ThA2

# LOW-LOSS, ULTRA-COMPACT MONOLITHIC INTEGRATION OF HIGH-SPEED POLARIZATION-DIVERSITY PHOTODETECTORS

R.J. Deri, J.B.D. Soole, A. Scherer, C. Caneau, A.S. Gozdz,
N.C. Andreadakis, V. Shah, L. Curtis, J.-I. Song, and R.J. Hawkins,[a]

Bellcore, 331 Newman Springs Road, Red Bank, New Jersey 07701-7040
a) Lawrence Livermore National Laboratory, Livermore, California 94550

Polarization-selective optical devices are required for polarization-diversity coherent lightwave receivers.[1] Monolithic integration of such devices with photodetectors improves detector functionality and eliminates package complexity by reducing part count and hybrid optical interconnects. Compatibility with high III-V materials' cost, however, requires simple, high-yield processes and compact device size. We previously proposed a simple and compact integration scheme employing metal-loaded vertical couplers for polarization splitting and vertically-coupled photodiodes for O/E conversion. Initial experiments using InGaAsP/InP demonstrated satisfactory *optical* functionality, with 10.6 and 16dB polarization selectivity for TE and TM polarized-light.[2] Here we show how such integrated devices can be modified to achieve suitable *electronic* performance, including wide bandwidth and high quantum efficiency.

Fig. 1 shows a schematic of our device. Photosignals input via a laterally tapered rib waveguide are launched into a pair of coupler/photodetector units, each performing O/E conversion on orthogonal polarization states. The taper is essential for minimizing lateral diffraction in the couplers, to achieve high quantum efficiency with narrow diode mesas (28µm) suitable for high-speed operation. The near-adiabatic, parabolic taper[3] is 177µm long. We use vertical couplers to eliminate coupler gap lithography, reduce coupler length, and increase the optical bandwidth. Regrowth-free integration of short detectors (20µm TE, 34µm TM) is achieved by "impedance matched"[4] vertical coupling to *pin* mesa photodiodes. Metal loading of the first coupler causes phase-mismatch for TM-polarized light, so that only TE-polarized signals are coupled to the first photodiode, while the second coupler/detector pair captures the remaining TM-polarized light. Our design eliminates difficult-to-define lithographic features (coupler gaps, Y-junctions) and epitaxial regrowths. The small size (~400µm) and simple processing of this photonic circuit render it ideal for high yield fabrication.

Photodiodes were passivated with polyimide collars and connected to bond pads placed on the InP:Fe upper coupler cladding (not shown in fig. 1). Leakage was 8-11nA at -4V bias, primarily due to finite resistivity of the semi-insulating guides rather than the junction. Measured capacitance at -4V was 100, 142fF for the TE, TM detectors. A thin (1µm) *i*-InGaAs depletion layer was used to minimize photodiode nonplanarity; twofold capacitance reduction could be achieved with thicker *i*-layers without compromising detector performance. Diode series resistance ≈20Ω was estimated from S-parameter data.

On-chip optical insertion losses (photocurrent output/optical input) at $\lambda$=1.52µm were 1.5dB TE and 2.2dB TM. Detection quantum efficiencies of 42% TE and 35% TM, *including fiber input coupling*, were obtained using conical fiber tips. These values arise from on-chip losses plus 1.5dB Fresnel reflection plus 0.8dB input mismatch. Polarization selectivities were 12.7dB TE and 11.3dB TM; for these values, only ≈1dB total IF signal variation due to polarization fluctuation is expected in receiver applications. The bandwidth of the larger TM detectors was ≈13GHz into 50Ω at -8V bias, determined using microwave wafer probes (fig. 2).

In summary, we have demonstrated compact photonic integration of polarization-diversity photodetectors with low insertion loss and high detection bandwidth. Our results show that such integration can enhance detector functionality, by incorporating high-performance waveguide optics, *without compromising chip size or ease of fabrication.*

This research was performed in part under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

**REFERENCES**


1. M. Erman, P. Riglet, et al., *15th European Conf. Opt. Commun.* (Gothenburg, Sweden; Sept. 1989). ThB20.
2. R.J. Deri, R.J. Hawkins et al., *Appl. Phys. Lett.* **59**, 1823 (1991).
3. A.F. Milton and W.K. Burns, et al., *J. Quantum. Electron.* **QE-13**, 832 (1977).
4. R.J. Deri, N. Yasuoka, et al., *Photon. Technol. Lett.* **2**, 496 (1990).


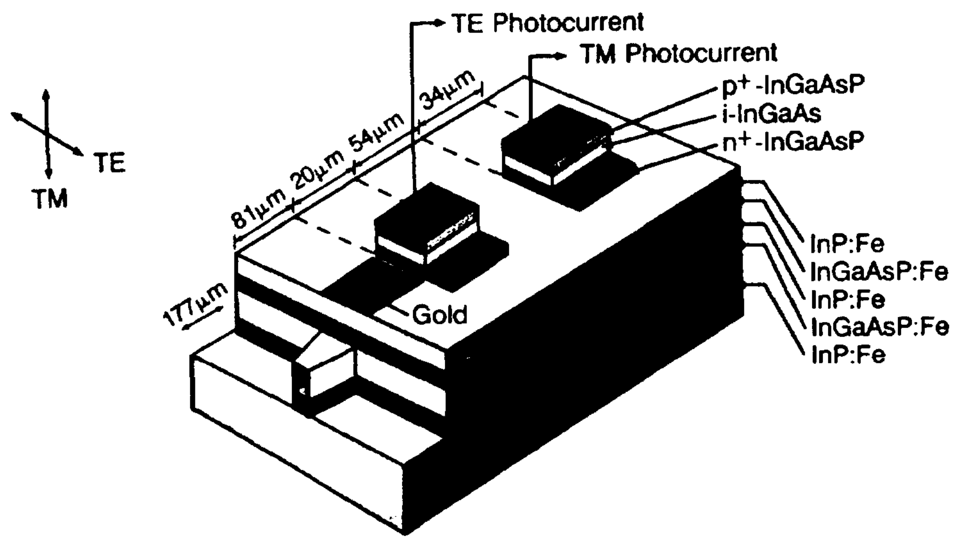


**FIGURE 1: DEVICE SCHEMATIC.** Detector passivation and interconnect metal not shown.

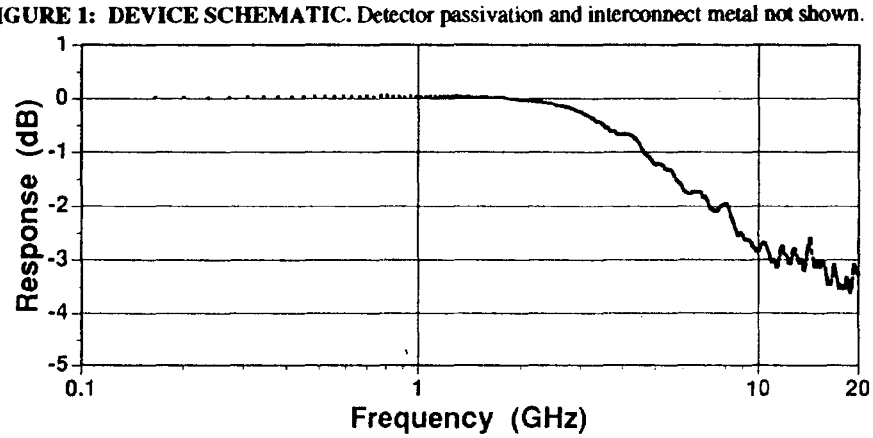


**FIGURE 2: TM DETECTOR BANDWIDTH DATA.**