THE SEMICONDUCTOR LASER

Enabling optical communication

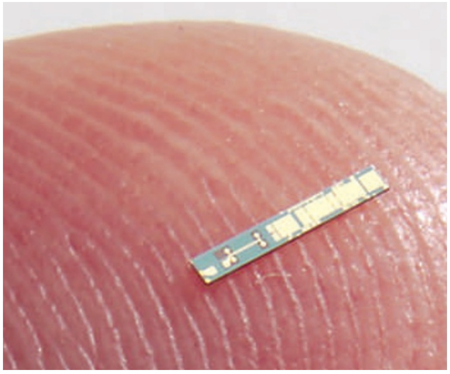
Ed Murphy

The semiconductor laser has revolutionized the way the world communicates, and it is continuously evolving with our ever-increasing demand for higher bandwidths.

At the birth of the laser in 1960, the primary modes of communication in the most technologically advanced nations were wired phone lines for voice communication, and broadcast transmission for television. Today, high-definition television, video-on-demand, broadband internet and mobile phones are available all around the globe. This exponential rise in cost-effective information transmission would not have been possible without the introduction of optical transmission systems, which in turn are enabled by semiconductor lasers. A hundred million new semiconductor lasers are deployed in communications systems every year, generating several billion dollars of annual revenue at the component level.

The first semiconductor laser was demonstrated in 1962, but it was not until the mid-1970s that the device design and materials science were advanced enough to allow for reliable room-temperature operation. These first lasers were made of gallium aluminium arsenide (GaAlAs) and operated at a wavelength of 0.8 µm. In 1976, the first optical transmission system was put into service, operating over 11 km of fibre at 45 Mbit s^{-1}. In the late 1970s, indium gallium arsenide phosphide (InGaAsP) lasers operating at longer wavelengths were demonstrated, enabling systems to transmit data at higher speeds and over longer distances. By the mid-1980s, transmission distances had increased to hundreds of kilometres and bit rates to 500 Mbit s^{-1}. Today, single fibres carrying signals at hundreds of different wavelengths can transmit terabits of information per second over transcontinental and transoceanic distances.

Semiconductor lasers have many intrinsic properties that make them ideal for fibre-optic transmission. These include high power outputs, small spot sizes and inherent coherence. Furthermore, it is possible to fabricate semiconductor materials that lase at wavelengths corresponding to the low loss and low dispersion regions of optical fibres. Semiconductor lasers for optical communications are formed on either InP (1.3 µm and 1.55 µm wavelengths) or GaAs (0.8 µm and 0.98 µm wavelengths) wafers.



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State-of-the-art indium phosphide laser chip. This combined laser and Mach–Zehnder interferometer monolithically integrates tunable laser chip technology with a 10 Gbit s^{-1} modulator.

Devices can be designed with well-controlled and narrow lasing linewidths, thus minimizing the effect of fibre dispersion and allowing multiple (~100) wavelengths to be carried in the same fibre without interference between the channels. Furthermore, they can be modulated at high rates. Today, signals are transmitted at data rates of up to 100 Gbit s^{-1}, which is equivalent to more than a million voice calls or thousands of video channels.

The development of efficient optical amplifiers in the 1990s was another major milestone for semiconductor laser technology. Such amplifiers compensate for the scattering loss experienced by optical fibres, and hence enable even longer transmission distances. Semiconductor lasers have a vital role in optical amplifiers because they act as a convenient pump providing optical power to the gain medium. In 1996, optical amplifiers with semiconductor pump lasers enabled the deployment of 5 Gbit s^{-1} transoceanic systems spanning more than 6,000 km without the need for any optical-to-electronic conversion.

There are two basic semiconductor laser configurations: edge emitters and vertical-cavity surface-emitting lasers (VCSELs). For edge emitters, epitaxial layers of various compositions of InGaAsP or GaAlAs are grown to form light-emitting p–n junctions. Photolithography and etching are used to form the laser waveguide, and emission is parallel to the plane of the wafer surface. The typical chip length of such devices is 500 µm to 2 mm, and the typical output spot size is of the order of 1 µm.

There are several types of edge emitters in common use today. Fabry–Pérot lasers, in which the end facets of the chip form the laser cavity, are used in short reach, low speed applications. Fabry–Pérot structures are also used for amplifier pump lasers. Distributed feedback lasers rely on a grating that is etched into the crystal surface along the length of the waveguide. This structure results in a narrower spectral line width, which is required for long-reach applications. Electro-absorption-modulated lasers monolithically integrate a modulator structure in series with a distributed feedback laser to separate the lasing and modulation functions, and thus enable even longer reach applications. In more advanced structures, current-tunable Bragg reflectors are integrated in series with a gain region, resulting in a laser that can be tuned over a broad range of wavelengths.

In contrast, VCSELs are designed for emission perpendicular to the surface of the wafer. These devices are cheaper to produce than edge emitters and are used as single devices or monolithic arrays in short-reach, cost-sensitive applications.

The next generation of optical transmission systems require higher speeds, lower production costs, lower power dissipation and smaller form factors, and semiconductor lasers are evolving to meet these needs. Semiconductor lasers have so far been the principal enablers of optical transmission systems, and they will continue to be a core technology as new and more capable systems are deployed. ❐

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