Asian Journal of Physics Vol. 17, No. 2 (2008) 181-183

The future of optoelectronics technology

Pankaj K. Choudhury[1] and Akhlesh Lakhtakia[2]
[1]*Faculty of Engineering, Multimedia University, Cyberjaya 63100, Selangor, Malaysia*
[2]*Computational and Theoretical Materials Science Group, Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802, USA*

R&D opportunities in optoelectronics technology exist in the areas of performance improvement, cost reduction, high-volume manufacturing, and integration with other technologies. Developments will be crucial to the expansion of the markets for optical communication, optical data storage, optical imaging, optical computing, and optical sensing systems.

Optoelectronics is a critical foundational technology that enables all primary functions of the evolving information industry. R&D at universities as well as in industries are playing significant roles in this evolution. As a subject, optoelectronics used to encompass electronics devices for the emission, modulation and transmission of light signals. However, today its scope has widened to incorporate photonics and electro-optics too. Photonics is focused on the applications of photons to transmit information, whereas electro-optics deals with the effects of electric fields on light passing through a material, as exemplified by solid-state and gas lasers. Commercially important technologies for communications, materials science, medicine and computing are leaping forward, due to recent and ongoing developments in optoelectronics.

In addition to the optoelectronics technology being essential for transmitting, gathering, and displaying information, it has a vital role in storing and processing information. Optoelectronics technology is needed not only as a competitive alternative to existing systems, but also for intelligent next-generation systems. As such, optoelectronic components underlie a substantial worldwide market for optics. Revolutionary changes in the communications landscape — such as mobile telephones, digital transmission, and multimedia — have been made possible by the evolution of technologies related to optoelectronics. High-bandwidth optical fibers play a very important role in this regard.

Truly speaking, there is no single "optoelectronics industry". Instead, there is a spectrum of several industries with a common platform technology and a common infrastructure. These industries are exemplified by optical-communication, optical-imaging, and optical-storage industries. As the reach of the internet expands and data services boom, high-speed and broadband transmission costs must decline.

Although sustained attention towards the communication bandwidth fuelled the amazing growth rate of commercial optical-communication systems, and wavelength-division-multiplexing (WDM) systems provided a major boost toward commercialization, a drastic reduction in the cost of optoelectronic components is required for high-volume access networks to become commonplace. Indeed, WDM systems and vertical cavity surface-emitting lasers (VCSELs) facilitate the integration of electronic and photonic components, thereby promising to render optical networks more affordable.

The main applications of optoelectronic components are in long-distance communications, local-access networks, local-area networks, and wide-area networks. The prediction of the growth of market volumes of specific optoelectronic components is a somewhat difficult exercise to undertake, but tunnel lasers, optical amplifiers, optical switches, multiplexers, and optical transreceivers are the key optoelectronic components required for commercial optical networks. Mass production of optoelectronic components is necessary to reduce their costs. Improved performance is also commercially desirable. From the applications perspective,

Corresponding author
e mail : akhlesh@psu.edu (Prof Akhlesh Lakhtakia)

the overall preference for telecommunications-inspired research has previously been driven by huge investments underpinned by the expectation of quick financial returns. But, many of these technologies have failed to meet realistic economic targets for volume supply, and may be considered as primarily the products of cottage industries. It is rather difficult to manufacture components in high volumes, when there is a proliferation of products available for a particular function. For example, optical switching could be considered as a very demanding function, but there are several different ways to accomplish it. So, it would essentially take several generations of equipment for industrial performance standards to develop and to be universally adopted for a specific technology to dominate others. In the meantime, one should expect only a steady improvement in the performances of optoelectronic components with simultaneous cost reduction due to high-volume manufacturing, which will surely enlarge the optical communications market.

Apart from the high-volume production of optoelectronic components, the assembly of active and passive components in an optical module is a significant issue, because the components are generally made of a variety of materials with different optical properties. Furthermore, the various shapes and sizes of different optical components constitute another problematic aspect in component packaging. Finally, some components require electrical inputs or outputs to perform electrical-to-optical or optical-to-electrical signal conversion. Thus, proper selection of materials and component geometries underlies the cost-effective production of reliable optoelectronic devices.

Optical-data-storage technology today competes with other data-storage technologies (such as magnetic tapes and magnetic hard disks). The key advantage of optical-data-storage technology is that it offers a reliable, removable, and portable storage medium with excellent longevity. Data storage is premised on two functions: recording and reproduction. The optoelectronic approach facilitates both of these functions with a common head positioned relatively far from the storage medium (unlike magnetic- drive heads), which essentially allows the storage medium to be reliable and removable. Thus, optical storage is a key enabler of applications requiring reliability and portability, such as the archival of digital photographs and medical images. These applications — which require access times less than 10 milliseconds, along with very large storage capacities and reasonable transfer rates — could increase the market for optical disks tenfold. Despite steady improvements in performance, however, optical-storage technology remains expensive.

Over the last five years, the optical-imaging industry has also seen significant growth. Conventional imaging through photographic films and cameras has been almost completely replaced by digital imaging: high-resolution scanning and digital printing. Digital cameras are commonplace for advanced imaging applications; e.g., digital microcameras are often used for security applications. PC-based imaging is more user-friendly than earlier, and photorealistic digital printers are able to interface directly with digital cameras. Digital infrastructure and broadband internet access enable a wide range of internet-based imaging applications, products, and services.

R&D communities are also investigating cutting-edge optical and optoelectronic approaches for high-speed optical computing and next-generation communication networks. Research efforts include the development of multilayer optoelectronic substrates with high-density optical interconnects and arrays of optical and/or electro-optic components for high-speed data transmission. Advanced integration technology is required for better performance and functionality of optical data-processing systems. High-density, multilayer interconnects with low transmission loss and small delay are essential requirements. These requirements can be met using the efficient monolithic IC technology, and the optimization of integration processes will enable mass production. High-resolution characterization of stress and strain distributions in multilayer interconnects in different types of packages will assist in better designs of compact multilevel interconnects and highly reliable packaging materials. To enhance interconnection in next-generation computing systems, optical interconnects today are more promising than their electrical counterparts, primarily due to the absence of electromagnetic interference and/or crosstalk. As enormous amounts of information passing through networks and high-speed exchanges of data between servers are driving a phenomenal growth of traffic. The information-technology industry is providing a key platform to investigate the physical limits of current components, interconnects, and assembly technologies.

Another attractive and rapidly growing application of optoelectronics technology is in sensing. In developed nations, optical sensors constitute a multimillion-dollar market. Optical-sensing technology has shown its big impact in the area of smart structures with several demonstrations of embedded sensor systems. Over the last couple of decades, the field of optoelectronic sensing has received great attention, as a variety of optical sensors, incorporating a variety of optical materials, have been devised for multifarious applications.

The principal applications of optoelectronic sensing have been in the aerospace, hydrospace, and biomedical sciences; in petrochemical, oil, and gas industries; and for electricity distribution. Applications for structural-health monitoring and safety assessment have also been quite attractive. The advantages of optical sensors have been confirmed through their continued use in industrial plants. To date, highly sophisticated optical instruments for sensing have been designed for remote measurement capabilities and multiple sensing. Miniaturized optical probes have been devised for clinical and biomedical applications. The future of optoelectronic biosensing appears to lie in the integration of several kinds of sensors into a single catheter that should fit through the smallest vessels in a human body.

Although optoelectronic sensors offer significant advantages over other types of sensors, they are expensive to manufacture. Efforts are underway to improve fabrication techniques and device reliability, and to reduce costs. The development of sensor networks plays a very important economic role, as multiplexed and distributed sensing systems offer simultaneous measurement of different parameters and/or at different locations — which is the key for using optoelectronic sensors in process-control technology.

Environment assessment and control is a rapidly growing global issue that requires technoscientists to address a multitude of concerns that have spawned from relentless industrialization for over two centuries. Recent research trends suggest among the hottest applications of optoelectronic sensor systems is the one for monitoring environmental safety. Inexpensive optoelectronic chemosensors must be developed for monitoring various chemical processes taking place in the built environment. However, the lumping of various environmental sensors into a single technology is problematic because the recent trend is now to fabricate hybrid devices, i.e. a monitoring system involves a combination of various technologies. Undoubtedly, environmental safety legislation will continue to drive the need for increasingly versatile monitoring systems, and optoelectronic sensors will play vital role for decades to come.

To conclude, R&D opportunities in optoelectronics technology can be found in the areas of performance improvement, cost reduction, high-volume manufacturing, integration with other technologies related to micromechanics, software technologies, etc. The future of optoelectronics research in industrial as well as academic communities is very bright indeed, and we expect that ongoing advances in optics and photonics will revolutionize the 21st century as they began doing in the last quarter of the 20th.

[*Received* : 10.7.2007; *accepted*: 31.7.2007]