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Hotline

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PPPL Researchers Develop Novel Plasma Applications

By Anthony DeMeo

Over the years, the value of plasma physics as a scientific discipline has been greatly enhanced by the recognition of its wide practical and scientific applications. Currently, more than a dozen PPPL staff members are applying knowledge of plasma science and technology, gained in fusion research, to projects ranging from the development of novel fire suppression systems to the application of computer modeling techniques to study charge deposition in the xerographic process.

For example, Boris Grek is studying the use of laser diagnostic devices, developed to monitor fusion plasmas, for the measurement of physical properties of textile fibers during manufacturing (see PPPL Digest, August, 1995). His work will eliminate the need to stop the manufacturing process to sample output, leading to greater production efficiency. Hideo Okuda, working with a local small business, Charged Injection Corporation, is applying theoretical and experimental plasma physics principles to solve problems in the field of electrostatic atomization. There is a multitude of applications for Okuda's work including more effective fire sprinklers, as well as improved fuel combustion and spray painting efficiencies (see PPPL Digest, May, 1996).

PPPL physicist Hideo Okuda is conducting research on the electrostatic atomization of liquids and powder droplets. This photo depicts the behavior of an electrostatically-charged water mist as a fire extinguisher. Since a flame is a good conductor of electricity, the charged mist is attracted to the fire, eliminating the need to deluge an entire area with water.

Special Issue

Environmental Benefits

Most people agree on the longer-term environmental benefits of fusion energy, but may not be aware of the nearer-term environmental benefits of the plasma research underway at PPPL. Physicists David Mikkelsen and Brent Stratton are working with Drexel University and Plasma Technology, Inc., a small business in Santa Fe, NM. Mikkelsen and Stratton are applying their unique expertise in the spectroscopic analysis of high temperature fusion plasmas and their knowledge of chemical kinetics modeling to the emerging field of plasma chemistry. Their work involves monitoring plasma "torches," which can be used for the conversion of complex hazardous wastes into useful materials such as syngas. The PPPL group performs spectroscopic analysis to identify the species and the concentrations of the chemicals present. These measurements are modeled using a chemical kinetics code with the ultimate goal of improving the efficiency of the conversion process (see PPPL Digest, March, 1996).

Tom Holoman adjusts PPPL's experimental arc furnace.

Steel Recycling

Improved efficiency is also on the mind of Stewart Zweben and his team, which is applying plasma physics and their knowledge of electromagnetic design to electric arc furnaces such as used for recycling steel. The production of recycled steel using electric arc furnaces is a $30 billion business worldwide, comprising about 40% of total steel production. According to Zweben, "A better understanding of the physics of the arc plasma will lead not only to improved efficiency, but also better control of industrial arc furnaces. We hope to extend this research to assist in the development of these furnaces for the destruction of hazardous organic and nuclear wastes."

"A better understanding of the physics of the arc plasma will lead not only to improved efficiency, but also better control of industrial arc furnaces."
—Stewart Zweben

Chemical Synthesis

Meanwhile in the L-Wing, PPPL's Phil Efthimion and Jim Gorman are ready to begin synthesizing chemicals using a small plasma device they built. The synthesis process utilizes the plasma's energetic electrons (a few electron volts) to break apart the molecular bonds of chemicals introduced to the plasma device. This breaking apart is commonly referred to as molecular dissociation. By careful control of the gas temperature, the molecular fragments, known as free radicals, are expected to combine into the chemical of interest. The plasma device includes a small linear vacuum chamber and solenoidal magnetics. The plasma is produced by a few hundred watts of 40-MHz radio frequency waves introduced with a spiral antenna through a large vacuum

HOTLINE

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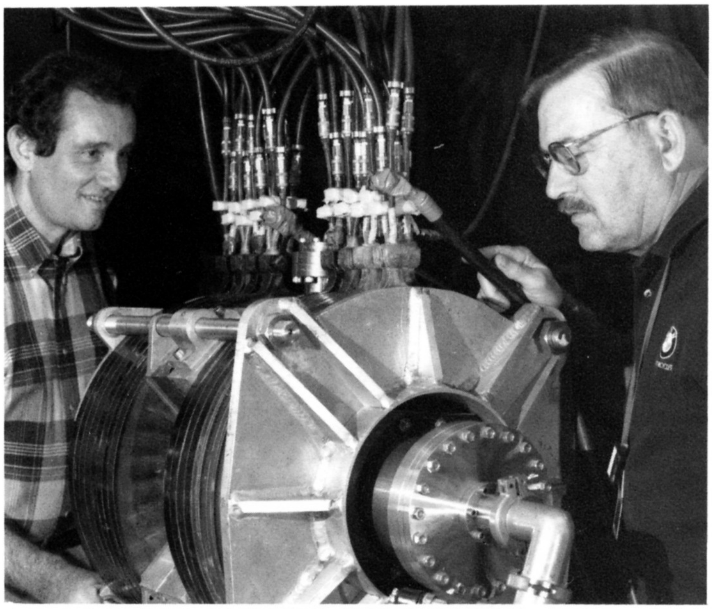


Phil Efthimion (left) and Jim Gorman with the plasma device they built for the synthesis of chemicals.

window. According to Efthimion, "The plasma synthesis of this chemical is economically competitive with traditional chemical manufacturing techniques because it has the potential of synthesis with no metallic contamination. The market value of the chemical with this high degree of purity is ten times that of its normal purity grade, making the use of plasmas cost effective." Presently, the plasma device has been operated and tested with argon gas, and the gas handling system is being modified for chemical synthesis.

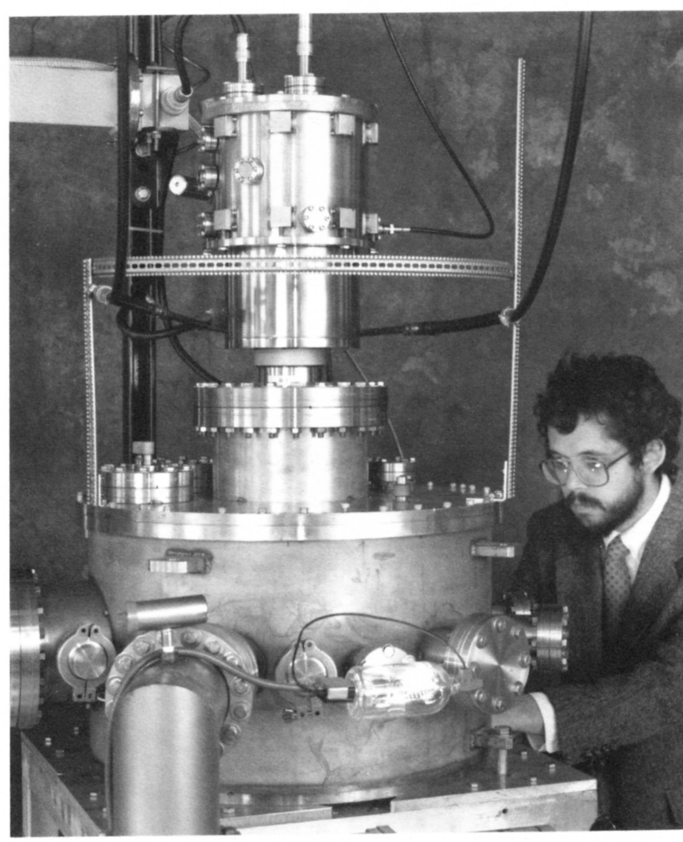
Materials Processing

The use of plasmas for materials processing is not new at PPPL. For many years, small groups of Laboratory physicists have studied important applications including plasma processing of semiconductor materials and studies of spacecraft materials erosion. In these applications the plasmas are used, directly or indirectly, to drive chemical or physical surface processes.

For example, in semiconductor processing, plasmas are used directly in over a third of the steps required to produce modern computer chips. Without the aid of plasmas, much of the dramatic improvements in modern electronic technology could not have been made. However, in some situations direct plasma processing almost has been pushed to it's limits. One method which appears to overcome those fundamental limitations is materials processing with hyperthermal atomic beams (HABs). In the late 1980's, PPPL physicists were able to simulate the environment encountered by a spacecraft traveling in low-earth orbit, i.e., through a thin atmosphere of atomic oxygen. Using plasma ions reflected from a metal plate, they created a beam of neutral oxygen atoms and aimed the stream at candidate materials to measure erosion.

"Intense hyperthermal atomic (and molecular) beams may provide revolutionary methods to manufacture new materials..."
—Matthew Goeckner

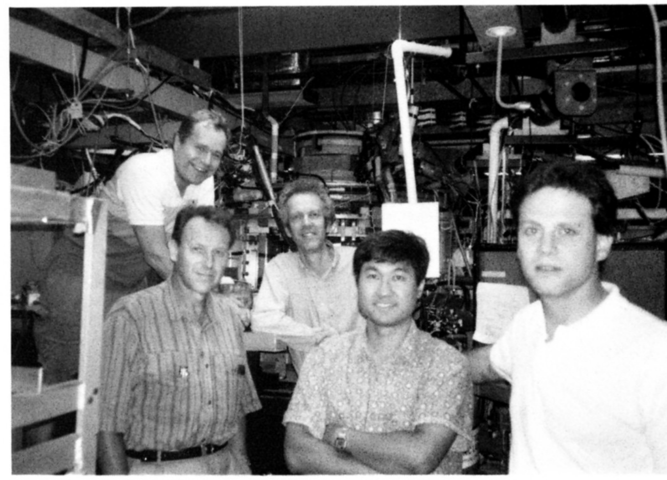
The future for HABs is bright. According to PPPL physicist Matthew Goeckner, "Intense hyperthermal atomic (and molecular) beams may provide revolutionary methods to manufacture new materials, to alter materials properties, and to deposit and remove materials from surfaces. Films and coatings play a major role in a wide variety of applications including power generation, transportation, and environmental remediation." Matthew and his colleague Sam Cohen, along with two graduate



Matthew Goeckner with the unique, compact hyperthermal atomic beam device developed at PPPL.

students Jeff Wang and Jaeyoung Park, and technician Tim Bennett, are using a unique, compact HAB device developed at PPPL. While there are many novel features to the source, the most radical is the use of two reflections to create the neutral beam. As with the earlier neutral beam sources, the first bounce serves to neutralize energetic ions. However it is the second bounce which will make the new source successful in material processing. This is because the second bounce allows one to produce a contaminant (particle and photon) free neutral beam, which is uniform.

The group has proposed using the beam to improve the characteristics of coatings used in a wide variety of energy-intensive applications, including coatings which protect components, improve efficiency, and reduce pollution.



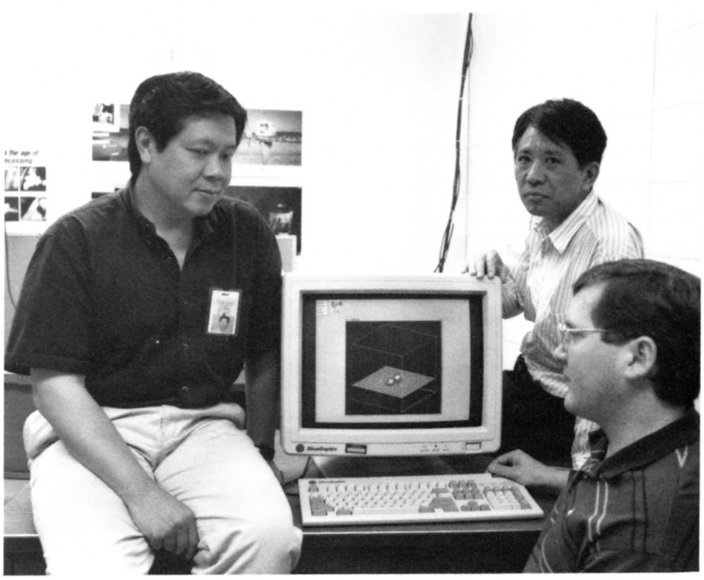
At the VERSATOR tokamak at MIT are (from the left) Ivan Mostovesky (MIT), Szymon Suckewer, Charles Skinner, Joel Villasenor (MIT) and Steve Paul.

Modeling Xerography

The field of xerography has come a long way over the last thirty years from machines producing a few copies per minute to today's high-speed duplicators, virtually eliminating small lithographic printing presses. Color copiers such as that in PPPL Graphic Services have revolutionized in-house production.

In the xerographic process, a corona discharge deposits an electrostatic charge on a photoconducting surface which is then exposed to an image of the item being copied. The charge drains from the blank areas which become conductive when exposed to light, leaving an electrostatic image. The image is then transferred to paper and an oppositely charged toner (ink) is applied. The ink is then fused to the paper by the application of heat.

Color copying involves the re-charging of the photoconductor surface for each of the primary colors comprising the image. Repeated charging can result in image defects. This is where PPPL physicist Hideo Okuda comes in. He is lending his expertise in electrostatics and charged particle/fluid dynamics to Xerox to develop detailed simulation models of the charging process. Knowledge gained from the simulations will complement experimental data, which is difficult to obtain because of the complexity of the copying process. Xerox hopes to eventually simulate the complete photocopying process as a way to study design trade offs between image quality and cost.



Meng H. Lean, Principal Scientist with the Xerox Webster Research Center, is shown with PPPL's Hideo Okuda and Scott Parker. The computer graphic depicts the three-dimensional simulation of the charging of toner (ink) particles and the photoreceptor surface in laser xerography.

X-ray Lithography and Microscopy

Another group of PPPL physicists and their colleagues hope eventually to make use of a tokamak for the production of soft X-rays for lithography and microscopy, as well as a host of other applications, including the study of radiation effects on biological cells and the sterilization of biomaterials and artificial organs.

Compared to a synchrotron, the conventional source of X-rays, a compact tokamak has several distinct advantages. The construction and operation of a compact tokamak is much simpler and far less expensive than the smallest synchrotron. In fact, a suitable tokamak would fit into an area about the size of two offices, whereas a typical synchrotron requires a space about half the size of a football field.

Because of the large number of ions and electrons (radiators) in a tokamak plasma, it can provide a much larger amount of soft X-ray radiation compared to a synchrotron. A compact tokamak can be operated in either a steady-state or pulsed mode, with very good stability and reproducibility of radiation characteristics. The radiation can be controlled and maximized for particular wavelengths by choosing the appropriate plasma composition. Possibly, a tokamak could augment the operation of a synchrotron, whenever a much more intense source of X-rays at a specific wavelength is needed for a particular application.

In projection soft X-ray lithography, an x-ray image of a circuit pattern is projected on to the surface of the silicon wafer, causing chemical changes in its photoresist coating conforming to the circuit pattern. The pattern is then etched into the surface by chemical treatment. The use of X-rays to "print" finely detailed integrated circuit patterns on semiconductors could result in a 100-fold increase in the number of components accommodated on a silicon chip. One can only imagine the impact of still smaller components for computers, consumer electronics, and a broad range of other applications.

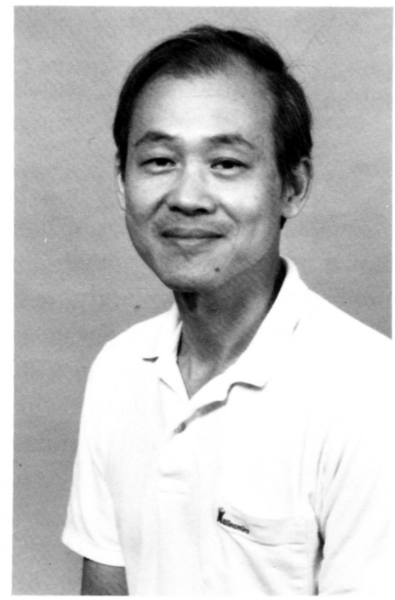
The idea of using a small tokamak with central plasma temperature not exceeding 150-200 electron volts was conceived a few years ago by Szymon Suckewer in collaboration with Daniel Cohn and Leslie Bromberg, both of the MIT Fusion Center.

Szymon Suckewer is leading the PPPL team consisting of himself, Charles Skinner, and Steve Paul. Miklos Porkolab, director of the MIT Fusion Center, is leading MIT's effort. Currently the work is being done collaboratively with Applied Physics Technologies Corporation of Stony Brook, NY. In a few weeks, the group expects to perform final experiments on the small MIT tokamak, VERSATOR, followed by the preparation of proposals to different government agencies.

Photocathode Electron Projection

X-rays are not the only way scientists hope to increase the number of components on the surface of a chip. Comparable improvements can be obtained using electron microlithography. In collaboration with AT&T, PPPL's Long-Poe Ku was able to simulate a fundamental improvement to a technique known as photocathode electron projection. In such systems, a magnetic field is used to focus electrons emitted photoelectrically from a cathode patterned with the circuit to be etched.

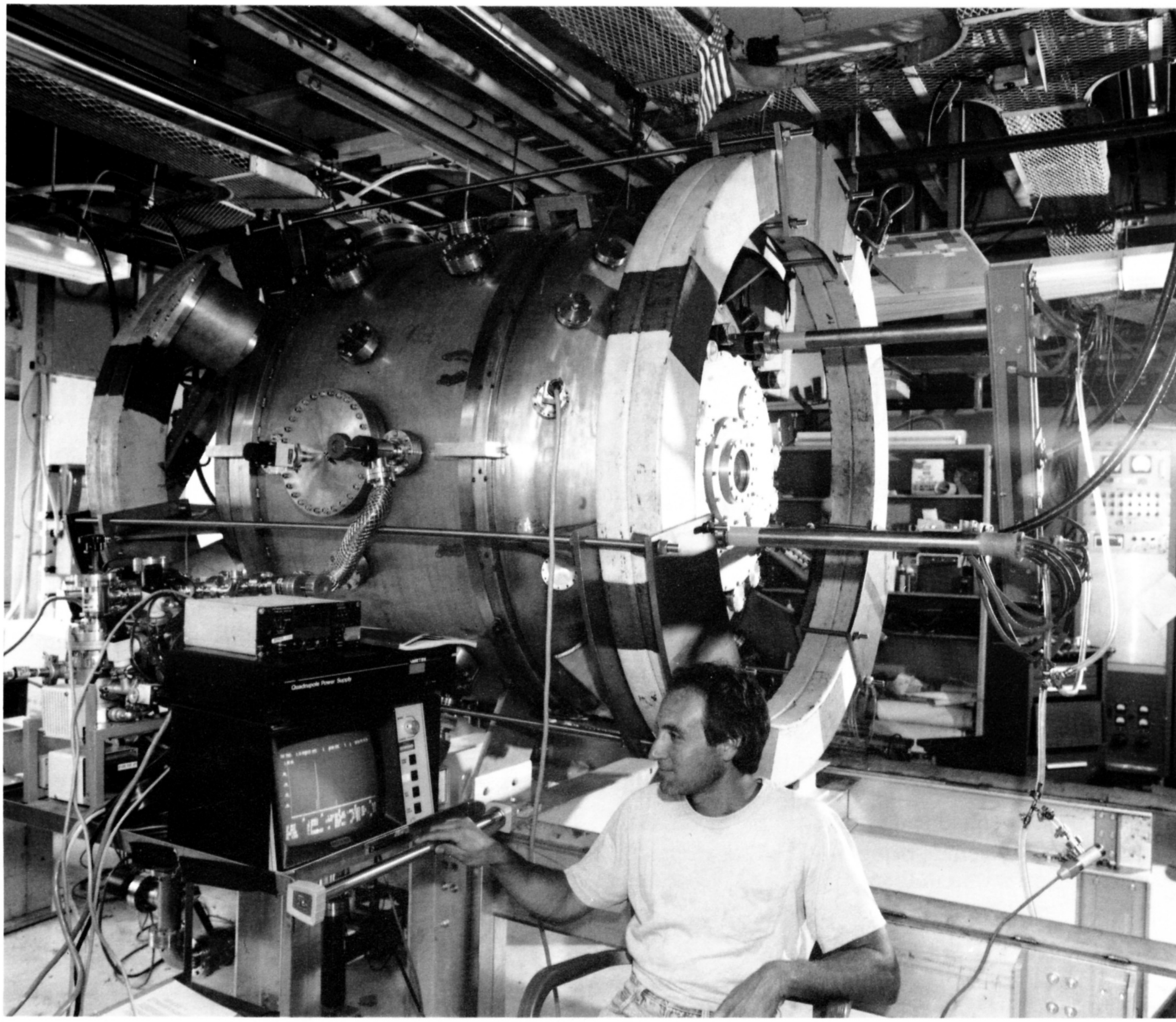
Long-Poe Ku has simulated a novel improvement of this technique using magnetic field compression to achieve greater pattern reduction down to resolutions of 100 nm. His technique would allow a 1-cm-square array of chips to be etched simultaneously.



PPPL's Long-Poe Ku

In Long-Poe Ku's system, the photo-emitted electrons are accelerated by a grid. After passing through the grid, the electrons enter an electric field-free column in which the magnetic field strength is increased at the end where the silicon wafer is located. The electrons spiral around the converging magnetic field lines, much the way they do in a tokamak, resulting in an image compression.

As a result of his computer simulations of the system, Long-Poe Ku believes that the compression technique is feasible and that a "table-top" demonstration could be constructed for about $250K using available superconducting magnet technology.●



PPPL's Dave Cylinder and the Magnetic Reconnection Experiment (MRX).

MORE TO COME...

The projects described in this issue do not cover the entire realm of non-fusion work at PPPL. Other efforts are underway, most notably the Magnetic Reconnection Experiment (MRX) which involves fusion and solar physics aspects. The MRX and other programs will be covered in separate articles in upcoming editions of the PPPL Hotline.