mission across the traversing slits with no filters. The measured loss agrees very well with loss calculations using a Gaussian beam profile. This clearly shows that all coupling loss is due to beam spreading (guiding loss), as no extraneous loss occurs from fabrication of the slits.

The characteristics of the 1.3/1.55-μm WDM receiver is summarized in Table 1. Electrical/optical conversion efficiency of 0.86 A/W is achieved for the 1.55-μm light detected with an 80-μm diameter photodiode. The efficiency of 0.37 A/W measured for the 1.3-μm light was limited by the loss due to the wide first slit (170 μm) used in this experiment. However, the loss can be as low as 0.5 dB by narrowing the slit to about 40 μm. The cross talk to the 1.3-μm signal is less than −45 dB, and to the 1.55-μm signal varies from −14 to −22 dB, depending on polarization. Because there are no reflecting surfaces, back reflection of −65 dB is easily obtained. Furthermore, very good second- and third-order distortion characteristics were obtained for the 1.55-μm analog video signal.

We have demonstrated for the first time a dual-wavelength receiver consisting of an embedded fiber circuit and surface-mounted photodiodes. Low coupling loss in this circuit leads to high receiver performance for 1.3/1.55-μm WDM signals. This embedded fiber circuit technology can realize low-cost, high-performance devices for impending subscriber optical communication systems.

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TuJ6 3:30 pm

Micromachined tunable three-dimensional solid Fabry-Perot etalons

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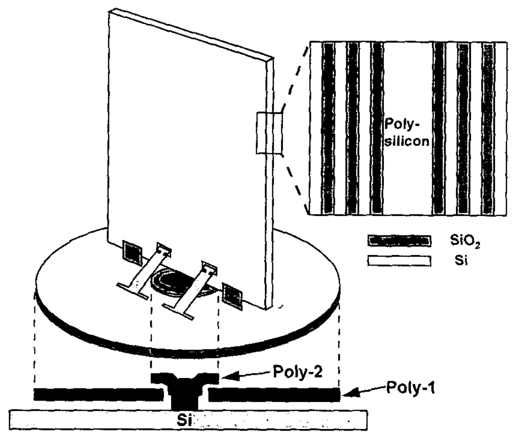
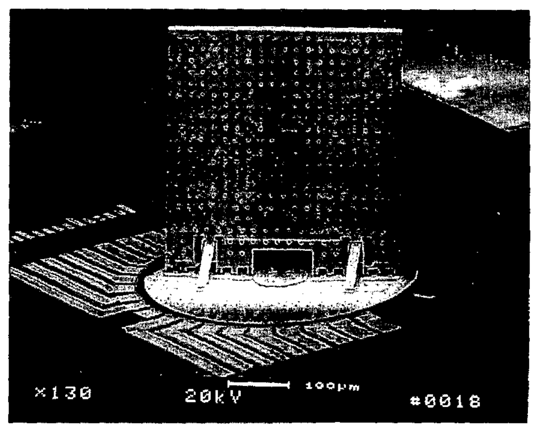
Broadband tunable Fabry-Perot etalons have been widely used in wavelength-division multiplexing (WDM) systems as wavelength demultiplexers. Various approaches have been proposed to enhance the integrability of Fabry-Perot etalons. Micromachining has shown great potential for tunable filters. However, most of the microfabricated Fabry-Perot filters reported to date are in-plane structures with surface-normal optical access, which limits their integrability with other micro-optical elements. On the other hand, surface micromachining offers a new approach to implement three-dimensional free-space micro-optics monolithically. Previously, we have proposed a "Free-Space Micro-Optical Bench (FS-MOB)" technology for free-space integrated optics and optoelectronic packaging.[1,2] In this paper, we report on the first fabrication of novel three-dimensional tunable solid Fabry-Perot etalons monolithically integrated with rotational stages using the FS-MOB technology. Very broad tuning range (58.5 nm) is achieved by rotating the etalon.

Figure 1(a) shows the schematic diagram of the tunable Fabry-Perot etalon. It consists of a solid etalon and a rotational stage. The etalon is made with polysilicon material and stands perpendicular to the substrate so that it can be easily integrated with other optical components. For example, the etalon can be cascaded with another etalon with different free-spectral range

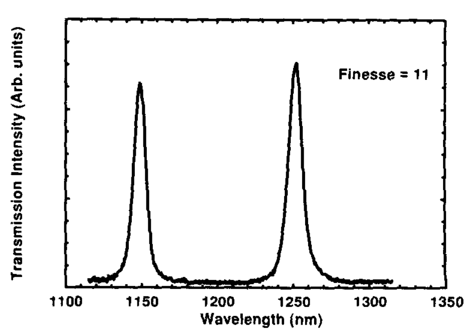


(a)

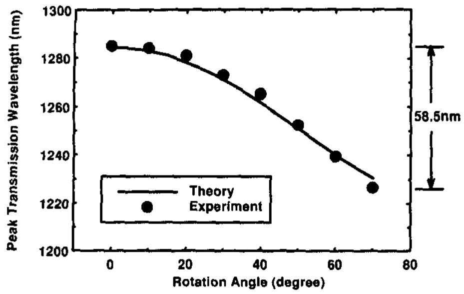


(b)

TuJ6 Fig. 1. (a) Schematic drawing and (b) SEM micrograph of the solid Fabry-Perot etalon integrated with a rotational stage.



TuJ6 Fig. 2. Transmission characteristics of the three-dimensional solid Fabry-Perot etalon at 50° incident angle.



TuJ6 Fig. 3. The peak transmission wavelength of the three-dimensional Fabry-Perot etalon versus the rotation angle of the on-chip rotational stage.

to optimize the filter bandwidth; or it can be integrated with bulk-micromachined V-grooves for aligning input and output optical fibers. The three-dimensional etalon and the rotational stage are fabricated integrally using the micro-hinge technology.[3] The structure of the rotational stage itself is similar to that of the micromotors. Three pairs of SiO_2/Si quarter-wavelength dielectric mirrors are coated on both sides of the polysilicon plate after it is assembled to increase its reflectivity at 1.3 μm. The Fabry-Perot etalon can be angle-tuned by rotating the integrated stage. Figure 1(b) shows the scanning electron micrograph (SEM) of an assembled solid Fabry-Perot etalon integrated with a rotational stage. The stage has been rotated by 45° in the SEM.

The transmission characteristics of the tunable etalon are characterized using a white-light source and an optical spectrum analyzer. Figure 2 shows the transmission spectrum of the solid Fabry-Perot etalon at 50° incident angle. The finesse of the etalon is 14 for normal incidence and 11 for 0° incident angle. Figure 3 shows the experimental and theoretical peak transmission wavelengths versus the tuning angle. A tuning range of 58.5 nm is achieved by rotating the Fabry-Perot etalon over 70°. The theoretical analysis is performed using the matrix formulation approach for multilayer structure.[4] Very good agreement between experiments and theory is obtained. The finesse of the current etalon is limited by the reflectivity and the residue scattering loss in the polysilicon plate. The latter can be reduced by employing air gap between two plates as the cavity, which can be realized by the same technology.

In summary, we have demonstrated three-dimensional tunable solid Fabry-Perot etalons fabricated integrally with rotational stages using the surface micromachining technique. A tuning range of 58.5 nm has been achieved by rotating the on-chip rotational stage over 70°. The three-dimensional Fabry-Perot etalons can be integrated with other free-space micro-optical elements fabricated by similar technique, and have applications in WDM systems for optical communication at 1.3 μm and optical sensors.

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TuK 3:00 pm–4:00 pm
Room B

Tutorial: Undersea Lightwave Systems

Neal S. Bergano, *AT&T Bell Laboratories, Presider*

TuK1 (Tutorial) 3:00 pm

Undersea lightwave systems

Shu Yamamoto, *Instructor*
KDD R&D Laboratories, 2-1-15 Ohara Kamifukuoka, Saitama, Japan

Recently undersea lightwave systems using optical fiber amplifiers have been widely deployed. The tutorial will review the current technologies used in the transoceanic systems as well as the technology options available for the future systems.

TuL 4:30 pm–6:30 pm
Room A1

Advances in Optical Fibers and Cables

Frederick M. Sears, *Siecor Corporation, Presider*

TuL1 4:30 pm

Ultranegative delta cladding for modified chemical vapor deposition

A. E. Miller, R. L. Opila,* M. F. Yan,* *AT&T Bell Laboratories, Whippany, New Jersey 07981*

Ultranegative cladding refractive index depressions >0.5% are required to decrease or eliminate core GeO_2 content and provide greater design flexibility for transmission and specialty optical fibers.[1,2] Fluorine incorporation as mole fraction, $x_{SiO1.5F}$, is controlled by ambient SiF_4 partial pressure, P_{SiF4}, as:[3]

$$x_{SiO1.5F} = KP_{SiF4}^{0.25}$$

where K is the equilibrium constant. Normalized index depression, Δ^-, is then:

$$\Delta^- = x_{SiO1.5F}/10.6.$$

Previously, Δ^- values >0.5% from F-doping have been