[2] T. Imamura, H. Hoko, S. Ohara, S. Kotani, and S. Hasuo, *Superconductivity Electronics*, K. Hara, Ed. Tokyo: Prentice-Hall & Ohmsha, 1987, p. 22.

**VIB-3 Superconducting versus Optical Interconnections**—S. K. Tewksbury, L. A. Hornak and M. Hatamian, AT&T Bell Laboratories, Holmdel, NJ 07733.

High-$T_c$ superconductors, combined with "cold" silicon MOS devices, may provide superior high-speed interconnections within electronic systems [1] for interconnection distances between about 1 cm and a few meters. Optical interconnections, avoiding the need for reduced operating temperatures, are also targeted for this distance range. Our studies on advanced interconnection technologies assume an advanced packaging scheme using wafer-level electronic components. Here, we contrast the results of our work on "long" (30 cm) YBaCuO microstrip interconnections and "short" (< 10 cm) waveguided optical interconnections.

4000-Å YBaCuO films were coevaporated on 1-in square $LaGaO_3$ substrates and a 30-cm microstrip (125-$\mu$m-wide line on 375-$\mu$m pitch, using a spiraled rectangular layout) was patterned by liftoff.[1] Separate substrates with superconducting signal and ground plane were separated by a 125-$\mu$m-thick sapphire spacer. DC resistance of pressure contacts at the ends of the line was less than 1 Ω below 30 K. Two-point dc resistance measurements showed a sharp transition (about 2 K) at $T_c = 86$ K and a small normal resistance intercept at 0 K. TDR measurements showed the expected small variation in delay below 50 K, with a rapid increase in delay above 60 K. By monitoring changes (due to impedance changes) in the several transmission amplitude response zeroes between dc and 1.2 GHz, several low-frequency performance factors were readily evaluated. Critical current $J_c$, defined here as the dc current level causing a 1-dB decrease in a small amplitude, 20-MHz fundamental, decreased from $2 \times 10^5$ Acm$^{-2}$ at 68 K to $0.3 \times 10^5$ Acm$^{-2}$ at 80 K. The transmission amplitude response showed negligible effects of dc currents (up to levels near the critical current) and of externally applied magnetic field (up to 400 G, well above $H_{c1} \approx 100$ G) at temperatures below 76 K. This suggests that flux motion did not induce significant line resistance under those conditions. As the temperature increases above 76 K and approaches $T_c$, the transmission zeroes are increasingly damped, with the expected large dc attenuation appearing above $T_c$. These results suggest 1) that flux motion does not introduce significant nonlinearities below 76 K, 2) that $J_c$ rather than $H_{c1}$ is the appropriate limit on maximum current density, and 3) that high-performance transmission lines can be achieved if the low surface resistance expected for superconductors is achieved. In separate measurements at Lincoln Labs[2] on similarly prepared films, the surface resistance of a YBaCuO ground plane used with a niobium resonator at 4.2 K could not be distinguished from that of a niobium ground plane, placing an upper limit on surface resistance about eight times that of niobium.

Optical interconnects are the principle competitor to superconducting transmission lines for very high data rates on wafer-level components. We have recently evaluated an alkyl-silicon polymer waveguide material in which the waveguide is defined simply by exposure to deep UV, requiring no etching or other patterning of the material. Attenuations less than 0.5 dB/cm were measured on 1-cm waveguides and low loss bends (1-mm radius) and single plane crossovers were demonstrated. Spin applied over a planarizing layer, the optical interconnects formed are directly compatible with underlying electronics and optoelectronics and suitable for length up to several cm (limited by attenuation). The major limitation lies in the optoelectronic sources and in the receiver circuitry. Successful development of GaAs-on-silicon would greatly relax this constraint for adding optical interconnects to silicon VLSI wafer-level components.

[1]Films were deposited and patterned by R. E. Howard, P. M. Mankiewich and B. L. Straughn, AT&T Bell Labs. Substrates were grown and prepared by C. D. Brandle, AT&T Bell Labs.

[2]Dan Oakes, MIT/Lincoln Labs.

[1] S. K. Tewksbury, L. A. Hornak, and M. Hatamian, "High-$T_c$ superconductors: Potential for expanding the performance of digital systems," in *Progress in Superconductivity*, vol. 8, C. G. Burham and R. D. Kane, Eds. World Scientific, 1988.

**VIB-4 Performance of Vertically Coupled Backside Fiber-Optic Interconnects to GaAs**—Robert W. Ade and Eric R. Fossum, Center for Telecommunications Research, Columbia University, New York, NY 10027, and Michael A. Tischler, IBM Thomas J. Watson Research Center.

A vertical coupling technique suited for dense fiber-optic interconnection of 2-D device arrays in GaAs has recently been developed; it employs cavities etched in the backside of the wafer to align each fiber to a diaphragm photodetector (DPD) fabricated on the front-surface epitaxial layers. Operation of the fiber-pigtailed DPD's is described below. Enhanced optoelectronic performance due to the backside approach, as well as the capability of addressing interconnect arrays with approximately 10 fibers/mm$^2$, is reported.

Photodetectors were fabricated on MOVPE-grown epitaxial films consisting of the following layers: a 4-$\mu$m $Al_{0.35}Ga_{0.65}As$ stop-etch/window layer, a 1-$\mu$m undoped GaAs buffer, and a 0.4-$\mu$m GaAs MESFET layer with $N_d = 8 \times 10^{16}$. Metal-semiconductor-metal (MSM) diodes, FET's with direct illumination of the transistor channel, and a Schottky diode/FET amplifier pair were placed on adjacent mesas. Portions of the GaAs substrate were removed after device fabrication by selective $CCl_2F_2$RIE [1], leaving the detectors on epitaxial diaphragms approximately 125 $\mu$m in diameter. The vertical anisotropy of the RIE process reduces the area consumed by each interconnect so that simultaneous pigtailing of adjacent DPD's was readily achieved for devices spaced only 250 $\mu$m apart.

Photocurrent crosstalk, arising from steady illumination of an adjacent detector site, was less than −50 dB for DPD's coupled via backside cavities. This figure is lower than for front surface illumination (−20 to −25 dB crosstalk) because of reduced light scattering. An upper bound on crosstalk during pulsed operation was established at −20 dB, the sensitivity limit of the measurement. Rise and fall times for the photodiodes in the present study were determined to be less than 1 ns, which was the response time of the optical source. The FET structure accommodating direct illumination of the transistor channel operated in a photoconductive mode, with a fall time of 5–10 ns and gain-bandwidth product of 1 GHz.

Backside illumination yielded a threefold higher responsivity (0.4 A/W) for MSM diodes with 50-percent metal coverage of the active region. This is due to an elimination of shadowing by metal contacts, an increase in the effective optical thickness (because of reflection from the contacts), and more efficient carrier collection. The net quantum efficiency at 840 nm of the pigtailed Schottky and MSM diodes ranged from 45–60 percent at low bias (< 5 V). Finally, the dark current (1 nA at −5 V) and photoresponse of the DPD's did not show any degradation as a result of the backside RIE process.

[1] R. W. Ade, E. R. Fossum, and M. A. Tischler, "Fabrication of epitaxial GaAs/AlGaAs diaphragms by selective dry etching," *J. Vac. Sci. Technol.*, vol. B6, p. 1592, 1988.

**VIB-5 Germanium p-Channel MOSFET's with High Channel Mobility, Transconductance, and *k*-Value**—Suzanne C. Martin, Lorin M. Hitt, and James J. Rosenberg, Division of Engineering, Brown University, Providence, RI 02912.