

Scanning the Issue

Special Issue on Blue Sky Electronic Technologies

The past half century has witnessed advances in electronics and photonics technology progressing at ever increasing rates. Much of the advancement has resulted from the semiconductor revolution, which has produced fabrication technology capable of producing mechanical and electronic structures with precisely defined impurity densities and nanoscale dimensions. This ability stems from parallel advances in materials growth technology, patterning techniques, imaging and manipulation capability, and advances in characterization and testing. When taken together, these techniques form the basis for designing and fabricating electronic devices and structures with atomic level control. Nanotechnology permits the realization of new devices and structures with performance far exceeding that available from current systems and will keep electronic systems on Moore's Law [1]. Materials research on the nanoscale offers the potential to produce materials that do not exist in nature. These materials can be synthesized with idealized and optimum properties. Parallel effort in nanoelectronics and nanophotonics presents the opportunity to fabricate devices and circuits with orders of magnitude increase in performance compared to present devices. As circuit size is reduced, system speed increases, and it is possible for electronic circuits to operate well into the high millimeter-wave frequencies and potentially into the terahertz regime. Very interesting applications in sensing of biological and chemical agents may be possible in the terahertz spectrum. The integration of biology with electronics and photonics is emerging as a potentially high payoff technology area. This work involves both the use of molecular concepts for circuit implementation and the investigation of chemical and biological agent properties by electronic and optical methods. This may lead to entirely new systems for a wide variety of sensing, detection, imaging, and communications applications. However, before next-generation systems are realized for practical application, many fundamental challenges remain. Recent breakthroughs provide evidence of potential success.

Next-generation electronic and photonic systems will be significantly impacted by nanotechnology, and rapid developments in nanotechnology are generating progress

in a diversity of technology areas and applications. It has been predicted that nanotechnology advances will provide the basis for the next worldwide economic boom. Research funding for nanotechnology has grown dramatically worldwide during the past decade [2]. This special issue of the PROCEEDINGS is devoted to blue sky technologies. The project is an attempt to look into the crystal ball and get an assessment of where electronics and photonics technology have brought us and where we are heading, as well as to help define major challenges. The special issue includes 14 invited papers, selected to give an overview and assessment of electronics and electrooptical technology in a variety of areas. While we are not attempting to cover all technical areas, which is beyond the scope of any single issue, the selected areas give a view into some of the more interesting areas for future investigation. An attempt to examine existing areas enabled by advances in nanotechnology, as well as new directions, has been made.

The issue begins by directly addressing the color blue. Production of blue light emission has always been a challenge for semiconductor-based devices due to energy bandgap limitations, and the lack of a suitable blue light emitter has prevented the development of full color displays based upon red-green-blue (RGB) techniques. However, recent developments in the growth of nitride-based semiconductors now permit efficient, high quality blue light sources (LEDs and lasers) to be produced. Semiconductor growth based upon molecular beam epitaxy (MBE) and organometallic chemical vapor deposition (OM-CVD) technology permit high quality AlGaIn/GaN quantum wells to be fabricated. These quantum wells can be doped with indium to produce light emission ranging from yellow to deep blue. Both LEDs and lasers are produced. The blue LED permits the development of efficient solid state lighting that can compete with incandescent and fluorescent tubes. The incandescent light bulb is basically unchanged since the days of Edison. However, solid-state light bulbs are now a possibility. Shur and Zukauskas examine this subject in the first paper, "Solid-State Lighting: Toward Superior Illumination," and provide an overview of the history of lighting, and show where solid state lighting is going and present further prospects.

A key technology issue is addressed in the second paper by Brueck in his paper "Optical and Interferometric Lithography—Nanotechnology Enablers." The success of the

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electronics industry in producing chips with exponentially increasing device counts and capacity has been fundamentally dependent upon the ability to scale devices and circuits to ever decreasing dimensions. This ability stems from remarkable advances in short wavelength lithography technology, and state-of-the-art production steppers now use 193-nm excimer laser sources and can produce linewidths down to ~ 34 nm. Brueck examines the subject of nonlinear spatial frequency multiplication techniques to produce further reductions in linewidth. He demonstrates that interferometric lithography provides an inexpensive, large-area lithography technology. Such a capability will be required to keep circuit scaling on Moore's Law, which is expected to remain valid for at least one or two more scaling generations.

In the third paper, "Terahertz Frequency Sensing & Imaging: A Time of Reckoning Future Applications?" by Woolard *et al.*, potential applications of terahertz technology are addressed. Much recent interest has developed in the use of terahertz waves, particularly for biological and chemical sensing. The development of terahertz technology will impact applications areas in defense, security, biology, and medicine. Some of the most promising uses of terahertz technology are examined. However, before successful systems can be developed, a viable device and component technology must be developed. Active terahertz sources, in particular, are a challenge. Generation of signals in the 1–3-THz region can currently be accomplished by indirect generation using up-converted radiation from electronic sources or down-converted radiation from optical sources. No techniques for direct generation of signals above about 1 THz are currently available.

Left-handed metamaterials offer very interesting benefits for a variety of microwave and millimeter-wave circuit applications. These materials result from artificial dielectric structures, which can be designed to have anti-parallel phase and group velocities, or equivalently, negative permittivity and permeability constitutive parameters ϵ and μ . Although the theoretical prediction of these negative refractive index materials dates back to 1967, practical realization has only recently been reported. Such materials will find use in a wide variety of applications. The subject is addressed in the paper by Caloz and Itoh, "Metamaterials for High-Frequency Electronics."

The potential development of molecular devices and circuits has been predicted and interesting preliminary results reported. However, before practical molecular circuits can be implemented, techniques for coding and managing signal transfer in highly dense circuit environments need to be developed. Molecular circuits would have device packing densities and speeds orders of magnitude greater than current semiconductor circuits. Heat dissipation will be a major challenge. Seminario *et al.* address this issue in their paper, "Scenarios for Molecular-Level Signal Processing," and propose two new paradigms to process and transmit information in molecular circuits that can defeat the heat dissipation problem.

The scaling of device and circuit dimensions to the nanometer and subnanometer scale approaches or engages

the quantum limit. While the onset of quantum effects is generally a fundamental limit to device scaling, it offers the potential of using quantum effects to produce novel devices, circuits, and systems. Quantum computers are a distinct possibility and, if successfully developed, would provide the capability to examine problems currently beyond available computing capability. Kastner examines this subject in his paper, "Prospects for Quantum Dot Implementation of Adiabatic Quantum Computers for Intractable Problems," and examines schemes for implementing quantum computers to address problems that cannot be solved on classical computers. Such capability would find wide use for problems such as weather prediction, molecular modeling, and other large-scale problems.

In their paper, "Integrated Biological-Semiconductor Devices," Stroschio and Dutta examine the potential of nanotechnology to integrate electronic and optical devices with biological systems. Direct electrical interfacing at the biomolecular level opens the possibility of monitoring and controlling critical biological functions and processes in unprecedented ways and potentially enables a variety of areas such as prosthetic devices, medical monitoring devices, medical delivery systems, and patient monitoring systems. Such applications require the integration of man-made nanostructures with biological structures. The potential of this promising technology and future directions based on these concepts are addressed.

Noise presents a fundamental limitation to the operation of any electronic or photonic device. Nanotechnology raises new issues of electronic noise since the noise fluctuation phenomena become increasingly important as device dimensions are scaled. Phase ($1/f$) noise is particularly important for many systems applications. Handel *et al.* address the subject of phase noise in nanosystems in their paper, "Nanoscale Engineering for Reducing Phase Noise in Electronic Devices." They investigate phase noise in the quantum limit and examine the coherent and conventional quantum cases. They apply their theory to practical devices such as GaN/AlGaN modulation doped FETs (MODFETs), resonant tunneling diodes (RTDs), bulk acoustic wave (BAW) and surface acoustic wave (SAW) quartz resonators, microelectromechanical systems (MEMS) resonators, and spin valves.

The suggestion and demonstration of utilizing self-assembled molecules as the active region of electronic devices has recently emerged as a potential technology for fabrication of novel devices. However, basic electronic transport in these materials is not well understood. Wang *et al.* examine electronic transport mechanisms in their paper, "Electronic Transport in Molecular Self-Assembled Monolayer Devices." They make use of an existing and well characterized self-assembled molecular system (alkamethiol) to investigate fundamental transport mechanisms. A variety of analytical characterization tools are employed to investigate the surface and bulk properties of the self-assembled monolayers. Implications for advanced molecular devices are presented.

As semiconductor scaling continues fundamental limits to continued miniaturization will eventually be reached. Elec-

tronic devices may approach this limit in the near future. Photonic devices, however, have unique properties that may profit from further miniaturization. Bhattacharya *et al.*, address the issue of control and manipulation of light on planar integrated circuits in their paper, "Quantum Dot Photonic Crystal Light Sources." They report very high speed integrated optical devices at the 10–100- μm -length scales, but discuss a need to further reduce the size of the devices to make them competitive in size and cost to existing electronic devices so that the photonic and electronic devices can be integrated onto single chips. A wide range of applications ranging from communications to displays and sensors are predicted to be impacted by the new integrated electronic/optical circuits.

A very interesting area for next-generation systems lies in advanced computing. An attractive application involves the use of grid computing for advanced simulation of nanoelectronics structures and devices. Fortes *et al.*, in their paper, "Virtual Computing Infrastructures for Nanoelectronics Simulation," describe the operational principles, components, and organization of a grid-computing infrastructure termed In-VIGO, which enables computational engineering and science in a virtual grid-computing environment. They review the requirements of a cyberinfrastructure for computational nanoelectronics and describe the In-VIGO system, which enables the use of computational electronics tools over the Web. Such advanced simulation capability can be made available to a diverse scientific and engineering user community and will be instrumental to exploitation of nanotechnology advances for practical design application.

The dependence upon advanced simulation capability and the growing importance of Web-based tools and communications introduces risk due to potential unwanted intrusion. Internet security issues are becoming increasingly important, and advanced intrusion detection systems that can monitor computer networks for evidence of malicious actions are required. The Internet is essentially a network of networks composed of autonomous subsystems managed by companies, organizations, and governments with differing and sometimes conflicting goals. The connection between multiple networks makes it necessary to distribute intrusion detection sensors across multiple protected networks, manage their configuration as the security posture of the networks change, and process the results so that a high-level view of the security state of the network can be provided to the system administrators. In their paper, "Hi-DRA: Intrusion Detection for Internet Security," Kemmerer and Vigna present a network surveillance, analysis, and response system for high-speed WANs. The system provides a framework for the modular development of intrusion detection sensors in heterogeneous, high-speed environments. Support for the dynamic configuration of the sensors and the collection and interpretation of results is provided.

Moore's Law has provided the guidance for the semiconductor scaling revolution over the past 40 years. Although Moore's Law was merely an observation, coupled with a projection to the future, it has proved amazingly robust. In many ways, Moore's Law is a self-fulfilling prophecy, since the semiconductor industry has addressed Moore's Law through the International Roadmap for Semiconductors prepared and periodically updated by the Semiconductor Research Corporation (SRC). Technical areas are mapped and problems identified for concentrated research and development. This process has kept the industry on Moore's Law for four decades. The original observation that led to Moore's Law statement was based as much on economics as physics. Gea-Banacloche and Kish address the physics underlying Moore's Law and resulting limits in their paper "Future Directions in Electronic Computing and Information Processing." They show that the synergic effects of increasing thermal noise, heat dissipation, and bandwidth during miniaturization will manifest themselves in either a high bit-error rate or chip overheating. Ramifications for further improvements in electronic computing and the resulting application to advanced, future information processing are discussed.

The last paper in the special issue addresses a specific application enabled by advanced technology. Fork *et al.*, in their paper, "Surface High-Energy Laser," discuss the prospects for producing solid state lasers that can provide greater than 100 kW of output power. Such lasers would be able to provide output power that could effectively compete with gas lasers, but that could be fabricated in much smaller and more cost-effective packages.

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