Newsletter Of The Plasma Science Society Of India

# Plasma INDIA

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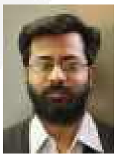
## PLASMA 2004- Report

The 19th National Symposium on Plasma Science & Technology was held at The Physics Department, Budhelkhand University, Jhansi, from 7-10 Dec, 2004. The conference Convenor was Dr. A.K. Singh and Seceratary, Dr. B.S.Bhadoria. The focal theme of the conference was "Scope and Challenges in Plasma Science & Technology". The Symposium was inaugurated by Prof. Ramesh Chandra, Vice Chancellor, Bundelkhand University.

View of the dais during the inauguration function of Plasma-2004

The General Body Meeting of the PSSI was also conducted on Dec 8th. The GBM announced the names of the newly elected members of the executive members of PSSI. Professor S. Bujarbarua of CPP, Guwahati was declared the new President of PSSI for the next term.

## The Buti Foundation Young Scientist Award - 2004



The Buti Foundation awarded the "Young Scientist Award" for the best presentation at Plasma-2004. This award was instituted to promote young researchers working in the field of Plasma Physics. The first recipient of this award was ***Mr. Sambaran Pahari***, Ph.D. student of IPR for the presentation of his research work entitled "*Confinement of electron plasmas and observation of modes in a toroidal Penning trap*". The award consisted of a certificate of excellence and a cash prize of Rs.5000/- and was presented by Professor B.Buti, Chairperson of the foundation, who is also one of the founder members of PSSI.

For more details : http://www.butifoundation.org

**IMPORTANT :** The PSSI Member list is currently being updated. Members are requested to kindly send in their details, including **postal and e-mail address.**

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A view of the participants of the conference.

Prof. D. Bora, addressing the PSSI General Body

Prof. B. Buti addressing the valedectory function

## PLASMA-2005

The 20th National Symposium on Plasma Science & Technology is scheduled to be held at the International School of Photoniocs (ISP), Cochin University of Science & Technology, Cochin, Kerala. Details of dates and deadlines will be posted on the PSSI as well as ISP web pages in due course.

**http://www.plasma.ernet.in/~pssi**

**http://www.photonics.cusat.edu**

The Plasma-2004 had 9 technical sessions and 3 poster sessions. Over 220 contributed papers were presented as oral or poster presentations. There were also 7 plenary talks and 19 invited talks delivered by eminent personalities working in the field of plasma science & technology, during the course of the conference.

## PSSI Research Scholarship

Every year PSSI awards a research grants to enable Research Scholars and Post-doctoral Fellows (below 32 years) to do collaborative research at a research institute other than their own. This grant includes a stipend of Rs.1,500/- p.m. for three months, second class to and fro rail fare and local accommodation.

Applications from candidates for this are accepted twice a year in April and October. The format for the application is available on the PSSI home page. For any further details, the candidate may contact Dr. Amita Das, Secretary, PSSI (E-mail : amita@ipr.res.in)

PSSI Members are requested to encourage young research scholars to apply for this fellowship, which provides them a chance to interact with the people working in their field at any national research centers.

## India To Be A member Of The Asia Pacific Fusion Society (APFS)

The Asia Pacific Fusion Society (APFS) has decided in their last meeting (attended by Prof. P. K. Kaw, Director, IPR) that they would include India as a member country. Three members would represent India at the APFS. The PSSI has proposed the following names at the GBM held on Dec. 8th.

1. Director, IPR, Gandhinagar.
2. Head, Laser Plasma Physics Division, CAT, Indore.
3. President, Plasma Science Society Of India (PSSI).

# Laser Produced Plasma Source For EUV Lithography

**S.S. Harilal**

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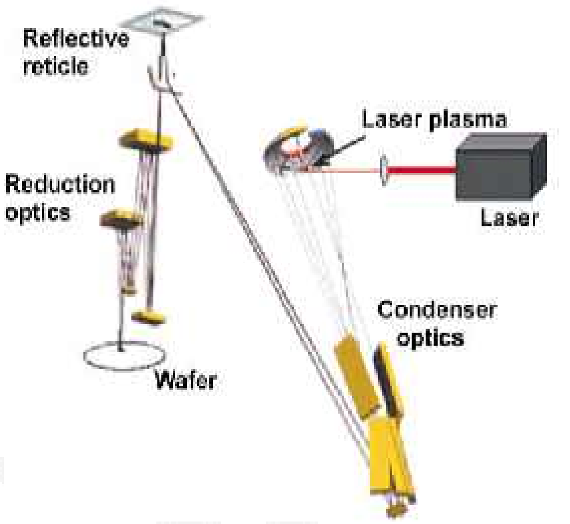
In the manufacturing of integrated circuits (ICs), there exists a key process called lithography. A lithographic system includes exposure tool, mask, resist, and all of the processing steps to accomplish pattern transfer from a mask to a resist and then to devices. Optical lithography is exposing optically active surfaces to patterns of light. In the earlier days optical sources at 405 nm (Hg H-line) and 436 nm (Hg G-line) were used which succeeded in demonstrating a step-and-repeat optical projection camera at a line width of 1 µm. After that, it is necessary to reduce the wavelength of the light used for imaging and to design imaging systems with ever-larger numerical apertures. The reason for looking for shorter wavelength is based on following two equations. The resolution or achievable minimum line width ($L_w$) using optical lithography is given by $L_w = k_1\lambda/(NA)$, where $\lambda$ is the wavelength of the source, NA is the numerical aperture of the imaging system and $k_1$ is a constant that depends on the image contrast enhancement and photo-resist processing. The strategies to meet the continued demands for higher resolution is to migrate from visible light to deep-UV wavelengths for resist exposure. Most advanced chips today are printed using 248 nm (KrF laser) light. Leading manufacturers, such as IBM, have recently transitioned to 193 nm (ArF laser) light, which enables printing features smaller than 100 nm. This trend is continuing to lower wavelengths viz. using 157 nm ($F_2$ laser). With the present state of art optical technology, the maximum resolution available to print critical circuit features having dimension of about $\lambda/2$. The limits of optical lithography have been reviewed in Ref [1]. Over the next several years it will be necessary for the semiconductor industry to identify a new lithographic technology that will carry it into the future, eventually enabling the printing of lines as small as 30 nm. Potential successors to optical projection lithography are being aggressively developed and these are known as “Next-Generation Lithographies” (NGL’s). EUV lithography (EUVL) is one of the leading candidates for the NGL technologies; others include x-ray lithography, ion-beam projection lithography, and electron-beam projection lithography.

Extreme-ultraviolet (EUV) lithography is considered an attractive candidate to succeed conventional optical lithography in the coming years. There are a lot of difficulties that arise with EUV lithography compared to Optical Lithography. EUV radiation is strongly absorbed in virtually all materials, including gases. So EUV imaging must be carried out in vacuum. The lack of optical materials with good transmission or reflection properties in the EUV wavelength range hindered the progress of EUV lithography. But situation changed dramatically after the findings of Mo-Si multi-layer mirrors which has got reflectivity as high as ~ 68 % at a narrow wavelength range centered around 13.5 nm in the EUV spectral region [2]. Since then a lot of efforts has been going on to develop efficient EUV source at 13.5 nm, high resolution optical imaging systems using Mo-Si mirrors, low-defect EUV masks, EUV photoresists and metrology techniques.

The advantage of EUV is the continuation of optical techniques at the significantly reduced wavelengths (13.5 nm verses 193-248 nm), permitting the achievement of significantly small feature size (100 nm or smaller) with modest numerical aperture and large depth of focus. To enable this technology, a source will be required that reliably provides sufficient power at 13.5 nm to yield adequate wafer throughput in a manufacturing tool. Researchers are looking for different kinds of 13.5 nm source, including synchrotron radiation, discharged produced plasma and laser produced plasma. The use of synchrotron radiation as the light source is not practical considering the cost as well as the size and is more complex technologically. The primary disadvantage of a discharge source is the low yield and the production of debris between the electrodes, which results in the need for a debris mitigation system. In addition, the production of excess peripheral heat requires a spectral filter and other thermal management capabilities. The advantage of using laser produced plasma as a light are the power scalability through the tuning of laser parameters, high spectral purity, good dose control, spatial stability, minimal heat load, and a large solid angle of collection [3].



Schematic of the EUV lithographic system with laser produced plasma as the source.

EUV lithography differs from excimer-laser based UV lithography in that instead of using a laser to directly etch the patterns onto the chips, it uses optical or electrical energy to heat a donor material to a very high temperature, forming a plasma around 13.5 nm that is used to etch the patterns. The primary development goals involve creating the output power necessary for production-level EUV lithography at levels below 50-nm and reducing the debris generated in the process. A laser produced plasma light source consists of a pulsed laser which can be focused to an intensity in the 50-500 GW/cm$^2$ range on a target material, generating a plasma which emits radiation characteristics of highly-ionized target atoms. Recent advances in high repetition rate high average power laser systems suggest the feasibility of modular, flexible, and relatively inexpensive microelectronics production facilities based on laser plasma sources. A wide range of targets is available for use in laser-produced plasma schemes, ranging from gaseous and cluster targets, micron-sized liquid targets, cryogenic water droplets and macroscopic solid targets. A suitable scheme will require a 3% conversion efficiency of incident laser pulse energy to soft X-rays in a 2% bandwidth centered at 13.5 nm peak. The schematic of the lithographic system incorporating EUV emission from laser produced plasma is shown in the figure.

The most formidable problem confronting the advancement of this technology is the design and experimental demonstration of a reliable, clean, and cheap target system that meets very stringent production-line criteria. The debris damage to the x-ray optics is the biggest obstacle to the application of laser-produced plasmas as EUV sources for projection lithography. Considerable work has been expended on exploring the feasibility of using laser produced plasmas of xenon clusters produced by supersonic jets or gas puffs from nozzles or solid xenon targets or liquid xenon jets[4]. The disadvantage of xenon plasma as a EUV light source is that the strong 4d-4f transition band of the xenon ions has a peak intensity at a wavelength of 11 nm. The emission around 13.5 nm is relatively weak. The reported conversion efficiency (CE) of flowing xenon target is 0.65% and with cryogenic solid planar xenon is 1.2%.

High-Z solid targets, for example, those elements in the vicinity of Sn, characteristically emit broadband spectra that come from many excited levels of different ionization stages. These energy levels are so close that the radiation they generate in the EUV range can be considered as a continuum (unresolved transition array, UTA). Metal targets have got much higher conversion efficiency at 13.5 nm compared to gaseous or liquid targets. For example, Spitzer et. al [5] studied tin as an efficient target to convert Nd:YAG radiation to 13.5 nm EUV radiation, achieving over 2% conversion efficiency. But conventional solid metal targets pose extreme debris problems. Several authors have experimentally measured and characterized the debris ejected from clean, smooth surfaced, solid metal targets and found that the deposition rates of these targets on nearby collectors is much excess of these stringent lithography requirements. The use of thin tape laser targets, which emit most of the debris safely at the rear side of the tape, while XUV radiation is emitted unaltered in the forward direction is an option. Another method involves the use of a fast rotating disc target which adds additional sideward momentum to the larger debris particles, thereby creating an angular zone which is free from the harmful particulates. Also, the level of debris ejected from thin-film-coated, tape-drive targets or fast rotating disc targets are also unacceptable, even if interdiction measures are invoked.

From the reasons cited above a lot of efforts is going on worldwide to develop new types of Sn based targets. These include Sn doped low-density hydrocarbon foam targets, Sn mass limited targets, Sn dot targets etc. These types of targets have only the mass of tin that is necessary for forming the radiating plasma. By constructing the target in such a way, a better conversion efficiency from laser to 13.5 nm is expected. More than that the usage of tin embedded low-Z form target will definitely reduce the debris ejected from the source. But condensable target like these will require more debris mitigation than xenon target. Some new concepts have been formulated in an effort to address the debris problem; they are usage of a magnetic field to control the ions in the plasma, electrostatic repeller field[6], presence of ambient gas *etc.* Flora et. al [7] used krypton ambient as stopper for ions and small debris in laser plasma sources without much attenuation of the EUV radiation. The gas effectively quenches the high-speed atomic debris particles by momentum transfer in multiple collisions (drag effect)[8]. Our preliminary studies with a magnetic trap showed slowing of the ions especially at later times of evolution when it expanded across the field[9]. A systematic study of expansion dynamics, plasma evolution, EUV spectroscopy, estimation of conversion efficiency and debris characterization with new forms targets are essentially needed to envisage its use in EUV technology. Presently UC San Diego is collaborating with General Atomics for developing and characterizing different kinds of Sn based targets for EUV laser produced plasma source.

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### About The Author

Dr. S S Harilal hails from Alleppey in Kerala. He took M.Sc. in Physics (1992) from Kerala University and his Ph.D. in laser produced plasma (1998) from Cochin University of Science & Technology, Cochin. He has served as Lecturer in Physics at Sree Narayana College from 1996-1999 (affiliated to Kerala University). He has been a Humboldt fellow at Univ of Bochum during 1999-2001. Presently he is working as Assistant Research Scientist with UC-San Diego. His research interests include laser plasma spectroscopy, EUV and X-ray spectroscopy and high energy density physics.

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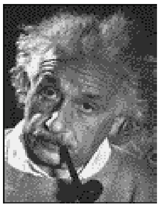
### Science Smilies

Matter is fundamentally lazy : It takes the path of least effort.

Matter is also fundamentally stupid : It tries every other path first.

*A certain Physics Review referee..*
*Considers all papers with glee..*
*"What's new is not true,*
*And what's true is not new,*
*Unless it was written by me."*

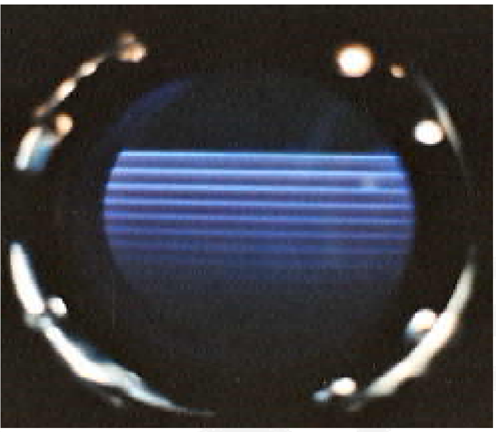
Two atoms bump into each other. One says “I think I lost an electron” The other asks, ‘Are you sure?’, to which the first replies, “I am positive”



*"If we knew what it was we were doing, it would not be called research, would it?"*
*Albert Einstein*
*(1879-1955)*

## Magnetic Field Measurements In BETA

**D Chenna Reddy and Amit Sircar**, Institute For Plasma Research, Gandhinagar



Precise magnetic field measurements are important in a number of plasma physics experiments. Traditionally, these fields are measured using Hall probes or flux loops. For measuring the average fields in toroidal devices, we have developed a method in which an electron beam is launched along the toroidal field. The beam path becomes visible at suitable fill pressures and beam currents, which can be imaged.

The drifts suffered by the beam can be measured from the images and used to estimate the average R and Z components of the magnetic fields. This method has been successfully used in BETA device. The measurements indicated an average vertical field of about 0.3% of the applied toroidal magnetic field.

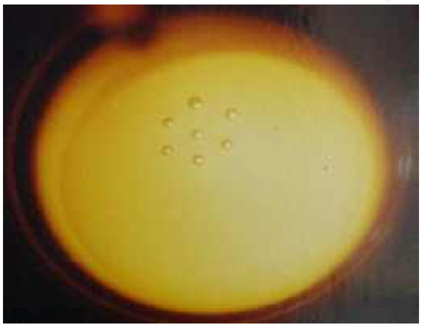
## Coulomb Crystals

**S.V. Kulkarni**, Institute For Plasma Research, Gandhinagar

Coulomb crystals continue to be an object of extensive study in a variety of model systems ever since the theory of Wigner crystallization first appeared in 1939. They have been experimentally observed on the atomic scale as ion and electron crystals, on macroscopic scales as colloidal crystals in aqueous solutions and most recently as plasma crystals in dusty plasmas. The novel method of producing water droplets in a thin layer of oil is developed and macroscopic two-dimensional Coulomb crystals of charged water droplets on the surface of a thin layer of mineral oil that covers a volume of de-ionized water are produced[1]. The ordered patterns, which are obtained at atmospheric pressure and room temperature, evolve dynamically as a result of electro-hydrodynamic instabilities induced in the system due to the simultaneous application of a corona discharge and a DC voltage bias. The crystal dimensions can be controlled by the external voltages and the size can be varied from a few millimeters to a few centimeters. Coulomb crystals of water droplets of large size and small size were obtained in water. In another set of experiments, Coulomb Crystals were produced of centimeter sized spherical objects at room temperature and atmospheric pressure. The method employs negative corona for charging using high voltages and oppositely charged background.Using positive DC high voltage confines the spherical objects to arrange themselves in a closed packed hexagonal structures.

Both the types of Coulomb crystals can be maintained for long periods (several hours) and also melted in a controlled fashion. Thus our system could be a useful and simple experimental model for a variety of fundamental studies related to phase transitions and dynamical pattern formation in driven non-equilibrium systems as well as to applications of such concepts in various technologies.

To the best of our knowledge both the methods of producing crystals are new and the Coulomb crystals of cm size spherical objects are not reported anywhere in literature.



Single hexagonal structure of water droplets formed after adjusting the oppositely charged background.

Coulumb crystals created using centimeter sized spherical objects.

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[1] Kulkarni S.V. and Sen Abhijit, Phy.Rev.Lett., **93**, No. 1, July 2004, pp. 14501-14504

## Report of the Fourth IAEA Technical Meeting On Steady-State Operation Of Magnetic Fusion Devices And MHD Of Advanced Scenarios

This International meeting, organized by the Institute For Plasma Research, Gandhinagar, was held at Ahmedabad from February 01-05, 2005. More than 35 participants from various European and Asian countries as well as those from USA and India who are involved in experiments with magnetic fusion devices took part in this meeting.

Some of the aspects covered at the meeting include superconducting devices, long pulse operation and advanced tokamaks, steady state fusion technologies, heating and current drive, particle control and power exhaust. Theoritical aspect and modelling of steady state plasma and feedback control were also discussed at the meeting. These discussions were spread over 9 plenary talks, invited talks and several oral and poster presentations. A visit to the Institute for Plasma Research was also arranged for the particpants during the course of the meeting.

Prof. P.K. Kaw, Director IPR addressing the meeting

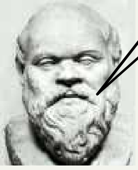
Participants during one of the scientific sessions

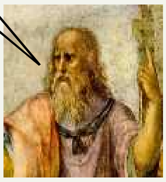
Photo : K.K. Mohandas

Some of the participants during their visit to IPR

***Plato*** : The next statement by Socrates will be false.

***Socrates*** : Plato has spoken truly !





The Plato-Socrates paradox is a classic example of the liar-paradox discussed by medivial logicians. If Plato was right, then what Socrates says is wrong, and *vice versa*. Neither sentence talks about itself, yet, taken together, they change the truth value of the other, so that we are unable to say which of the two is true or false.

Source : Martin Gardner “Aha ! Gotcha” Paradoxes to Puzzle & Delight, WH Freeman & Co, NY, 1982

## SST-1 Assembly Update

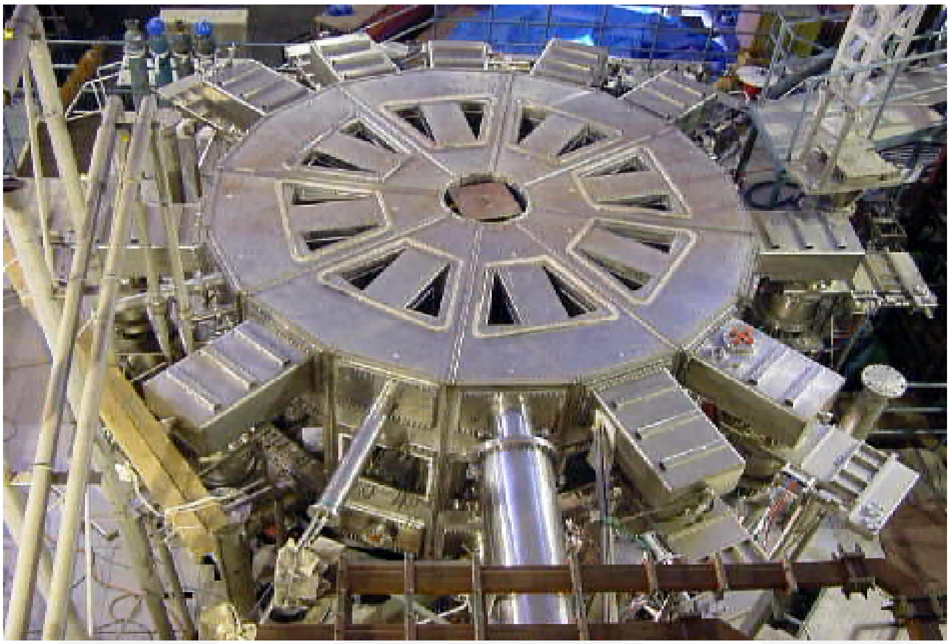


Photo : K.K. Mohandas

Top view of the SST-1 assembly as on 10-Jan-2005

The last phase of SST-1 assembly and testing was accomplished by December 2004. The major liquid helium (LHe) cryogen supply and return connections for all the superconducting magnets were welded, tested and qualified for the performance requirement. The cryostat was then sealed (as seen in the above photograph). All the liquid-nitrogen cooled ($LN_2$) thermal shields, which are mounted over the vacuum vessel and on the inside surface of the cryostat wall were integrated with the liquid nitrogen supply. These connections were also tested and qualified as per performance requirement. The main $LN_2$ & LHe supply for the SST-1 machine and their return lines from the cryogenic plant were established and tested. The thirteen turbo-molecular pumping stations, each having 5000 lt/sec pumping speed, along with roots pumps, rotary pumps, gate valves and other instrumentation were erected and commissioned for the cryostat evacuation to the design base pressure of $1x10^{-5}$ mbar. All the necessary instrumentation for diagnostic, control and monitoring of the magnet health were installed and tested. SST-1 machine is now ready for the series of commissioning tests prior to the first plasma discharge.

As a part of commissioning test, leak testing of the cryostat and vacuum vessel was performed and qualified. Cryostat was evacuated to the designed pressure of $1x10^{-5}$ mbar using four turbo-molecular pumping stations. Machine is currently being made ready for the TF magnet cool-down and plasma operation. By the time this goes to the press, the cooldown of the magnets to required temperatures would have been initiated. We hope to have the first plasma shot soon after that.

--- *Bharat Doshi*

### Plasma Conferences in 2005

A comprehensive list of the upcoming worlwide conferences in Plasma Science & Technology can be found at this web site. http://www.ewh.ieee.org/soc/nps/PlasConf/mtg05.html

**Note from the Editor:** PSSI members wishing to contribute to this Newsletter may please send in their contributions in the form of research notes or popular articles on any plasma-related topic to the Editor, Plasma India. Please refer to the PSSI homepage for further details.

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