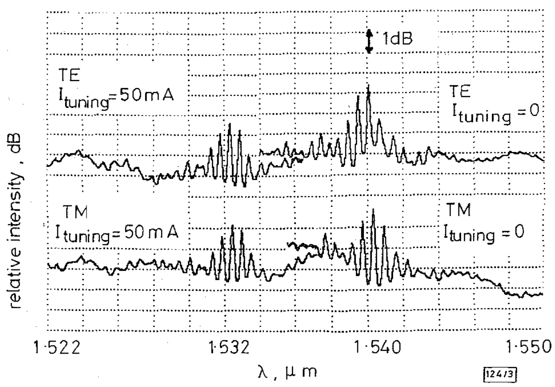

Fig. 3 *Superimposed spectra for TE and TM amplified spontaneous emission of device, with and without tuning current*

(point (i)) we observe a fibre to fibre net gain of 1.8dB at the peak Bragg wavelength, using a 100mA amplifier bias current. The launched power by the laser (point (ii)) was –6.6dBm, and the received power (at point (iii)) was –10.8dBm. The power budget at point (i) is estimated to be composed of –5.5dB fibre coupling loss (occurring twice), –5dB filter loss, –1dB transition loss (occurring twice), and 20dB total on-chip amplifier gain. To reduce the modal birefringence of the filter, a mask with different stripe widths was used for defining the mesas of the SIPBH waveguides. Five different stripes were used, with increasing stripe width by the mask pixel resolution of 0.125μm. Using this technique, a device with the correct width to height ratio for zero birefringence can be obtained. Further reduction of Fabry-Perot fringes from residual

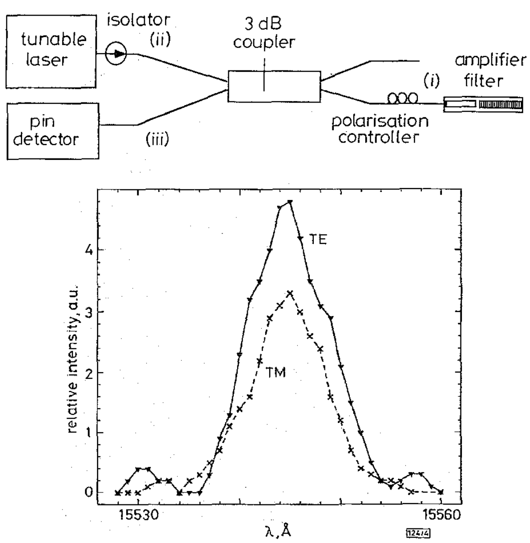

Fig. 4 *Filter responses*

Top: Schematic description of experimental measurement setup
Bottom: Spectral response of filter for two input polarisations

front facet reflections was obtained by using a tapered window structure [6]. The filter response for a device with a good TE/TM wavelength match, and reduced residual reflection, is shown in Fig. 4 (bottom). The width of the filter reflectance band is ~9Å FWHM. The dispacement between the Bragg peak wavelengths for the two polarisations is < 1Å. The side lobe to main lobe ratio is better than –12dB, and the rejection ratio (peak power to out of band power ratio) is better than –20dB.

One should note that in a receiver configuration, the 3dB coupler of Fig. 3 can be replaced with a 3-port optical circulator, thus eliminating the 6dB loss associated with the round trip through the coupler. In conclusion, we demonstrate a polarisation insensitive tunable reflective filter, with an integrated in-line optical amplifier providing a net fibre coupled gain for the device. The filter has a width of 9Å FWHM, and can be tuned over a spectral range of 95Å. It may be useful for low noise WDM receivers, and for channel selection in WDM networks.

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Surface-micromachined tunable three-dimensional solid Fabry-Perot etalons with dielectric coatings

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Indexing terms: Micromachining, Integrated optics, Interferometry

Tunable three-dimensional solid Fabry-Perot etalons with multilayer dielectric coatings have been successfully demonstrated. The out-of-plane etalon is monolithically integrated with a rotation stage using the surface-micromachining technique. A wavelength tuning range of 58.5nm has been achieved at 1.3μm wavelength using the on-chip rotation stage.

Introduction: Tunable Fabry-Perot etalons have very broad applications in wavelength-division multiplexed (WDM) optical communications, optical sensing, and spectral analysis. Monolithic out-of-plane etalons that are perpendicular to the substrate are desirable in many applications because it enables the etalons to be integrated with other free-space micro-optical elements or fibre alignment structures (V-grooves). Monolithically integral out-of-plane free-space micro-optical elements have recently been implemented by surface-micromachining techniques [1 – 4]. In this Letter, we report the experimental results and the theory of surface-micromachined three-dimensional tunable solid Fabry-Perot etalons monolithically integrated with rotation stages. The etalons are coated with dielectric multilayers to increase their finesse. A very broad tuning range (58.5nm) is achieved by angle-tuning using the on-chip rotation stage. The experimental results agree very well with theoretical calculations based on the matrix formulation.

Design: Fig. 1*a* shows a schematic diagram of the tunable solid Fabry-Perot etalon. The vertical polysilicon etalon plate allows

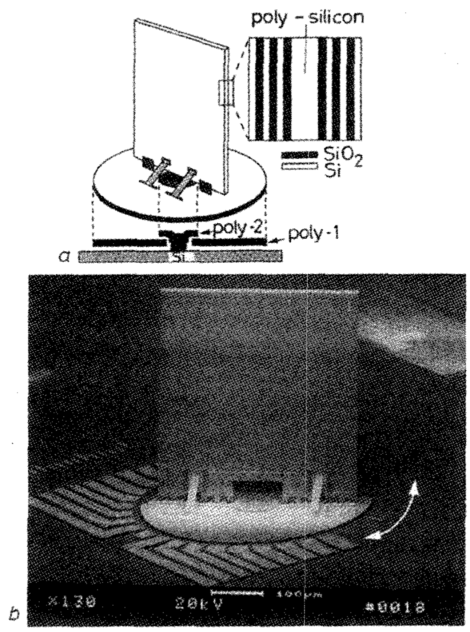

Fig. 1 *Tunable solid Fabry-Perot etalon with integrated rotation stage*

a Schematic drawing
b SEM micrograph

optical beams to propagate in parallel to the substrate. Therefore, it is very suitable for integration with other similarly fabricated optical components such as micro-lenses [1], mirrors [2, 3], and gratings [4] on the Si free-space micro-optical bench. This etalon is integrated with a rotation stage for angle-tuning. High-reflection (HR) coatings consisting of three pairs of quarter-wavelength SiO_2/Si multilayers are applied to both sides of the polysilicon plate to increase its finesse. The dielectric mirrors are designed for maximum reflectivity at 1.3μm at normal incidence. Fig. 1*b* shows the scanning electron micrograph (SEM) of the assembled solid Fabry-Perot etalon and the rotation stage. The stage in the SEM has been rotated by 45°.

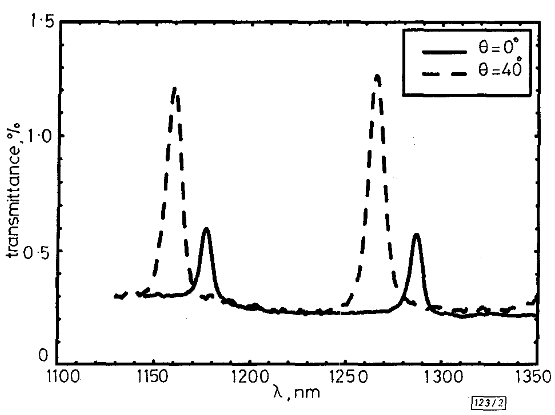

Fig. 2 *Transmission characteristics of three-dimensional solid Fabry-Perot etalon at 0° and 40° rotation angle*

Experimental results: The transmission characteristics of the tunable etalon are characterised using a white light source and an optical spectrum analyser. Fig. 2 shows the transmission spectra of the solid Fabry-Perot etalon at 0 and 40° rotation angles. The background is caused by light leakage through the release holes as shown in Fig. 1*b*. These release holes are not essential and could be eliminated in the new design. The transmittance of the HR-coated etalon is much lower than that of the uncoated etalon (~80%) because of the residue loss in the polysilicon plates (7.9% per pass) [5]. The finesse of the etalon is 14 at normal incidence, and 12.5 at a 40° angle. The finesse decreases slightly with rotation because the reflection peak of the HR coatings shifts towards long wavelength and the reflectivity at 1.3μm decreases. The transmittance also becomes higher for angled incidence because there are fewer passes through the polysilicon. The cavity loss can be reduced by employing an air gap between two HR-coated plates at the cavity, which can be realised by the same technology. Fig. 3 shows the peak transmission wavelength against the rotation angle of the on-chip rotation stage. A broad tuning range of 58.5nm is achieved by rotating the stage over 70°.

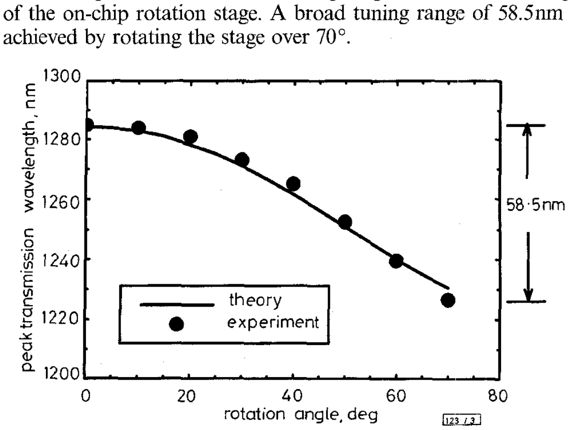

Fig. 3 *Peak transmission wavelength of three-dimensional Fabry-Perot etalon against rotation angle of on-chip rotation stage*

Theoretical calculation: The transmittance of the solid etalon can be calculated using the matrix formulation for multi-layer structures [6]:

$$\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} = D_0^{-1}(D_1P_1D_1^{-1}D_2P_2D_2^{-1})^3 \times D_pP_pD_p^{-1}(D_2P_2D_2^{-1}D_1P_1D_1^{-1})^3D_0$$

where D_0, D_1, D_2 and D_p are the dynamic matrices for free space, Si, SiO_2, and polysilicon, respectively; P_1, P_2 and P_p are the propagation matrices for Si, SiO_2, and polysilicon, respectively. The calculated transmittance $T = |1/M_{11}|^2$ is also shown in Fig. 3. Very good agreement between experiments and theory is obtained.

Conclusion: We have demonstrated a novel out-of-plane tunable Fabry-Perot etalon with integrated tuning rotation stage using the surface-micromachining technique. A finesse of 14 and a tuning range of 58.5nm has been achieved by turning the on-chip rotation stage over 70°. The measured tuning characteristics agree very well with theory.

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