PHOTONIC AND ELECTRONIC DEVICE TECHNOLOGIES

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In the past year, AT&T has put into service the FT Series G lightwave system. Operating at 1.7 gigabits per second, it is the world's fastest telecommunications system in commercial service. The system uses the latest InP-based (indium phosphide) photonic devices and GaAs-based (gallium arsenide) electronic devices. These compound semiconductor devices have a major role in digitizing the nationwide network and bringing new services to business and residential customers. This issue of the *AT&T Technical Journal* is devoted to the technologies on which these advanced photonic and electronic devices are based.

Compound Semiconductor Properties

Compound semiconductors have many material properties that distinguish them from silicon—the most commonly used semiconductor. The direct bandgap of several compound semiconductors leads to one important property: the ability to emit or absorb a photon efficiently as a result of electron/hole recombination or formation. These photon/carrier transitions permit the fabrication of photonic devices not possible with other materials. The ability to form lattice/matched heterojunctions in which the bandgap can be tailored to enhance photon or carrier characteristics has been exploited to yield photonic devices with new or enhanced functions.

The earliest applications of photonic devices included visible light-emitting diodes (LEDs), used as indicator lamps and later as displays—most commonly seen in consumer products such as calculators. However, when semiconductor lasers and LEDs whose emission could be matched to low-loss optical fibers were introduced in the early 1970s, the resulting photonic devices had a tremendous effect on telecommunications and point-to-point interconnection through fiber optics.

With longer repeater spacing, higher capacity, and improved digital quality, optical fiber began to dominate the long-haul telecommunications network, driving other technologies, such as satellite transmission and microwave radio, into more narrowly defined markets.

Intercontinental communication via undersea lightwave transmission is now a reality with the successful deployment of the transatlantic TAT-8 cable. Fiber optics is also making significant inroads in the subscriber loop, delivering services to the end user. In this issue of the *AT&T Technical Journal*, Dutta discusses some of the more recent advances that have contributed to this revolution as well as a new class of quantum-well photodetectors and self-electro-optic-effect devices for photonic switching.[1]

For electronic applications, the higher carrier mobility and lower junction capacitance of compound semiconductor devices are particularly important because they lead to circuits that are as much as five times faster than silicon. As a result, GaAs integrated circuits have made a significant contribution in high-performance electronics, such as in central processors for very fast supercomputers and in high-capacity lightwave and mobile communications systems.

Recent results have shown that InP has even greater potential than GaAs for high-performance devices with a lower surface recombination velocity. InP is better suited to the intrinsically higher performance bipolar technology. Shah and Pei show how InP, with its higher electronic mobility, has been used in InP heterojunction bipolar devices with unity gain frequencies exceeding 100 gigahertz.[2]

Fabrication and Packaging

While compound semiconductor devices offer considerable advantages over silicon, their fabrication poses serious technological challenges. Compound-semiconductor single-crystal growth and the epitaxy of heterostructures are more complex processes than silicon fabrication, and the wafers produced are smaller and of lower quality than silicon wafers. However, these wafers have unique properties. The paper by Clemans, Ejim, Gault, and Monberg describes single-crystal growth.[3] Papers by Panish,[4] and by Johnston, DiGiuseppe, and Wilt[5] deal with epitaxy. Panish's paper focuses on molecular-beam epitaxy, while Johnston et al. examine liquid-phase epitaxy, trichloride and hydride vapor phase epitaxy, and metal-organic chemical vapor deposition.

The lack of a stable oxide and lower thermal stability makes processing of compound semiconductors more complex and difficult. Material constraints determine how electronic and photonic devices are fabricated and what impact this has on device performance. Dautremont-Smith, McCoy, Burton, and Baca discuss these issues.[6]

Packaging high-performance photonic and electronic devices presents an additional and often unique set of challenges. For very fast electronic devices, frequency response is often dominated by the need for special materials and conductor layouts in package design. On the other hand, aligning a photonic device with single-mode fiber can mean holding the positioning to tolerances of less than a micrometer over many years. These and other packaging issues are discussed by Alles and Brady.[7]

The Future

In looking to the future, as the materials and process technologies advance, more complex devices will continue to emerge. Indeed, many monolithic photonic arrays and photonic devices integrated with electronic devices have already been demonstrated—as have photonic switches that use light to control light in the true essence of optical logic. The commercialization of these and even more forward-looking devices is some years away, and depends on a variety of market and business factors. However, the work described in this issue of the *AT&T Technical Journal* will surely provide the technological underpinning to support these products.

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