

Tutorial 82 - - March 2008

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Putting Photons on the Chip

by George A. Riley, PhD

Introduction

Smaller die and higher speed required for the next generation of high-performance microprocessors will require unconventional interconnection techniques. One leading candidate, on-chip lasers and photodetectors for photonic interconnection, was recently demonstrated by the PICMOS project, funded by the European Commission. [1]

An optical interconnection layer containing lasers, waveguides, and photodetectors may be added to a silicon die, providing ultrahigh bandwidth communication with lower power consumption and protection from electromagnetic crosstalk and noise.

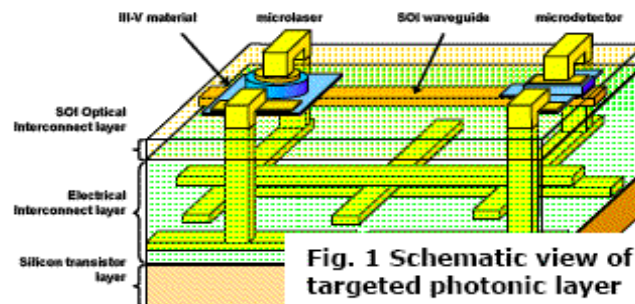


Fig. 1 Schematic view of targeted photonic layer

Figure 1 shows the PICMOS silicon-on-insulator (SOI) optical interconnection layer with silicon waveguides connecting a microlaser and microdetector. The high speed optical layer also shows connections to the copper electrical interconnection layer of the die.

Waveguides

The silicon waveguides are fabricated in a thin silicon layer deposited on the SOI wafer, using conventional etching and photoprocessing. The high refractive index of silicon allows sharp bends with low losses. Waveguides are about 550nm wide, and 220nm thick. They may be spaced as closely as 1 micrometer apart. After placement, the waveguide layer is planarized to receive the microlasers.

Microlasers

While silicon is optimal for the waveguide, it is not a suitable for efficient lasers. Instead, InP epi-layered die are directly bonded to the SOI wafer, using SiO_2 to SiO_2 molecular bonding. This heterogeneous die-on-wafer assembly does not require high-precision alignment, since the laser geometry will be created in place on the bonded die.

Figure 2 shows several 9 by 5mm InP die bonded to a 200mm wafer. Die size can vary from 1mm square to 1cm square, depending on the application. After bonding, the InP substrate is removed, leaving only the epitaxial layers.

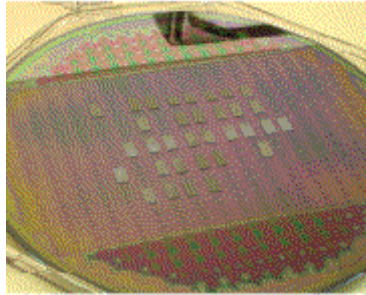


Figure 2. InP die directly bonded to wafer.

Ultra-compact disk lasers are defined by etching circles in the InP layer. Figure 3 is a cross-section drawing of the laser.[2] The disk is 7.5 micrometers in diameter. The layer stack is 1 micrometer thick.

It operates in a whispering-gallery mode, with emissions only around the periphery, allowing a top contact without loss. The bottom layer is too thin for a normal contact, so a tunnel-junction is incorporated to minimize optical loss at that interface. The bottom contact is offset on a thin transparent layer.

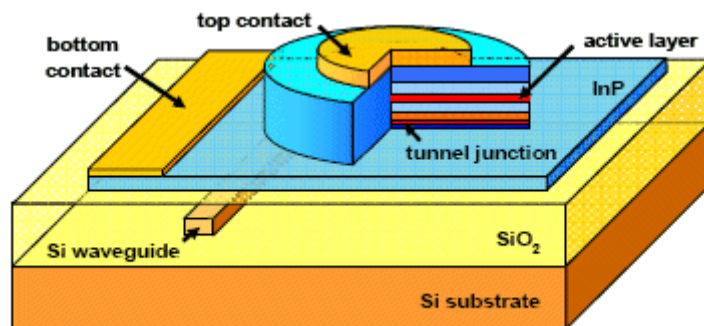


Figure 3. Schematic of disk laser and waveguide

System

Since the lasers are created by standard low-cost wafer lithography processes, their alignment to the underlying silicon waveguide is better than 100 nm.

Figure 4 shows a pair of lasers and their waveguides, showing how the waveguide alignment maximizes overlap with the radiating edge of the laser. Micro-photodetectors were similarly fabricated, with an absorbing layer of InGaAs.

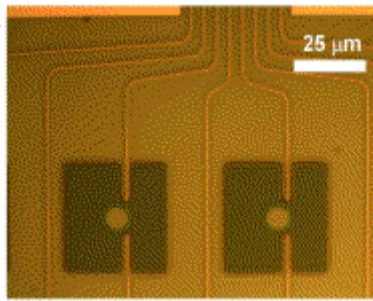


Figure 4. Completed lasers aligned with waveguides.

Results

Laser tests showed a continuous-wave output at room temperature, with a threshold current of 0.5 mA. The maximum unidirectional output power in CW operation was 10 microwatts. A demonstration chip containing about 250 waveguide-linked laser-detector pairs was tested and characterized, showing a full optical link.

The program is continuing towards integrating the photonic layer with CMOS circuits, and producing the combined devices in a standard CMOS fab.

For More Information

[1] PICMOS – Public Report at picmos.intec.ugent.be

[2] J. Van Campenhout et al., "Electrically pumped InP-based microdisk lasers integrated with a nanophotonic silicon-on-insulator waveguide circuit," *Optics Express* Vol.15, No. 11, 28 May 2007.

Numerous other technical publications are listed on the PICMOS site.

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