control plug | ~40 | 20 | $13^3$ | - | - | - |
| Main vessel cooling | - | - | - | 0.032 | 0.146 | $13^3$ |

from the main vessel - safety vessel inter space after transferring heat to the internals, is vent out to atmosphere through the outlet nozzle at the end of outlet manifold. Temperatures of air inlet, outlet, at outlet of each heater and temperatures of all the locations (56) in the model are monitored continuously by K-type thermocouples (61 numbers.) with error band of 1.1°C or 0.4% (whichever is greater) of the reading. Velocity of flow is measured using hot wire anemometer with an error band of 0.5% of the reading.

## Description of Electrical Heater and its Control

Cartridge type electrical heaters are used as heat source to give required heat input to air for maintaining inlet air temperature to mockup facility.

Heater arrangement for the mockup facility consists of three heater modules with 7 kW each connected in series. Total heater capacity of all the modules put together is 21 kW. Each heater module is ~1.2 metres long and constructed by joining two semi cylindrical parts. This type of heater is custom made for ease of mounting over a pipe. Each semi cylindrical portion of the heater module consists of three ceramic cartridge type heaters of 1 metre length. 230 V, 1 Φ, 50 Hz AC power supply is given to each heater module. 50 NB pipe carrying air passes through the center of the heater. Temperature of heater (chamber formed between heater

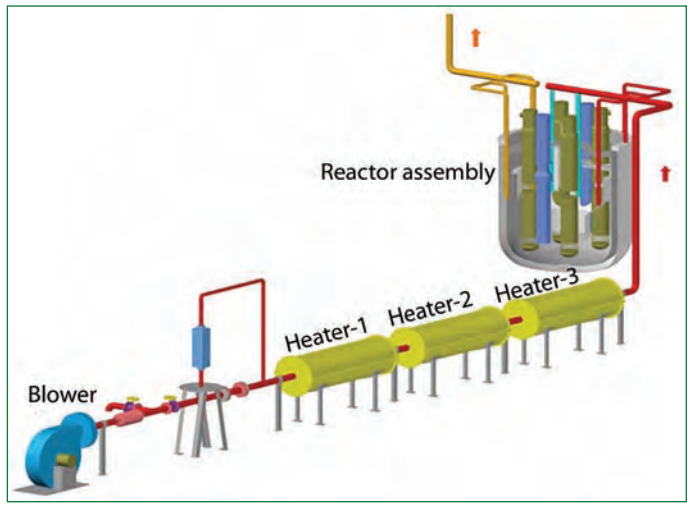



Figure 2: Schematic of PFBR preheating mockup facility

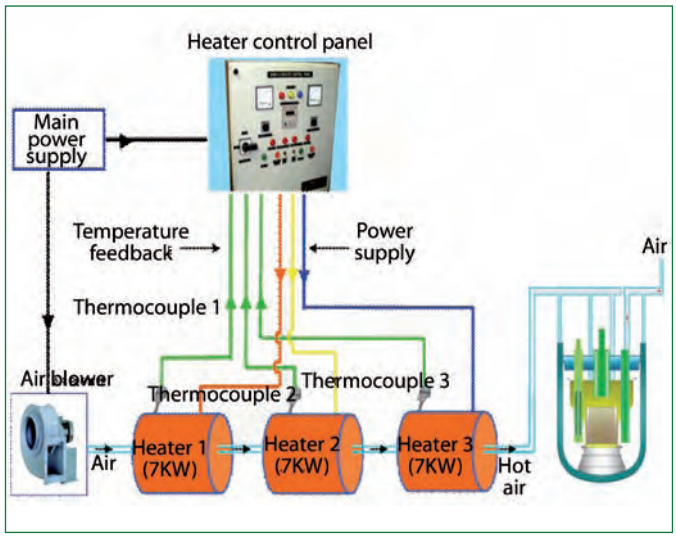



Figure 3: Heater power supply arrangement

elements and pipe) is continuously sensed (monitored) by the thermocouples located on each heater module. Air flowing in the pipe gets heated up by taking heat from heater elements. Figure 3 shows the heater power supply arrangement.

Temperature of the air entering the reactor assembly model is maintained by heater control. The heater chamber is maintained at a preset temperature by heater control unit based on the temperature sensed by thermocouples. When the heater chamber reaches the preset temperature, heater control unit adjusts heater power to maintain constant temperature.

## Preheating Mockup Facility - Instrumentation

Major components of reactor assembly are provided with sufficient thermocouples for monitoring and recording the temperature data in order to validate and study its temperature variation. The temperature of the air within the process line is monitored to (i) control the temperature of inlet air sent to model reactor assembly, (ii) estimate heater performance and (iii) to provide basic data for thermal balance estimation.

## Temperature Measurement

K-ype thermocouples are provided for monitoring the temperature of all the components and process line. The locations and number of thermocouples are listed in Table 3 and shown in Figure 4. Figure 5 shows photographs of thermocouples being fixed and routed in the facility.

## Temperature Monitoring and Recording

All thermocouples (61 numbers) are connected to two data acquisition systems through thermocouple extension cable. Both the data acquisition systems are further connected to a personal computer using Ethernet cable for continuous monitoring and recording of the temperature data during the experiment. Recording of data is done at two levels for diversity with one level at data

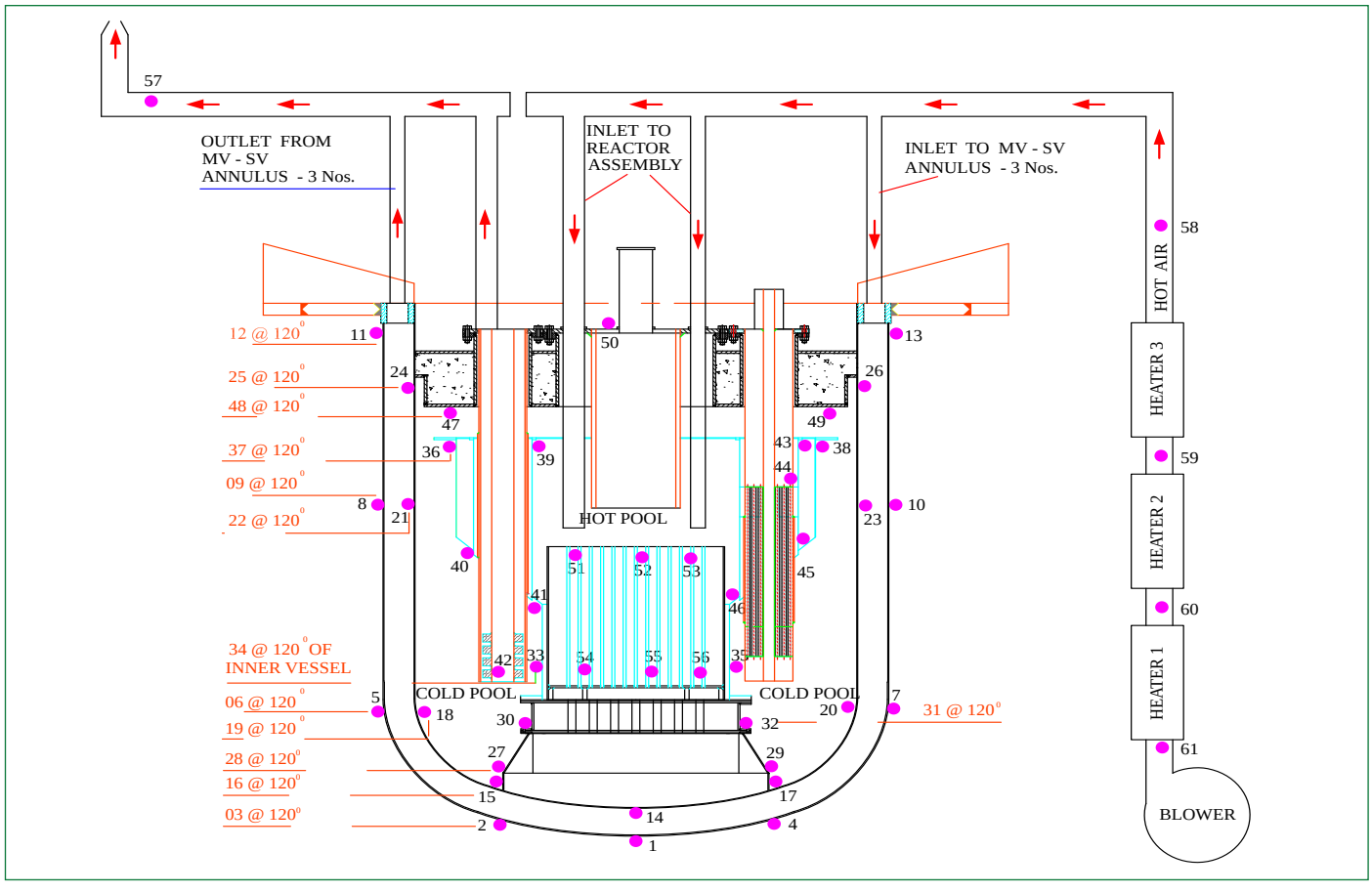



Figure 4: Location of thermocouples in preheating mockup facility

Table 3: Locations and number of thermocouples for mockup facility

| S. No. | Component | No. of elevation | No. of TCs | Identification in Figure 4 |
|---|---|---|---|---|
| 1. | Safety vessel | 05 | 13 | 01 to 13 |
| 2. | Main vessel | 05 | 13 | 14 to 26 |
| 3. | Core support structure | 02 | 06 | 27 to 32 |
| 4. | Inner vessel | 02 | 06 | 33 to 38 |
| 5. | Pump | 04 | 04 | 39 to 42 |
| 6. | IHX | 04 | 04 | 43 to 46 |
| 7. | Top shield | 02 | 04 | 47 to 50 |
| 8. | Core | 02 | 06 | 51 to 56 |
| 9. | Process line | 05 | 05 | 57 to 61 |

Figure 5: Photographs of thermocouples being fixed in the model

acquisition systems and the other in computer. Mimics for the data acquired are made to visualise the preheating process online.

### Preheating Methodology

Before heating, the test facility (Figure 6) is at normal atmospheric conditions. All the thermocouples are tested for healthiness. Blower is started, keeping bypass valve fully open and inlet valve fully closed. Inlet valve is opened incrementally to adjust flow through the system to the required flow rate and waited for stabilisation. The velocity of flow is measured at the outlet to reactor assembly model by anemometer. At this condition, heaters are switched on to raise the temperature of air flowing through the model. The system is allowed to stabilize and temperatures are monitored to notice stabilization time. Temperature is considered to be stabilized when there is no considerable change in the temperatures of any structural members for about 3-4 hours.

Once stabilized temperatures are reached, air inlet temperature is raised by 10 °C and allowed for thermal stabilization in model for the new inlet air temperature. The process is continued till all structures reach 180 $(^{+30}_{-0})$ °C.

Evolution of temperature in structures is monitored continuously during the experiment for understanding the phenomena. Thermal evolution obtained from the experiments give the data on


Figure 6: Pictorial view of test facility

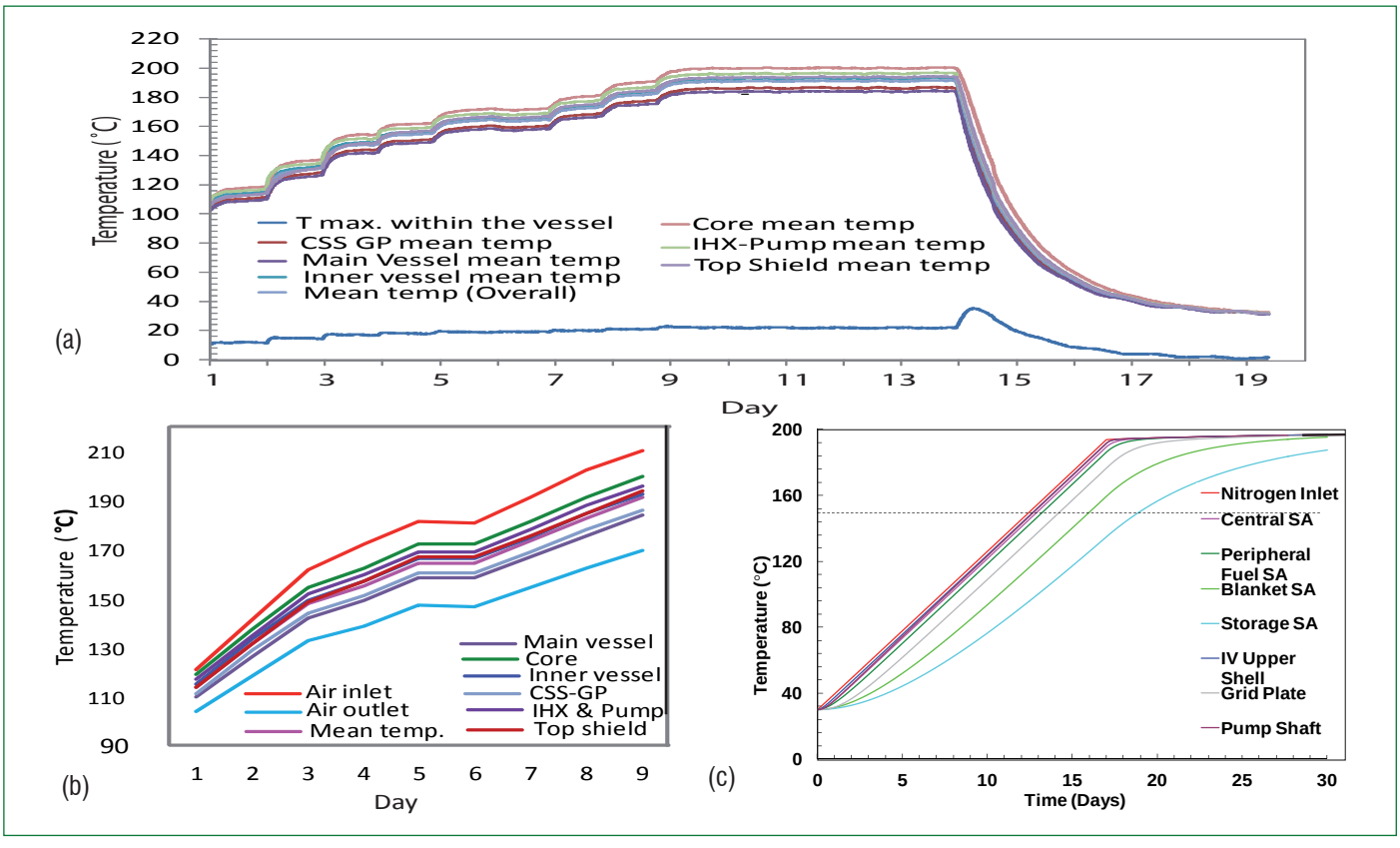



Figure 7: (a) Evolution of temperature in reactor assembly components during the preheating mockup study, (b) evolution of temperatures in the components during preheating and (c) temperature evolutions in various components of PFBR reactor assembly

temperatures of all the structural members relative to one another. Maximum and minimum temperatures are recorded along with their locations.

Information on temperature of internals with respect to main vessel is required to correlate the temperatures of internals during PFBR preheating with readings from thermocouples mounted on main vessel.

The observed temperature evolution during the preheating mockup study is shown in Figure 7a. The mean temperature of structures has attained a stable temperature after considerable time from the change in inlet air temperature. As the air temperature is increased, the temperature differences between air and structures and also among structures are increasing.

The maximum temperature difference observed is between the top portion of core and main vessel bottom portion. At the end of the campaign ΔT between these two locations is 22°C (which is within the tolerance limit of $^{+30}_{-0}$ °C). ΔT prevailing in each component is much lower than the maximum value.

It is observed from the results that all the components are getting heated up simultaneously and uniformly. Evolution of temperatures in the components during preheating is given in Figure 7a. The average temperature of individual structures and process parameters are given in Figure 7b.

The trend of temperature evolution has followed theoretical prediction for PFBR as given in Figure 7c. This trend conforms that the preheating scheme envisaged for PFBR is fairly qualified. Rate of heating during the mockup study is varied to check the effect of temperature rise rate on the structures and time to reach stable temperatures. It was observed that at increased rate of heating, temperature difference among the structures is increasing. Gas temperature during preheating required for attaining minimum temperature of structures to 180 to 210 °C.

A mockup facility to simulate PFBR reactor assembly preheating on 1/13$^{th}$ scale down model is commissioned at IGCAR. Mockup for confirming preheating scheme for PFBR has been conducted. Preheating mockup for the reactor assembly is continued till minimum temperature reached 180 °C. All the structures are simultaneously being heated up at uniform rate. The maximum ΔT in the structures at the end of preheating campaign is 22 °C which is within the tolerance limit of $^{+30}_{-0}$ °C. This shows that there is sufficient margin for any differences for model to full scale results.

Since the requirement for the mockup studies was aroused during the regulatory review on PFBR commissioning at AERB, the entire activities including design, construction, commissioning and mockup studies were completed within a short span of ~3 months.

*Reported by*
*V. Sudharshan and colleagues*
*Reactor Design Group*

# Young Officer's FORUM

## Optical Properties of III-V Nitride Nanostructures Grown by Chemical Vapor Deposition Technique

Shri Kishore Kumar Madapu obtained his M. Sc. in Physics from Osmania University, Hyderabad with the specialization of solid state physics. He is from the 5th batch of BARC training school at IGCAR campus and is currently working as Scientific Officer in SND/MSG. His current area of interest is growth of III-V nitride nanostructures using chemical vapor deposition technique and their optical characterization by Raman spectroscopy.

Nanostructures of III–V nitride semiconductors, namely indium nitride (InN), gallium nitride (GaN) and aluminium nitride (AlN), attracted lot of attention in last couple of decades due to their potential applications in high frequency electronics and optoelectronic devices. Moreover, alloys of these material covers the direct band gap ranging from 0.7 (near IR) with InN to 6.0 eV (deep UV) for AlN demonstrating applications in light-emitting diodes (LED) and photovoltaic cells which spans the entire visible region. GaN with intermittent band gap around 3.4 eV demonstrated potential applications in white light and blue diode laser devices.

### Growth of GaN nanowires at Low Temperature

GaN possesses the unique physical properties like wide band gap and high melting point for applications at elevated temperatures. Moreover, GaN is considered a high-power optoelectronic device material because of its high electrical breakdown field and high carrier mobility in high electron mobility transistor structures in the AlGaN phase. GaN nanowire-based prototype devices have already been demonstrated which include hydrogen production by water splitting, field effect transistor, blue lasers and hydrogen sensors. However, controlled synthesis in large-scale and cost-effective methodologies is a challenge in the production of GaN-based nano devices.

Growth of high-quality 1-D GaN nanowires is possible using chemical vapor deposition (CVD) technique which is popular for cost-effective and large-scale growth of nanowires. In the CVD technique, nanowire growth is normally performed by following the vapor–liquid–solid (VLS) growth mechanism, with Ga metal as vapor source and Au nanoclusters as catalyst. Even though Ga starts evaporating above 800 °C, growth of GaN nanowires is reported at temperatures ranging from 900 to 1100 °C because of the very low vapor pressure of Ga below 900 °C in the CVD technique. However, GaN starts to sublimate above 800 °C and decompose at 1100 °C at atmospheric pressure. Decomposition temperature further reduces to 850 °C under high vacuum. Unfortunately, these decomposition temperatures are in the range of growth temperatures for GaN nanowires. Thus, there is a need for reduction in the growth temperature of GaN nanowires in CVD technique.

We have used a unique methodology to lower the growth temperature of GaN nanowires where a binary alloy of Ga and In is used as the precursor material in the vapor–liquid–solid growth mechanism. Growth of nanowires was carried out by a customized CVD setup with a horizontal tube furnace (Figure 1a). The vapor–liquid–solid mechanism for the growth of 1-D nanostructures with a intermediate step of alloy formation followed by a super-saturation at the interface for the nucleation and growth is described for the present system of GaN with Au as catalyst (Figure 1b). Pure Ga and In metals were

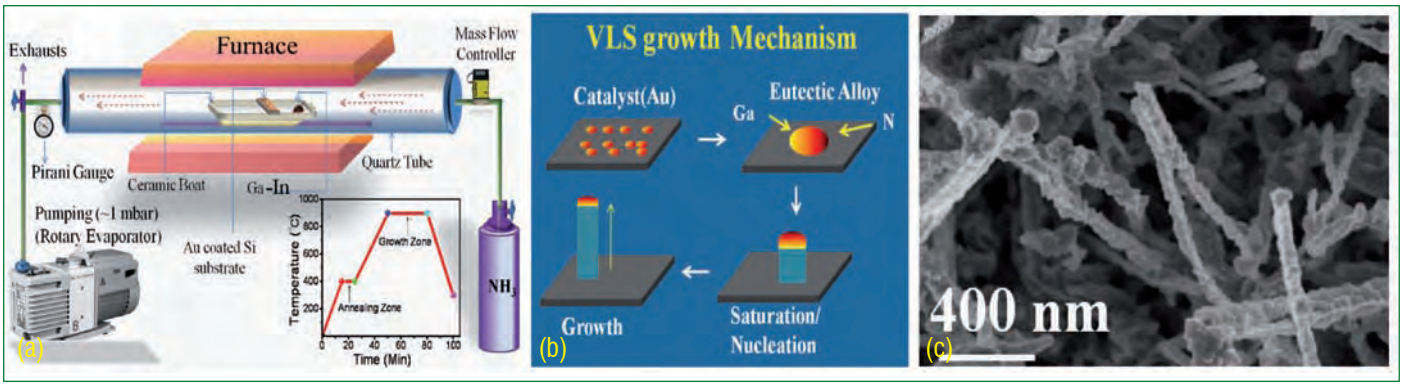



Figure 1: (a) Schematic of CVD system for the growth of nanowires, (b) step by step scheme nanowire growth via VLS mechanism and (c) typical image of nanowires grown at 700 °C

used as the source material in the mass ratio of 3:1. Polished Si (100) wafers were used as a substrate which was coated with Au (thickness ~3 nm). Source material and Au-coated substrate were placed inside the ceramic boat with a separation of two centimetre downstream from the source. The ceramic boat with source and substrate was transferred to a one inch diameter quartz tube and later the tube was degassed by rotary pumping. Growth of nanowires was carried out at 700, 750 and 800 °C for seven hours each in atmospheric pressure. Reactive ultrahigh pure $NH_3$ was introduced at growth temperatures with a constant flow rate of 100 standard cubic centimeters per minute. After the reaction, the furnace was cooled to room temperature under an $NH_3$ atmosphere.

Corrugated morphology of a few micron sized nanowires of 50-75 nm diameter grown at low temperatures is shown in the field emission electron microscopic (FESEM; Zeiss, SUPRA 55) image (Figure 1c). Raman spectroscopic vibrational properties of these nanowires using 514.5 nm excitation show symmetry-allowed modes of ~565 and 721 $cm^{-1}$ corresponding to $E_2$(high) mode and longitudinal optical mode of $A_1$ symmetry [$A_1$(LO)] of wurtzite GaN, respectively (Figure 2a) (inVia; Renishaw, UK). Raman spectra of GaN nanowires grown at 800 °C show the distinguished sharp Raman peaks corresponding to wurtzite GaN. In the case of nanowires grown at 700 °C, the Raman spectrum is broadened, which may be due to low crystallinity in the grown phase at low temperature. A low-temperature (80 K) photoluminescence (PL) study was used for analyzing optical properties of nanowires to shed light on the possible mechanism of low-temperature growth of GaN in the presence of In (325 nm excitation). Nanowires grown in the temperature range of 700–800 °C show strong emission in the energy range of 2.65 to 3.6 eV (Figure 2b). In the case of nanowires grown at 800 °C, two prominent emission peaks at 3.47 and 3.38 eV are observed. The symmetric peak at 3.47 eV with a typical width of 61 meV may correspond to the free exciton (FE). The FE emission line was followed by a broad peak at ~3.38 which can be attributed to the free exciton–phonon [$A_1$(LO) ~90 meV] replica (FE-LO). The weak and broad peak at 2.9 eV may be assigned as blue luminescence band originating from the transitions of carriers in the shallow donor or conduction band to the deep acceptor band.

Growth of GaN nanowires at low temperatures may be proposed in the framework of Raoult's law which is applicable only for ideal solutions. In the case of the real systems, Raoult's law shows two types, namely, positive and negative deviations. In the case of positive deviation from Raoult's law, the solution shows vapor pressure higher than that predicted for ideal solutions and vice versa for negative deviation. The vapor pressure of indium is higher than that of Ga at a given temperature. Applying Raoult's law for the Ga–In system, a solution of Ga–In possesses a vapor pressure greater than that of Ga. At a given temperature, In lifts the vapor pressure of the Ga so that the effective vapor pressure of Ga is high

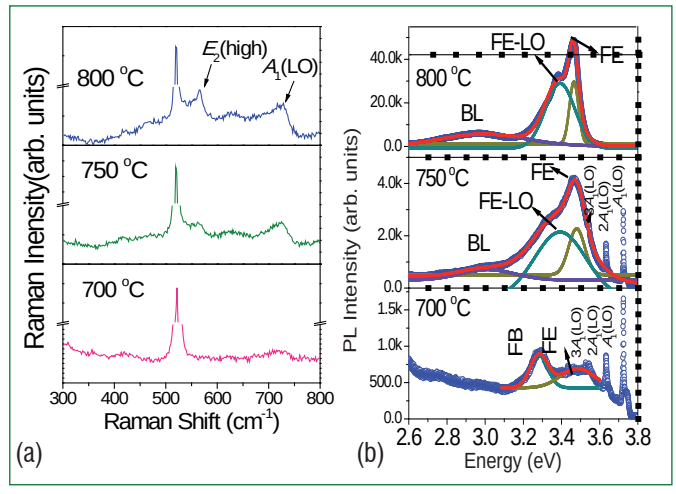



Figure 2: (a) Raman spectra of nanowires grown at three different temperatures and their corresponding (b) photoluminescence emission spectra

enough to initiate growth. Lowering of GaN growth temperature, as is claimed throughout the present study, is possible because of the positive deviation in Raoult's law exhibited by the Ga-In system. This deviation further increases the effective vapor pressure of Ga even at low temperatures. Lowering the growth temperature of GaN nanowires further enhances the interest for GaN device application.

### Growth of InN Nanostructures: Quantum Dots and Nanorods

InN has superior electronic properties like high mobility and high drift velocity, as compared to the other semiconductor materials because of its low effective electron mass. Because of this reason InN is considered as a future high–speed electronic device material. InN is reported to have high electron accumulation at the surface region. This unique property can be utilized in gas sensing applications. Despite its attractive properties, it is a less studied material because of the difficulty in the synthesis owing to its inherent properties like low dissociation temperature and high equilibrium pressure of nitrogen over InN.

Growth of InN nanostructures was performed in a novel technique by the nitridation of $In_2O_3$ powder with reactive ultra high pure $NH_3$ at different temperatures. Growth was carried out in the customized CVD setup (Figure 1a) with a horizontal tube furnace via a catalyst free vapor-solid process. Initially, 40 mg of $In_2O_3$ powder was kept in the ceramic ($Al_2O_3$) boat. Subsequently this boat was transferred to a one inch quartz tube and later the tube was degassed by rotary pump to the base pressure of $10^{-3}$ mbar. Nanostructures were grown in the temperature range of 550 to 700 °C (interval of 50 °C). Reactive ultrahigh pure $NH_3$ (100 standard cubic centimeters per minute) was introduced at the temperature of 400 °C with constant flow rate. After the reaction, the furnace was cooled to room temperature under the $NH_3$ atmosphere.

High resolution transmission electron microscopy (HRTEM; Libra 200 Zeiss) analysis reveals that the morphology of InN

nanostructures strongly depends on the growth temperature. 550 and 600 °C grown nanostructures comprises the quantum dot (Figure 3a) to nano-sized (Figure 3b) particles (5-100 nm). Morphology of these nanostructures is significantly changed to nanorods from the nanoparticles as the growth temperature increases to 650 °C (Figure 3c). The diameter of these nanorods is found to be ~100 nm and the lengths up to a several micrometers.

Raman spectra (Figure 4a) of nanostructures grown at 550 °C showed three prominent symmetry allowed Raman modes in the range of 88, 489 and 593 $cm^{-1}$ corresponding to the $E_2$(low), $E_2$(high) and $A_1$(LO) modes, respectively. Similar features are observed for nanostructures grown at other temperatures. However, asymmetric broadening is observed in the $A_1$(LO) phonon mode for all these nanostructures. This is because of the coupling of LO-phonons with plasma oscillations of free charge carriers of InN owing to its high electron carrier density. $E_2$(high) mode is broadened as the growth temperature of nanostructures increases. A sharp $E_2$(high) mode in the Raman spectrum of nanostructures grown at 550 °C reveals strain free growth of InN nanostructures. In addition to this, there is a continuous increase in the $A_1$(LO) to $E_2$(high) peak intensity ratio as the growth temperature of nanostructures increases (Figure 4b). A sharp increase in the $A_1$(LO)/$E_2$(high) is observed from 600 to 650 °C. This increase in the ratio may be attributed to the polarization of LO mode in the $A_1$ symmetry along c-axis which is favoured in case a wurtizte unit cell.

Thus, it is observed that the morphology of these nanostructures varies from quantum dots to nanorods depending on the growth temperature. Temperature dependent morphology was explained based on the competitive processes of nucleation rate and growth rates. Quantum dots and nanoparticles, as a nucleation rate dominated process, are grown at relatively lower temperatures. Nanorods are grown at high temperature due to long-range atomic diffusion through non-polar surface where growth rate dominates. Nucleation starts with multifaceted particles having polar surface planes and growth is carried over non-polar surface planes. A detailed structural analysis using HRTEM (not shown in figure) is used for the proposed model.

## Morphology of InN Nanorods using Spectroscopic Raman Imaging

Among several spectroscopic imaging techniques to visualise the nanostructures, Raman spectral imaging is one of the most indispensible non-destructive tools. Usually structures of nanometer size are visualized with the aid of either scanning electron microscopy (SEM) and transmission electron microscopy (TEM) or surface probe microscopy.

Imaging of nanostructures using Raman spectroscopy involves area mapping with the particular peak intensity in the Raman spectrum. However, there will be certain limitations in imaging

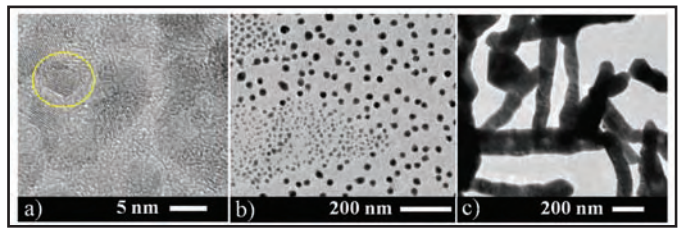



Figure 3: (a) HRTEM image of InN quantum dots (typical size 5-8 nm) and (b) larger sized InN nanopartilces grown at 550 °C. (c) low magnification TEM image of InN nanorods grown at 650 °C

of nanostructures with Raman spectroscopy; first and foremost is the average separation between the nanostructures in overall distribution as it is limited by the optical resolution in the Rayleigh's criterion. Secondly, spatial step size of micro-Raman spectrometer which is normally in the range of hundreds of nanometers. A typical Raman imaging technique involves illumination of a sample under a microscope, data acquisition from the mapped area on the sample, processing of data, qualitative analysis, quantitative analysis and visualization of the data as maps. Spatial resolution of the Raman images in the point and line illumination methods depends on the laser focused spot size, width of the laser line and spatial resolution of the movable sample stage in the rastering process. The laser focused spot size on a sample, when illuminated using an optical microscope is governed by the wave length of the laser light ($\lambda$) and effective numerical aperture (N.A.) of the lenses and are related as 1.22 $\lambda$/N.A.

We have studied the detailed vibrational properties of oblique and vertical InN nanorods grown by plasma assisted molecular beam epitaxy. Raman intensity mapping technique, using micro-Raman spectrometer, is employed to study the morphology of the grown nanostructures. The FESEM images show top view of vertical (Figure 5a) and oblique (Figure 5b) InN nanorods. The average centre-to-centre separations between NRs tips are ~500 nm and ~250 nm for vertically and obliquely aligned NRs, respectively. We have observed that tips of obliquely grown NRs are in close proximity to each other. Raman scattering studies (inset in Figure 5) were carried out at room temperature for both the samples. Similar Raman modes are observed for both vertically and obliquely oriented sample. Distinct peaks at 489 and

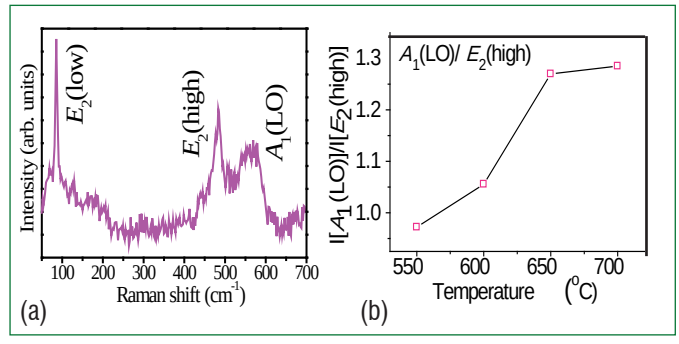



Figure 4: (a) Raman spectrum of InN nanoparticles grown at 550 °C and (b) variation $A_1$(LO) / $E_2$(high)

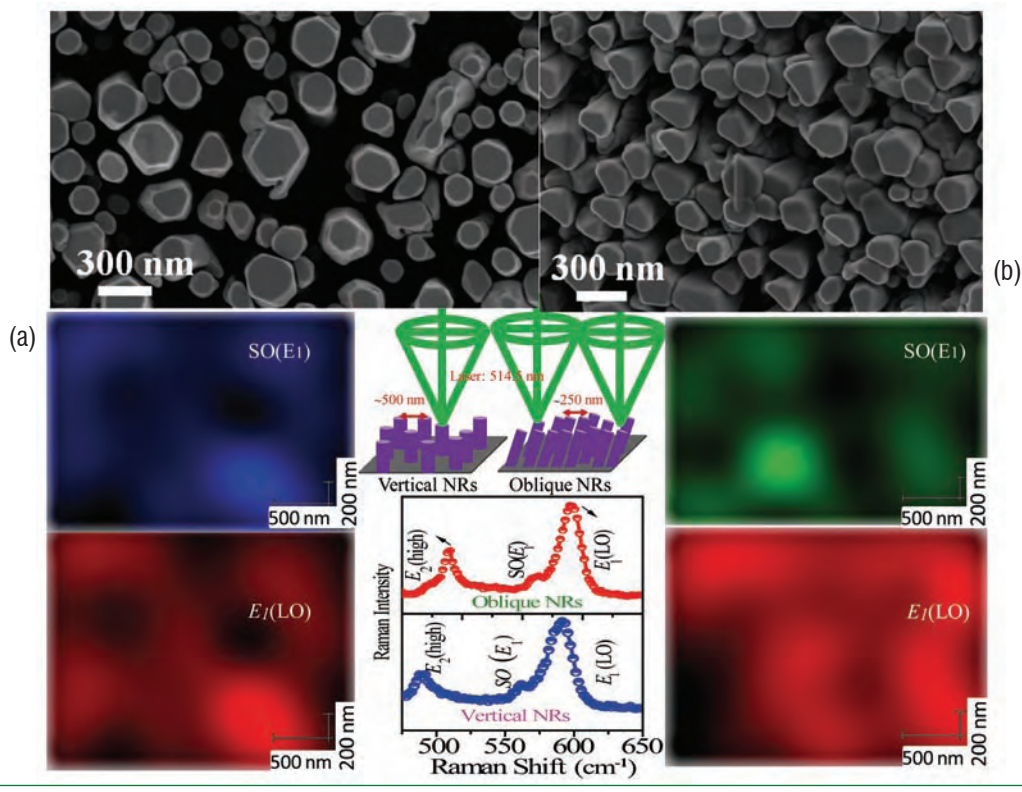



Figure 5: FESEM images of vertical (a) and oblique nanorods (b) and their corresponding Raman spectral imaging with $E_1$(LO) and SO($E_1$). Inset(top) schematic of laser illumination. Inset(Bottom) Raman spectra of nanorods

589 cm$^{-1}$ correspond to symmetry allowed $E_2$(high) and $E_1$(LO) modes, respectively, for wurtzite phase of InN. In addition to these peaks, an additional peak is also observed at 561 cm$^{-1}$, which is assigned to surface optical (SO) phonon mode of InN nanostructures belonging to $E_1$ symmetry [SO($E_1$)]. SO phonon modes are the vibrations of surface atoms whose amplitudes are confined to near the surface region of the material. Normally SO phonon modes are observed in compound semiconductors due to their formal charge separation between anion and cation sub-lattices. SO phonon modes are usually not observed in perfect crystal surfaces due to momentum conservation constraints. Wave numbers of SO phonon modes are very close to LO phonon mode, and their intensity is very weak in bulk materials. SO phonon modes are observed due to breakdown of translational symmetry of surface potentials at surface roughness or surface defects of the material.

Raman area mapping with intensities of $E_1$(LO) and SO($E_1$) modes for both vertical (Figure 5a) and oblique (Figure 5b) nanorods are performed with an optical resolution of ~400 nm for the excitation wavelength of 514.5 nm. Intensity distribution $E_1$(LO) mode of vertical nanorods reveals the distribution of the nanorods (Figure 5a) and resembles the distribution of the nanorods as shown in FESEM image. The SO($E_1$) intensity mapping also reveals similar distribution of the vertical nanorods. This may be due to the reason that separation of vertical nanorods (~ 500 nm) is sufficient to be distinguished in the Raman area mapping since we have performed the mapping with a step size of 400 nm. Mapping of oblique nanorods with $E_1$(LO) mode intensity (Figure 5b), however, does not show distinct distribution of nanorods. This can be due to the fact that $E_1$(LO) mode, originating from the bulk of the material, cannot distinguish the nanorods having tip separation ~250 nm as shown in the FESEM analysis. Moreover, it can be originated from side surface of the oblique nanorods (as shown schematically in the inset of Figure 5). Raman area mapping with SO($E_1$) mode intensity of oblique InN nanorods (Figure 5b), however, reveals the virtual distribution of the oblique nanorods. This is possibly due to the fact that tips of the oblique nanorods can invoke SO phonon mode with surface irregularities on it. Large separation assisted with surface irregularities on tips of vertical nanorods and thus helped us to resolve the nanostructures spatially in both the $E_1$(LO) and SO($E_1$) intensity mapping. Combining the information of Raman area mapping using bulk and surface sensitive phonon modes, we can find the distribution of nanostructures using their surface irregularities or surface defects confined to tips.

We successfully developed chemical vapour deposition technique for the growth of one dimensional III-V nitride nanostructures. Photoluminescence and Raman spectroscopic techniques along with spectroscopic imaging technique are used for the detailed optical characterization.

*Reported by Kishore Kumar Madapu*
*Surface and Nanoscience Division*
*Materials Science Group*

# Young Researcher's FORUM

## Evaluation of Creep Deformation behavior of 316LN Stainless Steel and Its Weld Joint using Impression Creep Technique

Shri Naveena obtained his Masters in Materials Science from Mangalore University, Karnataka. He joined IGCAR as a DAE-JRF in September 2008 and pursued his Ph.D. from HBNI under the guidance of Dr. M.D.Mathew, Former Head, Mechanical Metallurgy Division, Materials Development and Technology Group, Metallurgy and Materials Group. His Doctoral Thesis titled "Understanding Creep Deformation Behavior of 316LN Stainless Steel and Its Weld Joint Using Impression Creep Technique" has been submitted to HBNI. He has eight peer reviewed publications in international journals, five conference proceedings and has received Young Researcher's Award from the IIM Kalpakkam Chapter.

Conventional uniaxial creep testing requires considerable volume of material for specimen preparation and necessitates many such specimens to carryout creep tests at different temperatures and stresses in order to evaluate the creep properties. In addition, each creep test takes long duration. Hence, the test methodology is both material and time consuming. Further, when new materials are being developed, during their development stage, materials are often available only in small quantities. It is essential to make the effective use of small volume of material available for testing in any alloy development activity. In view of this, it is very important to establish a robust and reliable mechanical testing method that can accurately determine mechanical properties at both ambient and high temperatures from small volume of materials to assist in the development of new alloys. Impression creep (IC) technique is an innovative material non-invasive technique that can be used for evaluating creep properties of materials. The technique enables probing small volume of material in relatively short test time. Hence, the technique is attractive for rapid screening of creep properties of several laboratory heats for optimizing chemical compositions and is uniquely suitable for determining creep deformation characteristics of narrow microstructural zones of weld joints.

### Impression Creep Test Methodology

In an impression creep test, a constant load ($L$) is applied to a flat test specimen through a flat-ended cylindrical indenter of suitable diameter ($D$) at elevated temperature. The corresponding applied stress which is referred to as punching stress ($\sigma_{imp}$) is calculated from equation 1. The depth of penetration ($h$) of the indenter is recorded as a function of the elapsed test time ($t$). A plot of depth of penetration versus time gives the IC curve. The IC curves are characterized by a primary creep stage followed by a secondary creep stage. There is no tertiary creep stage in IC curves. This is because of the fact that in IC test, loading is compressive in nature.

$$\sigma_{imp} = 4L/\pi D^2 \quad (1)$$

As a consequence, creep cracks and necking of specimen which occur during the tertiary creep stage leading to fracture do not take place. The rate at which the cylindrical flat punch penetrates into the test specimen is controlled by the time dependent deformation of the material under the punch and thus directly determines the creep behavior of localized volume of material beneath the indenter. The constant rate at which the cylindrical flat punch penetrates into the test specimen is referred to as steady state impression velocity ($v_{imp}$) and is given by equation 2.

$$v_{imp} = dh/dt \quad (2)$$

### Impression Creep Testing System

A unique impression creep testing facility has been developed . The IC machine consists of a vacuum system (upto $10^{-6}$ mbar) which is used to avoid oxidation of the specimen at higher test temperatures. The furnace is located inside the chamber and there is a specimen cage which consists of two rigid frames, one fixed to the bottom plate of the specimen cage and the other connected to the pull rod which is free to move vertically. The former has an indenter holder to which the indenter is fixed and the latter has a sample holder over which test specimen is placed exactly below the indenter. The flat-ended cylindrical indenters are made of tungsten carbide and have typically 1 mm diameter. The pull rod is connected to the lever arm which has 1:10 lever ratio. The vertical movement of the pull rod and hence the impression depth is monitored through a linear variable differential transducer with an accuracy better than ± 0.5%. The maximum capacity of the load cell which is attached to the load train is 1 kN. The temperature controller is capable of maintaining the temperature on the specimen constant with an accuracy of ± 1°C. Data is collected and recorded using a PC-based online data acquisition system.

### Impression Creep Studies on 316LN SS

To validate the technique, systematic studies have been carried out on the creep deformation behavior of 316LN SS and its weld joint using this technique. IC tests have been carried out on four different heats of 316LN SS containing 0.07, 0.11, 0.14, and 0.22 wt.% nitrogen, at various temperatures in the range 600-700 °C, under different punching stresses in the range 400-800 MPa. The specimens used for IC tests were 20×20×10 $mm^3$ whose indenting surface was polished upto 1 μm diamond finish using standard metallographic techniques. The flat-ended cylindrical indenters of diameter 1 mm were employed. Tests were performed under vacuum of ~$10^{-6}$ mbar. Extensive studies on the size and shape of the developed plastic zone, the evolution of stress under the punch during elastic, plastic and creep process, onset of plastic deformation, the dynamics of the material flow in response to the indentation and the mechanism of material pile-up on the specimen surface during impression creep test have been carried out using experimental and finite element simulation studies. IC tests have also been carried out on the heat affected zone, the weld metal and the base metal of 316LN SS weld joint.

### Equivalence between Impression Creep and Uniaxial Creep Test Results

Typical IC curves for 316LN SS containing 0.14 wt. % nitrogen obtained at various temperatures, under a constant punching stress of 675 MPa are shown in Figure 1a. The longest test time in the investigation was about 1000 hours. Figure 1b shows the plot of variation of impression velocity with time for different test temperatures. The impression velocity decreased in the primary creep stage and then reached a constant value indicating a steady state creep region. Figure 1c shows the plot of the steady state impression velocity against the reciprocal of the absolute temperature on a semi-logarithmic scale. The Arrhenius relationship was obeyed. The apparent activation energy was calculated from Figure 1c as 500 $kJmol^{-1}$. This value is in general agreement with the apparent activation energy reported in the literature for type 316LN SS obtained from conventional uniaxial creep tests. IC tests were also carried out at different punching stresses (760, 675, 591 and 472 MPa) at 650 °C. The punching stresses and the corresponding steady state impression velocities obtained were converted to equivalent uniaxial stresses ($\sigma_{uni}$) and uniaxial steady state creep rates ($\dot{\varepsilon}_{uni}$) using equations;

$$\sigma_{uni} = \alpha\sigma_{imp} \quad (3)$$

$$\dot{\varepsilon}_{uni} = \frac{v_{imp}}{\beta D} \quad (4)$$

For most engineering materials, values of $\alpha$ correlation factor range from 0.26 to 0.36 and $\beta = 1$. In the present analysis $\alpha = 0.33$ and $\beta = 1$ have been used to correlate the creep data from impression and conventional creep tests. Figure 1d shows the comparison of the steady state creep rates obtained from uniaxial creep tests and equivalent steady state creep rates obtained from IC tests (derived from equations 3 and 4) for 316LN SS containing 0.14 wt. % nitrogen. The power-law exponent values (n) obtained from both the techniques were in close agreement. Based on the apparent activation energy value of $Qc = 500$ $kJmol^{-1}$ and stress exponent $n = 6.4$, it can be concluded that the rate controlling deformation mechanism is dislocation creep. Hence, the temperature and stress dependencies of steady state impression velocity in power-law creep regime can be described as;

$$\frac{v_{imp}}{D} = A_1\sigma_{imp}^{n}\exp\left(-\frac{Q_c}{RT}\right) \quad (5)$$

Applicability of the phenomenological equation for steady state creep rate proposed by Bird and co workers (Bird-Mukerjee-Dorn) (Equation 6) for the impression creep test results has been analyzed.

$$\dot{\varepsilon}_{uni} = A_3\left(\frac{b}{d}\right)^{p}\left(\frac{D_o Eb}{kT}\right)\left(\frac{\sigma_{uni}}{E}\right)^{n}\exp\left(-\frac{Q_c}{RT}\right)\gamma^{a} \quad (6)$$

The temperature-compensated steady state impression velocity (in place of steady state creep rate) for different temperatures (625, 650, 675 and 700 °C) at 675 MPa and for different

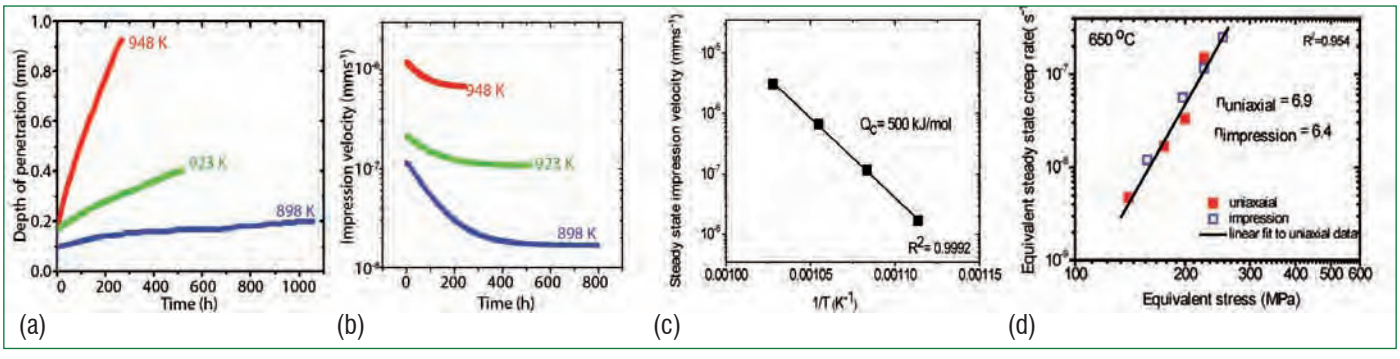



Figure 1: (a) Typical IC curves at various temperatures at a constant punching stress of 675 MPa, (b) variation of impression velocity with time, (c) Arrhenius type relationship between steady state impression velocity and temperature (semi log-scale) and (d) correlation between uniaxial steady state creep rate and equivalent steady state creep rate obtained from IC tests for 316LN SS

punching stresses (760, 675, 591 and 472 MPa) at 650 °C, were plotted against the modulus-compensated punching stress on a double logarithmic scale as shown in Figure 2. The temperature dependent elastic modulus E was calculated according to the equation E(MPa)=201660-84.8θ(°C). The $Q_c$ value obtained in the present analysis was used in the plot. It was observed that the phenomenological equation is also obeyed in impression creep test.

## Optimisation of Nitrogen Content in 316LN SS

In order to optimize nitrogen content in 316LN SS the effect of nitrogen on creep properties of 316LN SS has been evaluated employing IC technique as a faster and non-invasive method. Figure 3a shows the variation of equivalent steady state creep rate with equivalent stress (derived from Equations (3) and (4)) at various nitrogen contents. A dislocation creep mechanism was found to be obeyed (as identified by the value of *n*) which was also observed earlier from uniaxial creep tests. Figure 3b shows the variation of equivalent steady state creep rate with nitrogen content at different stress levels. The equivalent steady state creep rate decreased with increasing nitrogen content at all the stress levels. These results are found to be in good agreement with the results obtained from conventional uniaxial creep tests. IC testing system was thus found to be sensitive to capture the variation in creep rate due to very small change in nitrogen content in the alloy.

## Impression Creep Deformation

During impression creep process, material in the vicinity of indenter undergoes complex deformation due to the multi-axial nature of stresses under the indenter. Typical impression creep deformation aroud the indentation obtained by electron backscatter diffraction (EBSD) analysis is shown in Figure 3c. Three distinguished regions which are indicated with numbers 1, 2 and 3 were observed. In region 1 which is immediately under the punch, no significant change in grain shape was noticed. The material in region 2 was

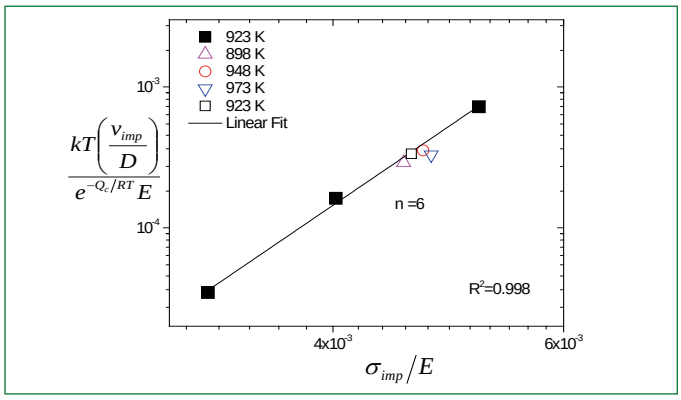



Figure 2: The variation of temperature-compensated steady state impression velocity with the modulus-compensated punching stress (log-log scale) for 316LN SS

found to experience extensive shear deformation. Region 3 which is away from the indentation exhibited no change in shape of grains which indicated the absence of plastic deformation away from the indentation and showed the localized nature of the impression creep deformation. The shape of the plastically deformed zone was found to be approximately hemispherical. In addition, two distinct features in region 2 were analysed; one was elongated grains and the other was fine/equiaxed grains. The deformation was found to occur predominently along (111) planes. The grains along the (101) planes which are the next most favourable planes for deformation in fcc metals and (001) planes were unable to sustain the shear deformation and hence could have undergone dynamic recrystallization.

## Size of the Plastic Zone

Microhardness measurements were made on the cross sectional surface to estimate the size of the plastic zone induced in the specimen. Figures 4a and 4b show the variation of microhardness around the indentation corresponding to 760 MPa. The average hardness in the undeformed region was 206 HV. Similar studies were performed around the other indentations. The high hardness in the plastic zone was attributed to the stain hardening due to

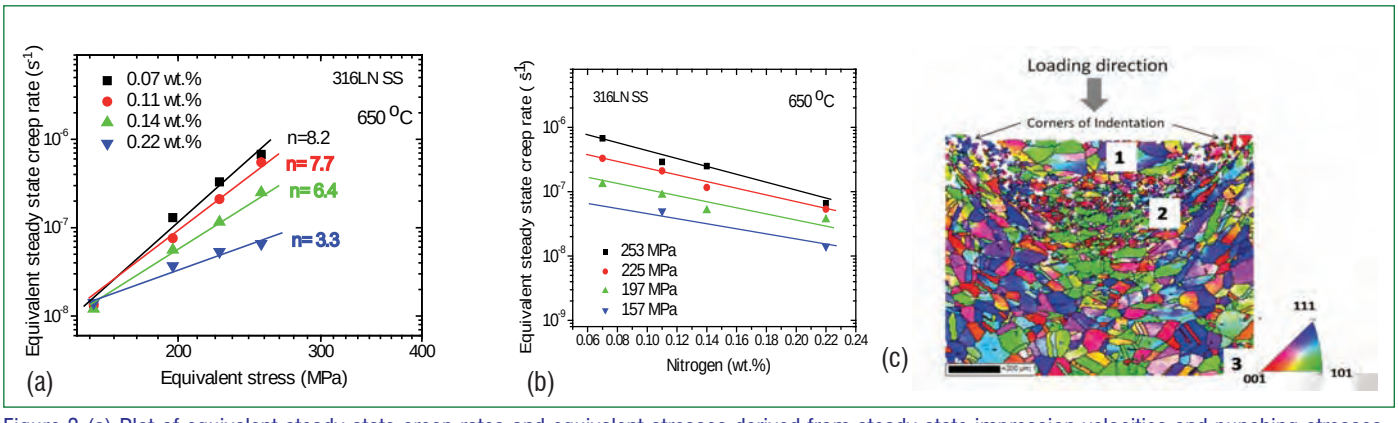



Figure 3 (a) Plot of equivalent steady state creep rates and equivalent stresses derived from steady state impression velocities and punching stresses, (b) variation of equivalent steady state creep rates with nitrogen content in 316LN SS for various stress levels and (c) electron backscatter diffraction micrograph of 316LN SS specimen tested under the punching stress of 675 MPa at 675 °C

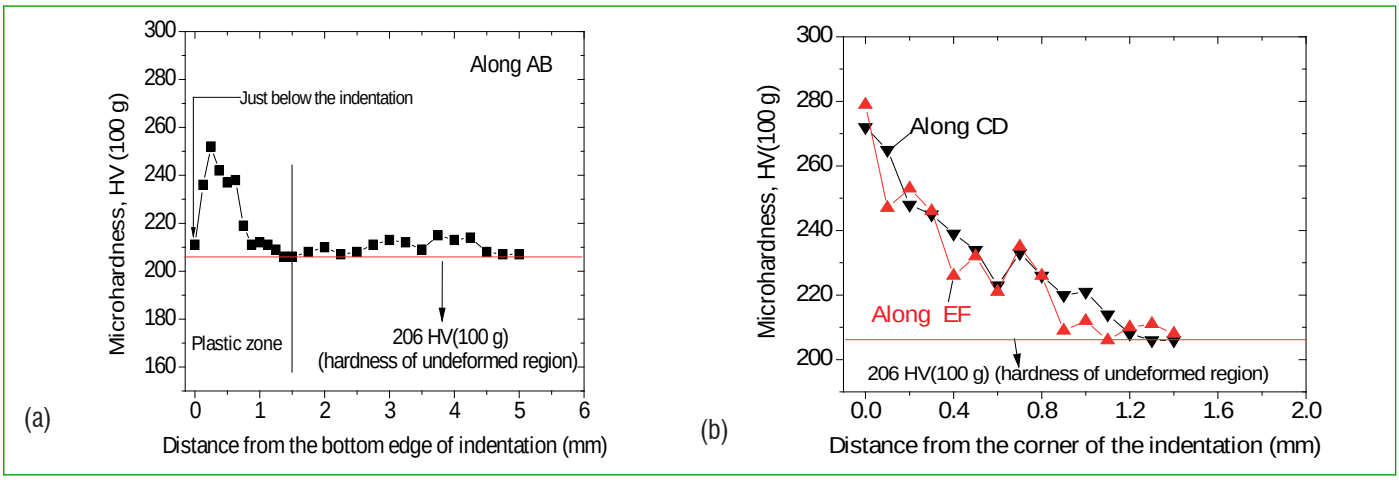



Figure 4: Variation of microhardness with distance from (a) bottom edge and (b) corner of the indentation corresponding to the punching stress of 760 MPa

plastic deformation. From these analyses, the size of the plastic zone around the indentation was estimated to be about 1.5 mm from the indentation edge.

### Spacing between the Adjacent Indentations

Typical variation of microhardness between the adjacent indentations at 760 and 591 MPa is shown in Figure 5a. As can be seen there was no overlapping of the plastic zones associated with the adjacent indentations. The surface profile measured across these adjacent indentations depicting the material pile-up around the indentations is shown in Figure 5b. The width of the pile-up from the indentation edge for the indentation corresponding to 760 and 591 MPa was about 1230 and 1030 μm, respectively. The centre to centre distance between the indentations was about 4800 μm. Therefore, based on the analyses of both microhardness and the surface profilometry between two adjacent indentations which confirmed no overlapping/interaction of the plastically deformed zones, the minimum centre to centre distance that should be maintained between adjacent indentations was predicted to be at least more than five times the diameter of the indenter.

### Finite Element Analysis of Impression Creep Deformation

An axisymmetric finite element model of indenter-specimen system has been developed using ABAQUS finite element analysis software to simulate the IC test. Figures 6(a) to 6(d) illustrate the evolution of Von Mises stresses in the specimen during loading. The total load applied was 530 N which corresponds to the punching stress of 675 MPa. The variation of Von Mises stress along the radial direction in the specimen indicating the onset of yielding, development of fully plastic zone and the width of the plastic zone is shown in Figure 6e. The onset of yielding of the specimen occurred at the circumference of the indentation when the applied load was 91.16 N at which the nominal stress was estimated to be 1.12 $\sigma_{yield}$ , where $\sigma_{yield}$ is the yield stress of the material. Thus, the onset of plastic deformation of the specimen was found to occur at a nominal stress of about 1.12 times the yield stress of the material which is in agreement with the theoretically predicted value of 1.1 $\sigma_{yield}$ . As the load is increased, the plastic zone grows and a permanent impression occurs with fully developed region of plasticity around the whole indentation. The width of the plastic zone was found to be about 1.5 times the diameter of the indentation which is in agreement with the experimentally determined value. Figure 6f shows the start of the displacement of nodes towards specimen surface at which the region under the punch had become fully plastic (at 311.5 N). Thus, the material

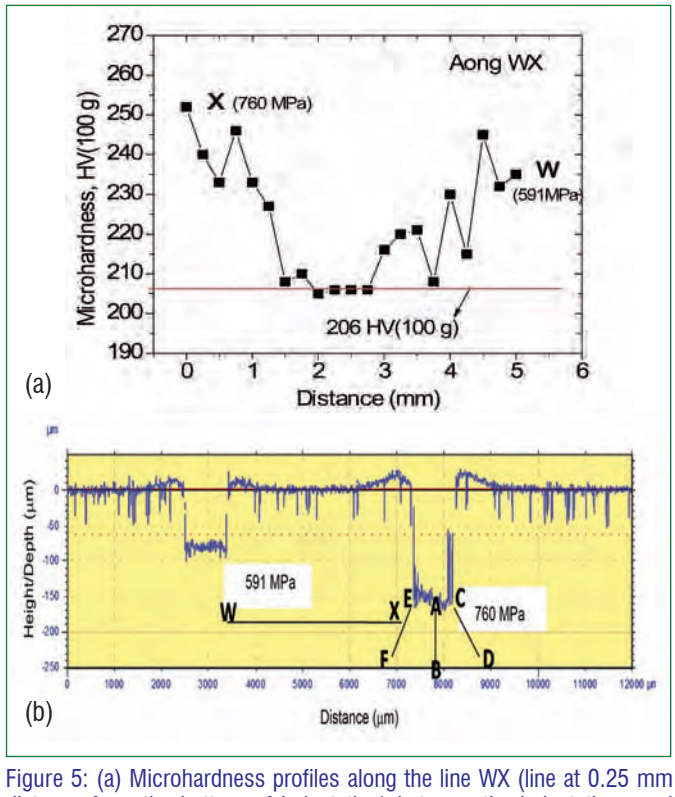



Figure 5: (a) Microhardness profiles along the line WX (line at 0.25 mm distance from the bottom of indentation) between the indentations and (b) surface profilometry of the indentations showing material pile-up

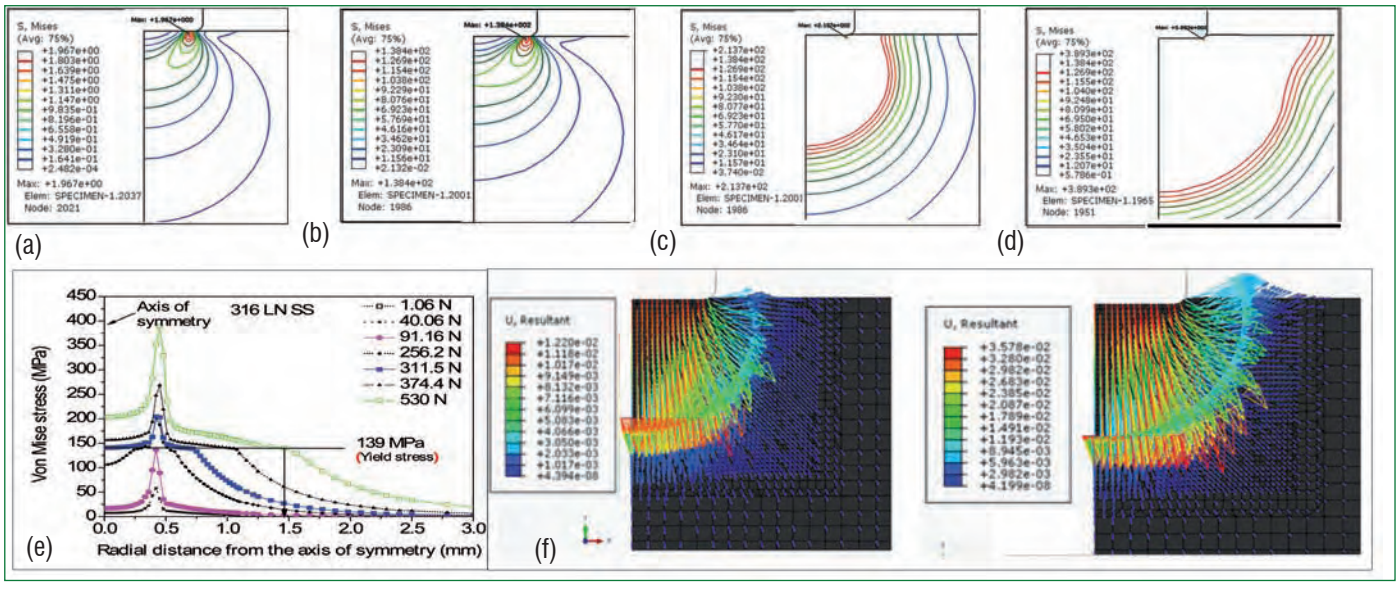



Figure 6: Development of Von Mises stress in the vicinity of the indentation in the specimen during loading: at (a) 1.06 N, (b) 91.16 N (start of yielding), (c) 311.5 N and (d) 530 N, (e) variation of the Von Mises stress along the radial direction during loading of the specimen and (f) displacement of nodes toward specimen surface illustrating the start of material pile-up on specimen surface after the plastic zone is fully developed

pile-up on the specimen surface was found to occur once the region under the punch became fully plastic.

### Creep Behavior of 316LN SS Weld Joint

IC tests have been carried out at 650 °C on the heat affected zone, the weld metal and the base metal regions of 316LN SS weld joint. The microstructure of the base metal was characterized by the equi-axed grains; the heat-affected zone consisting of coarse grains and the weld metal consisting of duplex microstructure of delta-ferrite in austenite matrix. The weld metal, the base metal and the heat-affected zone exhibited distinct creep behaviors (Figure 7a). Figure 7b depicts the variation of impression velocity with time. It is clearly evident that the weld metal deforms at the highest creep rate and the heat-affected zone at the lowest rate, thereby demonstrates that impression creep is a reliable technique to evaluate the creep behavior of different narrow microstructural zones. It can be concluded that the weld metal will have the lowest rupture life and the base metal will have the higher rupture life; these conclusions are in agreement with results from uniaxial creep tests carried out on base metal and weld metal separately.

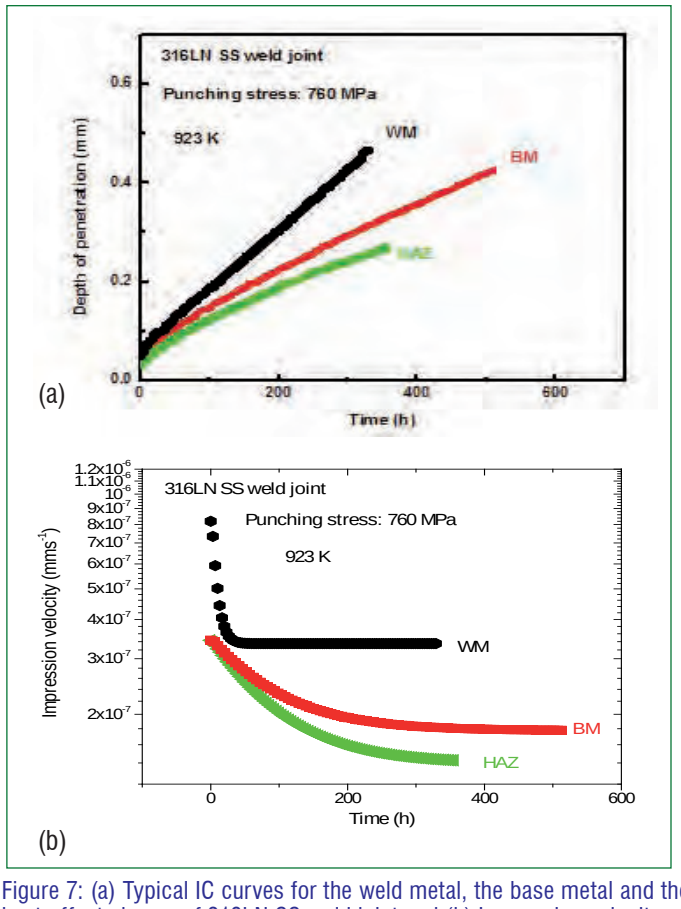



Figure 7: (a) Typical IC curves for the weld metal, the base metal and the heat-affected zone of 316LN SS weld joint and (b) Impression velocity vs time curves

A unique impression creep testing facility has been established. The technique has been validated on 316LN SS and various aspects of impression creep have been investigated in detail. Creep behavior of different microstructural regions of 316LN SS weld joint has been investigated. A good correspondence between the impression creep and conventional creep test results on engineering alloys demonstrates that the IC technique could be used to characterize creep behavior of materials. It can be concluded that the impression creep technique is capable of yielding a good amount of the information that can be obtained from conventional uniaxial creep testing.

*Reported by Naveena*
*Mechanical Metallurgy Division*
*Materials Development and Technology Group,*
*Metallurgy & Materials Group*

## Visits


Dr. R. K. Sinha, Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy with Dr. P. R. Vasudeva Rao, Director, IGCAR and Dr. P. Chellapandi, Director, RDG during his visit to the Reactor Design Group

Dr. R. K. Sinha, Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy with Dr. P. R. Vasudeva Rao, Director, IGCAR and Shri P. Janawadkar, Director, MSG during his visit to the MEG facility, Materials Science Group

Dr. R. K. Sinha, Chairman, Atomic Energy Commission and Secretary, Department of Atomic Energy visited IGCAR during April 12,2014. He met Dr. P.R. Vasudeva Rao, Director, IGCAR, senior colleagues of the Centre and discussed about various programmes in progress. He visited the PFBR preheating mock facility at Reactor Design Group, Magnetocardiography/magnetoencephalography facility at Materials Science Group, Madras Atomic Power Station and construction site of PFBR, BHAVINI.

## Awards & Honours

Shri G. V. Prasad Reddy, MMG has received the INAE Young Engineer Award for the year 2013 from the Indian National Academy of Engineering
He has also been awarded the Sudharshan Bhat Memorial Prize for the best Ph.D thesis in Metallurgical and Materials Engineering for the year 2014 from the Department of Metallurgical and Materials Engineering, IIT Madras, Chennai

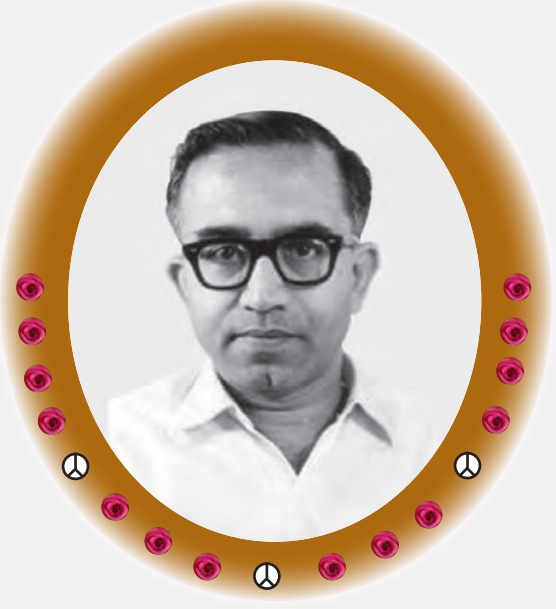
Shri V. Mahendren, MMG has received the Best ISSS Ph.D Student Award for his work on " Development of Magnetically responsive Smart Nanofluids for Optical Sensing Applications", during the Seventh International Conference on "Smart Materials, Structures and Systems" held at Indian Institute of Science, Bengaluru

## Best Paper/Poster Award

Quantitative HRTEM and STEM-EELS Studies of Phase Transformation in V-Ti-Cr Alloys
Shri Chanchal Ghosh, Dr. Joysurya Basu, Dr. Divakar Ramachandran and Shri E. Mohandas from MMG
International Conference of Electron Microscopy and XXXV Annual Meeting of Electron Microscope Society of India (EMSI 2014) held at University of Delhi, Delhi during July 09-11, 2014
Best Paper Award

Design of Loss of Signal Detector for Synchro-to-Digital Converter
Shri Ch. Deepak, Shri G. Venkat Kishore from EIRSG and Dr. G. Amarendra from MSG
IEEE International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT-2014), NICHE, Noorul Islam University, Kumaracoil, Tamil Nadu during July 10-11, 2014
Best Paper Award

# *Homage to Shri N. Srinivasan*



Shri N. Srinivasan, First Director of the Centre passed away on May 18, 2014. Shri N. Srinivasan was born on May 11, 1930. He joined the department in 1953 after graduating as Chemical Engineer and spent a few months at the Reactor School in Argonne National Laboratory, United States. He was responsible for the design of the plutonium plant at Trombay and also established indigenous technologies to reprocess spent fuels from thermal reactors. Shri Srinivasan established comprehensive facilities and initiated programmes towards development of fast reactors and associated fuel cycle, as the first Project Director of this Centre (erstwhile Reactor Research Centre). After his stint at IGCAR, he took over as the Chief Executive of the Heavy Water Board in 1982 and enabled the country to attain self sufficiency in heavy water production. He also served as the Chief Executive of the Nuclear Fuels Complex and Member, Atomic Energy Commission.

Shri N. Srinivasan among several others was a recipient of Padma Bhushan in 2000 and life time achievement award of DAE in 2009.

In the passing away of Shri N.Srinivasan, this Centre has lost a pioneering leader, well wisher and guide. The nation has lost a patriotic scientist whose every breath was for the growth and well being of India in general and Indian nuclear programme in particular.

*Arecaceae : Caryota Urens*



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