Abolishing copper interconnects

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A new generation of surface-emitting lasers has led to substantial improvement in data transmission speed over a wide range of operating temperatures.

The growing use of and dependence on interconnects to meet the rocketing bandwidth demands of high-performance computing systems has given rise to ‘computer interconnects’ as a distinct market segment. This exponential increase in bandwidth demand at all distances is forcing a transition from copper to optical interconnects down to the board-to-board level. General adoption of these new links is based on recent progress in the development of suitable light sources. The most appropriate, simplest high-speed optical source is the directly modulated laser. Used in optical interconnects, lasers must shine on three fronts: they must deliver high serial bandwidths, operate without cooling, and allow dense packaging. When it comes to combining all of these attributes with excellent beam quality, low cost, and economical use of energy, the vertical-cavity surface-emitting laser (VCSEL) is the technology of choice.

VCSELs for optical interconnects have attracted the attention of many institutes and companies worldwide. Our expertise in this field is in realizing high-speed, temperature-stable VCSEL devices. We emphasize these properties because we believe them to be strongly linked. To simultaneously make progress in both areas, however, we have had to radically redesign our devices. For example, we have introduced a new mirror design to enhance heat extraction, and a completely new active region (where the light is generated) to improve differential gain at high temperatures. These changes have markedly improved temperature stability and data transmission speed.

At present, research in optical interconnects is generally focused on two different wavelengths, 850 and 980nm, with longer wavelengths also of interest. The 980nm region has several advantages compared with 850nm. The transparency of gallium arsenide (GaAs) substrates at this wavelength allows realization of bottom-emitting devices, making possible higher packaging density and simpler integration in silicon-based systems. In addition, use of binary GaAs/aluminum arsenide (AlAs) distributed Bragg reflectors (DBRs) enhances the thermal conductivity of the mirrors, in turn leading to more effective heat extraction from the VCSELs.

Taking our previously reported oxide-confined 980nm devices as a starting point, we added a number of novel and essential features. First, we reduced the parasitics (i.e., unwanted circuit components) in our chip design by including multiple oxide apertures, a novel modulation doping profile, and an optimized geometrical chip and contact pad layout. Second, we optimized the active region for high-speed operation using highly strained indium gallium arsenide multiple quantum wells (MQWs). These strained MQWs show large differential gain and contribute directly to improved high-speed performance. We also introduced GaAs barriers for high electrical and...
thermal homogeneity in the active region to avoid gain compression at higher temperatures. We increased confinement of the optical wave by means of a half-lambda cavity and a high index-contrast binary bottom mirror, which led to shorter penetration of the light wave into the DBR. We reduced transport effects by omitting separate confinement heterostructures next to the active region and by placing the oxide aperture very close to it, thus avoiding current crowding. Finally, we further encouraged binary-mirror heat extraction through a double-mesa structure, through an active region placed very close to the heat sink, and by eliminating carrier reservoirs.

Figure 2 compares our results with previously published work by plotting heat-sink temperature against error-free bit rate. We obtained record error-free operation of our VCSELS with bit error rates of 10\(^{-12}\) with non-return-to-zero coding by a 2\(^{7}\)–1 bit-long pseudo-random-bit-sequence at record-high bit rates of 12.5Gbit/s at 155°C, 17Gbit/s at 145°C, 25Gbit/s at 120°C, 38Gbit/s at 85°C, 40Gbit/s at 75°C, 44Gbit/s at 25°C, 47Gbit/s at 0°C, and 49Gbit/s at –14°C.\(^2\) These results were all achieved with devices from a single wafer and processing run. We chose VCSELS with apertures from 5 to 7\(\mu\)m to adjust to the optimal power levels needed for detection. Our devices show clearly improved performance over the state of the art in high-speed lasers.

Even assuming these novel devices can meet demand for the next few years, it would be naive to believe that no further progress is needed. Energy consumption must still be reduced, and there is potential for far higher speeds from monolithic electro-optical modulated VCSELS. To address this issue, we are working in partnership with researchers at the University of Illinois at Urbana Champaign to develop nanocavity lasers.

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Philip Wolf received a Diploma in physics from TU Berlin (2011), where he is currently a PhD candidate in physics. His main research interests are ultra-high-speed, energy-efficient, and temperature-stable VCSELS for optical interconnects. He has authored or co-authored more than 20 papers. He received the SPIE Green Photonics Award for Communications in 2012.

References