

Miller S E. Integrated optics: an introduction.  
*Bell Syst. Tech. J.* 48: 205969, September 1969.

It is proposed that complex patterns of opticalwave circuits, whose communication function might be somewhat analogous to that of lowerfrequency integrated circuits, could be fabricated in a sheet of dielectric using photolithographic techniques. Prospective advantages include small size, stability, and reproducibility. The crosssectional dimensions of the guided beams would be on the order of 10  $\mu\text{m}$  or less, thus facilitating the achievement of desirable nonlinear effects at low absolute power levels. [The SC<sup>90</sup> indicates that this paper has been cited 136 times since 1969.]

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"The proposals recorded in this paper were conceived during the interval of a few days while preparing for an internal company review of research on optical communication. This was prior to the establishment of feasibility of lowloss lightwave propagation on glass fibers. Work at Bell Laboratories had created a rather refined technique of guiding a number of laser beams along a single path. This transmission technique used a cascaded series of lenslike focusing elements which needed to be stably and accurately positioned, and the entire length of the region traversed by the laser beam needed to be shielded from atmospheric absorption or scattering effects. The resulting cost made it necessary to carry a very large number of voice, data, or picture channels so that the perchannel cost would be attractive. Numerous laser carrier waves, each modulated with thousands of voice signals, were to be carried through the single chain of lenses from city to city.

"Research had also produced lasers, modulators, and detectors, but the existing technique was based on freely propagating beams from laser to modulator, and from modulator to the transmission medium and on to the detector. The arrays of optical elements to perform these functions were mounted on massive optical tables, and were sensitive to acoustic as well as thermal effects. Each channel might occupy space on the order of a square foot, with perhaps tens or hundreds of channels to be associated with a single lens guide. If

optical communication were, to become practical, there simply had to be a better way.

"The seeds of guidedwave circuitry had already been sown in some pioneering work at Wheeler Laboratories. There, laser beams had been guided along tracks of increased index created by thermal effects and later by proton irradiation of fused silica. I saw the possibility of making complex patterns of laser waveguides in dielectric plates using photolithographic techniques. Using some of my 1964 work on the relations between guidedwave parameters and permissible bending radius, I predicted that a few percent index change would create a waveguide that could successfully carry a laser beam through a bend with a radius of the order of a centimeter. This capability, in combination with photolithographic techniques, seemed to offer compact modulator and filter assemblies that could be readily reproduced.

"Reflection on the idea caused me to see other advantages. The guided laser beams were to be confined into a cross section with dimensions on the order of 10  $\mu\text{m}$  or less, giving relatively high fields at low absolute power levels. This facilitated getting desirable nonlinear effects at low power levels, and because the wave was guided, it would be feasible to have long interaction lengths not feasible in unguided beams.

"There was immediate enthusiasm among my colleagues. What I proposed fitted in with the interests and current directions of effort of other researchers. For example, unknown to me was another researcher's interest in making small optical waveguides to enhance the nonlinear opticalwave interactions noted above.

"The original need for miniature optical circuitry has disappeared. The sequenceoflens waveguide for laser beams has been replaced by hairized glass fibers, and initially at least each fiber will carry only one laser beam. There continues, however, a strong interest in thinfilm optical circuitry; modulators, channel combining filters and optical switches have been realized by researchers overseas as well as in the US. There is a conviction that the new miniaturized optical circuitry will prove useful; it is now being applied on a simplified scale—for lasermodulator combinations and laserarray assemblies, for example. We must wait a while longer to find out how useful this new technology will become."