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COLOR DOCUMENTS IN THE INTERNET ERA

Introduction

Since the days of illuminated manuscripts of the Middle Ages, the human eye has been drawn to the use of color in written texts. Today, the combination of computing, printing and communications technologies has enabled us all to become color document publishers. The progress and pitfalls of color printing, as well as the unique challenges presented by the advent of the Internet, provided the focus for the 2001 Industrial Physics Forum, held at the Hyatt Regency Hotel in Rochester, New York, October 21-23, 2001. Xerox, the host of this year's conference, inaugurated the era of personal publishing with the introduction in 1959 of the legendary 914 copier. Today, its laboratories have helped create the computer, communication and xerographic technologies on which the Internet era of color publishing is being built.

About Xerox Research & Technology

Xerox is a global corporation with operations worldwide and annual revenues of approximately $19 billion. The mission of its Research and Technology (XR&T) organization is to drive invention, innovation and integration throughout the corporation. XR&T works hand in hand with Xerox's business divisions, and is focused on five key areas: digital imaging, marking systems, materials and document services and solutions. XR&T also develops research, technology and business concepts that pave the way for new market opportunities. In fact, the commercial success of Xerox is largely based on the incorporation of new technology invented or acquired by XR&T into its product lines.

Paul Allaire, chairman of the board for Xerox Corporation, said that the company's success is the result of intense, non-stop innovation, starting with the 914 copier based on the invention of the xerographic process in 1938 by physicist Chester Carlson. Xerox's continued development of xerographic technology, ultimately lead to a nearly $200 billion industry worldwide. In 1998 the U.S. Government Committee for Economic Development cited Xerox as one of the great success stories of basic and applied research in American industry. Much of this research has been on topics in disciplines of direct interest to physicists, including applied physics, chemistry and surface science.

Since its inception in 1974, Xerox has contributed a steady stream of technological innovations to Xerox products based on physics and chemistry. These include the organic belt photoreceptor on which the company's black and white lens-light and digital copier and printer products have been built since the early 1980s. Today, Xerox is the world leader in monochrome image quality and image quality stability. More recently, XR&T has developed multiple new color xerographic technologies that form the basis of both current and future color xerographic copiers, printers and presses, as well as a new generation of chemical toner materials. Xerox now has 70% of the production color market, with $3 billion in sales in 2000, according to Allaire, and its new digital production press, the IGEN3, is expected to revolutionize the print industry.

Theme Session: The Physics of Color and its Presentation Across Networks

In his keynote address, Herve Gallaire, chief technology officer and president of Xerox Innovation Group, traced the evolution of color printing back to 2000 BC when alphabets and the first document media made their appearance. With the advent of the Gutenberg printing press in 1440, publishing moved from a private to a public sphere, and the invention of the first office copier in 1959 made the process even more personal. The 1970s saw the emergence of custom publishing with electronic documents and distribution, followed by the advent of the World Wide Web, which has made document publishing all the more dynamic. Gallaire sees this evolution as being indicative of "the democratization of publishing," and Xerox is committed to furthering this process in the digital age.

Color is an important aspect of future document publishing, whether it be in electronic or paper format. However, our eyes are 1000 times more sensitive to black and white print, with its sharper edges, than to color, which poses unique challenges for the color document industry. In order to succeed in today's competitive consumer market, "Color printing must be easy, affordable, reliable, and consistent," said Gallaire, and much of the recent R&D work at Xerox has focused on achieving those aims.

For example, the development of automatic image enhancement has made the production of quality color documents easier. Xerox has also made great strides in chemical toner technology, achieving particle sizes of less than 5 microns, thanks to a new production method called emulsion aggregation. Toner is "grown" chemically rather than manufactured by the traditional mechanical breakage process, improving image quality and resulting in a lower cost per printed page. The process enables the growth of toner particles from monomers, to polymers, to composite toner particles, and also allows for the manufacture of small toner particles with narrow particle size distributions and better control of the particle shape. Improvements in electronic color registration is another means of increasing affordability, most notably the use of computation to cancel common mechanical errors that cause color separation stations to be inaccurately aligned and unstable.

To improve reliability, Xerox developed integrated light sources enabling laser array scanning, as opposed to traditional mechanical scanning. The ideal goal is to achieve 14,000 lasers per pixel, although to date researchers have only managed to achieve an array of 200 lasers per pixel. A MEMS-based technology that has found a niche in an innovative air paper mover, comprised of a series of air jet valve arrays, that replaces mechanical precision with sensing, computation and actuation. Xerox researchers have also made substantial improvements in consistency and accuracy of color characterization and matching to combat so-called "printer drift"; the concept is that the color should be the same from print to print, month to month, and from printer to printer," said Gallaire.

The Internet is creating even more new needs for color document printing because of the wide range of file formats available [such as MP3, PDF, JPG, and GIF files], and the different kinds of viewing tools, such as color LEDs on cellular telephones. “The technology must adapt to address those challenges as it becomes ever more dynamic in content (with Hypertext and Applets) and format (static media, multimedia, and hyper media),” Gallaire concluded.

> ***Over the last decade, a steady evolution of digital color devices has led to an increasing capability to capture, display, and print high-quality color at decreasing costs. Once available only on sophisticated desktop computers, color quality is now common on portable laptop computers and is quickly becoming available on wireless handheld devices.***

But what is color, exactly? According to Mark Fairchild of the Munsell Color Science Laboratory, color is that characteristic of a visible object or light source by which an observer may distinguish differences between two structure-free fields of the same size and shape, such as may be caused by differences in the spectral composition of the light concerned in the observation. But the color we see is ultimately determined in the brain by a complex interaction between the light from an object and other objects around it, and by the conditions under which it is viewed. “Color is a perception,” he said. “Without an observer, there is no color. And color is an inherently subjective experience.”

Fairchild described the basic mechanism by which we see color. The retina of our eye contains photoreceptors that are sensitive to light. When light is absorbed by the photoreceptors, that energy is converted into electrical and chemical signals that the neurons in our eye and brain process. There are two kinds of photoreceptors in the retina: rods and cones. Rods mediate vision at lower levels of illumination. Cones mediate vision at higher levels of illumination, and there are three types, each sensitive to a different region of the visible spectrum: short-wavelength, middle-wavelength and long-wavelength. Our color vision derives from comparisons between the amount of light being absorbed by each cone type. These comparisons occur at different stages of processing that start in the retina and continue to the cerebral cortex of the brain.

Chromatic adaptation is the ability of the human visual system to adjust itself in response to varying illuminant conditions. In other words, we adapt to the color of the light source in order to better preserve the color of objects. For example, Fairchild demonstrated that if viewed under incandescent light, white paper has a decidedly yellow cast. However, we have the ability to automatically account for the yellowish light, and we therefore see the paper as white. “If you think about it, this makes a lot of sense,” said Fairchild. “It would be a very confusing world if objects were changing color every time the light source changed. From an evolutionary point of view, we still need to know if the fruit is ripe whether it is morning, noon, or evening. Chromatic adaptation makes this possible.”

This unique aspect to the perception of color poses significant problems for digital color management, according to Peter Crean, a senior research fellow at Xerox, since diversity in the color characteristics of devices can cause a poor match between the colors on a CRT display, for example, and those produced by a printer. In fact, poor color reproduction is the leading customer complaint, even more so than printer costs and system complexity. The range of colors that a device can reproduce, known as its color gamut, is considerably different from that of a printer. For instance, there are close to a million discriminable colors on a computer monitor, reproducing a fraction of the colors we see out in the real world. Faithfully translating a color picture from a computer to a printer, for example, requires mapping, or translating, one gamut to another in such a way that one preserves important color characteristics of the original image. Thus, providing consistent color output among different devices, and maintaining that consistency over time, presents a significant challenge for the industry, further complicated by the myriad of links available via the Internet.

Device technology is constantly evolving to improve color gamut, resolution, stability and the uniformity of devices. In addition, digital-imaging software can be used to characterize devices and to automatically compensate for differences among them. This process relates device-dependent signals — such as the amounts of cyan, magenta and yellow inks on an output device — to device-independent measures of color, such as spectral reflectivity. However, “The problem is not one of measurement and calibration; it is much more complex,” Crean cautioned. “We have more and more ways to project color, create color, because of the constant invention of new devices.”

While color measurement and characterization can address some of the inherent physical difficulties, the psychological and cognitive side of color perception must still be considered, especially given the diversity of devices and viewing conditions afforded by the Internet. For example, memory has been shown to strongly influence color perception by increasing the chroma and contrast of a scene. Xerox, Kodak and other companies are working to exploit this effect to automatically enhance the appearance of color prints. Xerox researchers are also collaborating with the Rochester Institute of Technology to explore models for individual color preference, which is often strongly affected by cultural background.

Throughout the history of xerography, physicists have played an important role in its development, dating back to Carlson’s invention of the process, which today is worth $20 billion to Xerox, and extending to today’s cutting-edge research on key xerographic materials, according to Dan Hays, another senior research fellow at Xerox. Carlson introduced the first automatic copier in 1944, paving the way for Xerox’s 914 copier in 1959, which made seven copies per minute and came equipped with a built-in “scorch eliminator,” more commonly known as a fire extinguisher. In Hays’ opinion, the future of xerography remains bright. “We are not entering a paperless society, despite the explosion of digital and electronic documents,” said Hays.

The late 1980s witnessed the introduction of the color xerography process, but it was slow, producing only three prints per minute. Today, the Xerox DocuColor 2060 boasts a rate of 60 prints per minute, maintaining excellent print quality over a wide range of print media at operating costs that are 40% lower than previous offerings. And the new DocuColor IGEN3 “is nothing less than a digital production press,” said Hays. “The new generation of color xerography enables both high-speed printing with variable information, print-on-demand, and distribute and print options.”

The process of digital capture can be broken down into two steps: first, the device must acquire the single; then it isolates and confines the data, separating and storing signals into pixels, and hopefully reducing such image sensor noise sources as optical and diffusion cross-talk. However, when it comes to digital capture, it is important to remember one vital fact: “All pixels are not created equal,” said Michael Guidash, a research scientist at Eastman Kodak Company, because of the wide range of applications and devices currently on the market. For example, there is a difference between standard silicon image sensor devices — found in low cost, low power consumer digital capture systems — and Charge Coupled Device (CCD) sensors, which target the high-end performance market, such as professional still cameras, satellite imaging, and multimedia cameras. Silicon image sensors, also known as active pixel sensors, serve as the “eyes” of digital capture systems, maximizing the percentage of pixel area that is photosensitive, as well as the efficiency of conversion. Higher-end systems have a larger detector area with larger pixels, and hence a higher image responsivity. They also have better dynamic range, which is the primary factor in determining image quality.

According to Ken Parulski, also a research scientist at Eastman Kodak, the company helped pioneer the age of digital photography with its development of a single chip color sensor with color filter array, which led to the development of the company’s DX3600 Zoom Digital Camera. The active matrix color LED is a key feature of today’s digital cameras because it gives instant feedback and enables instant “sharing” by the user. Future challenges include lowering power requirements: the LED requires a backlight, which is a drain on batteries, and doesn’t perform as well in outdoor settings. Parulski believes that wireless connectivity will be a key feature of the digital capture scenarios of the future. In fact, “Digital capture will be ubiquitous,” he said. “Image sensors will be as common as microprocessors are today.”

> ***Successful color imaging has always required an intimate collaboration among the physical and psychological sciences, Today, this collaboration must be carried out in the context of the information technology revolution. The advent of the Internet has helped create new and novel links among color devices. It has also promoted a separation among the steps of capture, creation, display, and final production of color.***

Policy Session: Physics-Driven Regional Development

Kevin Parker, dean of the University of Rochester, described the mission and status of the Center for Electronic Imaging Systems (CEIS), a New York state cooperative research center for universities and local industry. Its vision is twofold: to significantly enhance economic development of the New York State region through technology transfer; and to educate future electronic imaging leaders. To accomplish this, CEIS integrates the world-class electronic imaging research competencies at the University of Rochester, the Rochester Institute of Technology, and Cornell University with the product development and commercialization capabilities of its industrial members, which include Eastman Kodak, Xerox and 3M.

CEIS has already had an economic impact on the region, thanks to its contribution to the development of a new vision correction product introduced by Bausch and Lomb that has garnered $49 million in sales. And while the manufacturing facility for Xerox's TIJ printer has since closed, it had an estimated $4 million economic impact before shutting its doors, according to Parker. The center undertook several projects expected to have similar large impact in 2001, including Kodak's new automated feature extraction from aerial images and Xerox's intent based document abstraction. CEIS currently has a share of the royalties stake in intellectual property produced as a result of such cooperative R&D, although Parker reported that these rules are "currently in flux."

In 2001, CEIS was named one of New York's five original enhanced centers and was granted additional support to create the Microelectronics Design Center (MDC), a virtual center creating a critical mass in the field of microelectronics design research that links New York State industries with state-of-the-art science at New York universities. Eight of the state's finest research institutions have joined forces to form the Center; Alfred, Columbia, Cornell, Rennselaer Polytechnic Institute, Rochester Institute of Technology, SUNY Buffalo, Syracuse, and the University of Rochester. Member companies support and work with specific scientists skilled in the area of expertise that best meets their needs. The goal is to transfer new technologies for the production of successful products.

"The new Center will not only develop and transfer technology to our NYS industries that are based on electronic imaging systems, but also to other industry clusters such as computer, industrial control, and telecommunications," said Parker. "And it will enhance the state's ability to attract, train, and retain microelectronics designers to support these clusters. Thus, small and medium New York-based companies will be able to participate in the microelectronics industry that is revolutionizing newly developed products within other regions throughout the country and world."

> ***The Center for Electronic Imaging Systems (CEIS) provides a meeting ground where beneficial alliances can be formed and where jointly funded research and technology projects can be pursued by teams of academic and industrial researchers. The new Microelectronic Design Center focuses on research and technology transfer in microelectronics design that will enable and encourage the development of new and improved integrated circuits.***

The University of Central Florida has adopted a slightly different approach to a similar concept with its Center for Research and Education in Optics and Lasers (CREOL), according to M.J. Soileau, the institution's vice president for research. Tightly integrated with the university's School of Optics, CREOL is the research arm of the graduate school for optical science and engineering education and research. Its mission is to provide the highest quality education in optical science and engineering; enhance optics education at all levels; conduct scholarly, fundamental and applied research; and aid in the development of Florida's and the nation's technology based industries. Since its founding, CREOL has grown into an internationally recognized institute with 24 full time faculty members and 100 graduate students with research activities covering all aspects of optics, photonics, and lasers. It is housed in a state-of-the-art 82,000 sq. ft. building dedicated to optics research and education, and boasts $3.2 million in base funding from Florida state, although Soileau expects cuts to be made in 2002 as a result of the collapse of tourism in the region following the September 11 terrorist attacks.

CREOL was given a mandate at its inception to become a center of excellence in optics and lasers, in both research and education, and to act as an intellectual, scientific and technical resource to the laser and electro-optics industry. Towards this end, CREOL has formed strong bonds with industry, has become a major force in Florida's laser and optics community, and is a prime source of highly educated talent in the optics field. The participation of industrial corporations and businesses that are involved in the development or use of optics and lasers, or foresee their involvement in future applications and processes using optics and lasers, is critical to CREOL's continued progress in expanding its education and research programs, as well as aiding in the visualization of future developments and applications in optics and lasers.

The Florida High-Tech corridor has more than 150 companies that enable more than 7000 jobs, according to Soileau, and the optics industry in general has a projected growth rate of 25% per year in annual revenues. Companies that establish a close association with CREOL gain exposure to the latest developments in cutting edge technologies, access to sophisticated measurement and calibration facilities, early access to university graduates (the next generation of experts in lasers and optics) and useful research interactions with CREOL faculty. There also are many intangible benefits, most notably access to and associations and collaborations with other specialized facilities within the university, including the new Materials Characterization Facility and the Central Florida Innovation Corporation (CFIC), a new regional high technology business incubator facility. Partnership and sponsorship of research activities within the institute have many benefits to industrial corporations interested in optics and lasers, through the creation of new technology and fresh intellectual property, the solution of complex problems and the characterization of new industry-developed devices.

Donald Keck, vice president and executive director for research at Corning, Inc., described the establishment of a new cooperative high-tech optics research center, known as the Infotonics Center, planned for the Rochester area. The Infotonics Center grew from the efforts of a consortium of researchers working at various companies and universities throughout New York State. The objective is to bring these high tech researchers together in a single facility where they can partner with large and small companies from around the state to conduct research and development, prototyping and low volume manufacturing. Researchers from Corning, Eastman Kodak Company, Xerox Corp., Monroe Community College, Rochester Institute of Technology, and the University of Rochester will collaborate at the Center on ways to advance optics, photonics, optoelectronics, and microsystems. Over its first 10 years of operation, the center is projected to create 5,000 new jobs and many spinoff companies.

The center's purpose is to attract, retain and develop talent; to promote collaborations between universities, industry and government; to boost the regional economy; and to create a world-class photonics and microsystems prototype production facility. Keck cited photonics and MEMS as the key enabling technologies for microsystems, which is expected to drive growth in the region. The market for microsystems components should reach $38.5 billion in 2002, and information and communications is the fastest growing sector.

According to Keck, the New York state region from Albany to Buffalo is a booming economic zone, a technological and manufacturing hub particularly rich with knowledge and innovation in photonics, among other areas. The Infotonics Center espouses a unique approach to technology transfer, taking promising innovations “from concept to pilot production” by focusing on three phases of the development process: research, manufacturing infrastructure, and commercial development. “Other communities across the world are vying to supplant Rochester's unrivaled expertise in the lucrative imaging sector,” said Keck. “This new center will not only preserve our reputation as an industry leader and guard against high tech research from leaving our area, but it will position Rochester on the cutting edge of this fast-growing sector.”

The impact of photonics research in particular on industrial innovation and regional development is already clearly evident, according to Herwig Kogelnik, vice president of adjunct photonic systems research at Lucent Technologies/Bell Laboratories. There has been impressive progress in lightwave transmission capacity, most recently with the demonstration of 10 terabits per second, but data transmission rates over a single fiber are increasing by 100 times every decade. “Higher capacity requires greater bandwidth, and this staggering rate of progress must be supported by lots of innovation,” said Kogelnik.

As an example, he cited the development of Fiber Raman amplifiers, essentially lasers in which light couples to a glass lattice and is scattered, allowing gains at any wavelength, providing broader bandwidth, and improving optical signal-to-noise ratios. Another promising area of research critically dependent on advanced photonic components is the development of MEMS switches and cross-connects for optical networking, such as single crystal MEMS mirrors capable of tilting along two axis. A breakthrough technology that is already in use in the optics communications industry is tunable fiber Bragg gratings. Researchers continue to push the envelope to achieve higher bit transmission rates, with the ultimate goal being 40 gigabytes. Invented by Bell Labs researchers a mere 10 years ago, quantum cascade lasers are already used in sensing applications, and because they use narrower quantum wells than the semiconductor lasers currently used in optical communications, QCLs are considered an ideal replacement technology for the future.

Another potentially revolutionary area is photonic crystals, usually comprised of dielectric materials with holes arranged in a lattice-like structure that repeats itself identically and at regular intervals. If the assembly is built precisely enough, the resulting crystal will have what is known as a “photonic bandgap”: a range of forbidden frequencies within which a specific wavelength is blocked. Energy levels are created in the band gap by introducing defects, enabling researchers to custom-design the materials to allow highly precise control of the frequencies and directions of propagating electromagnetic waves. Photonic crystals are poised to reap their first commercial benefits with the emergence of a handful of start-up companies geared toward bringing the technology to market, initially as wave guides and high-resolution spectral filters in fiber optic telecommunications. Continued R&D is underway to give birth to the next generation of applications, such as photonic crystal lasers, light-emitting diodes (LEDs), and photonic crystal thin films serving as anti-counterfeit devices on credits. Ultimately researchers hope to build diodes and transistors from this novel material, in hopes of one day constructing an all-optical computer.

Progressions in photonics, optics, and lasers will play an increasingly important role in many segments of our society, our technological future and the economic strength of our nation.

Laboratory Tours

This year, conference participants were treated to two afternoon laboratory tours. On Monday, attendees were bused to Xerox's Joseph Wilson Center for Xerography for demonstrations of the company's latest development efforts, many of which had been described during the morning session. Topics included color xerography and various aspects of "smart" xerography, such as controls and sensors, color image processing and quality, and simulation based design. On Tuesday afternoon, participants visited the Center of Electronic Imaging Systems, the subject of one invited talk during the morning session. The demonstrations included astroflow visualization software, a new asphere manufacturing technology, work on laser confinement nuclear fusion, and the development of new clock technology for quantum computing applications.

Monday's tour concluded with the annual banquet in the evening, held this year at the George Eastman House, which featured the presentation of the AIP Award for Science Writing by a Scientist to Neil de Grasse Tyson, Charles Liu, and Robert Irion for their book, *One Universe: At Home in the Cosmos*. Also presented at the banquet was the 2001 AIP Prize for Industrial Applications of Physics, awarded to Charles H. Henry of Lucent Technologies/Bell Laboratories, "for fundamental contributions to the understanding of the optical properties of quantum wells and semiconductor lasers."

Frontiers of Physics

Ching Tang, a senior research associate at Eastman Kodak Company, reported on the status of ongoing research with organic light-emitting diodes (OLEDs), also known as semiconducting polymers (and, more colloquially, as plastics). OLEDs operate on the principle of converting electrical energy into light, a phenomenon known as electroluminescence. They exploit the properties of certain organic materials that emit light when an electric current passes through them. In its simplest form, an OLED consists of a layer of this luminescent material sandwiched between two electrodes. When an electric current is passed between the electrodes and through the organic layer, light is emitted with a color that depends on the particular material used. In addition to the luminescent material itself, other organic layers may be added to enhance injection and transport of electrons and/or holes.

Several companies are commercializing OLED-based products in areas less technically demanding than full-color computer displays, such as the use of unpatterned OLEDs as a large area light source. Simple monochrome alphanumeric displays are in pilot production, such as the latest crop of cellular phones manufactured by Motorola and Samsung. Pioneer has announced an automobile radio and navigation aid that uses a passive matrix screen to display traffic conditions on Japanese highways. Kodak/Sanyo introduced a full-color OLED display in 2000, and Sony now has a 13" SVGA display. eMagin introduced an OLED silicon microdisplay in 2001 for use as Heads-Up Displays for pilots. Idemitisu Kosan offers a passive matrix OLED display, while

Toshiba and Seiko Epson are marketing active matrix OLED displays, the latter supplemented with color pixelation technology provided by Inkjet.

The potential payoff of this research is huge. Tang reported that economic analysts predict that the display module market will reach $55 billion worldwide in 2002, and while CRTs continue to be a major player, flat panel displays have been making inroads into the desktop market. However, there are still challenges to be overcome if OLEDs are to achieve their commercial potential, most notably various materials issues, such as improved luminance efficiency and lifetimes; improved carrier transport mobility; and new advances in thin-film morphology. New manufacturing processes are also needed that will be lower cost than those used to produce LCDs. “Ultimately, we are in the OLED business to make some money,” Tang admitted.

In conventional electronics, only the charge of the electrons matters. But scientists have found that exploiting an electron’s other fundamental property -- its spin -- is opening up a brand new field, dubbed “spintronics” (for spin transport electronics). And that field is rapidly evolving toward the development of practical devices, according to Stuart Parkin, an IBM Fellow and project leader at IBM Almaden who has earned numerous honors and a catchy moniker (“The Spin Doctor”) for his pioneering achievements in this area. “Spintronics promises the possibilities of integrating memory and logic into a single device, allowing faster switching times and greatly increasing the efficiency of optical devices such as LEDs and lasers,” he said. “The control of spin is also central to efforts to create entirely new ways of computing, such as quantum computing, or analog computing, which uses the phase of signals for computations.”

Parkin’s talk focused particularly on magnetic tunnel junction (TMR) random access memory (RAM), a new storage technology that he believes will eventually replace the giant magnetoresistive (GMR) sensors and read heads used today. While similar to a GMR cell, TMR devices are nonvolatile memories that do not require power to store information. Parkin’s group has demonstrated the first MTJ-MRAM, achieving very fast reading/writing times when compared with other memory technologies, and IBM has formed a joint development alliance with Infineon to build the first commercial prototype. Honeywell and Motorola are also developing advanced protypes of this new memory devices, starting with a one-megabit chip being developed by Honeywell. Parkin believes the technology could eventually find use in everything from cell phones, PDAs, digital cameras, games, mainframe servers, routers, and notebook computers.

> ***The Frontiers of Physics session illustrated the broad range of questions physicists ask of nature in order to learn the large and small details of how the universe functions, satisfying the human need to know our place in the universe. This year’s topics in particular are expected to lead to innovations that contribute to the continued success of many companies in an increasingly borderless world economy.***

The 2002 Industrial Physics Forum will be hosted by the Thomas Jefferson National Accelerator Facility, in Williamsburg, VA, October 27-29, 2002, focusing on advanced materials processing, with a policy session on science in a security-conscious world. For more information visit:

www.aip.org/ipf

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