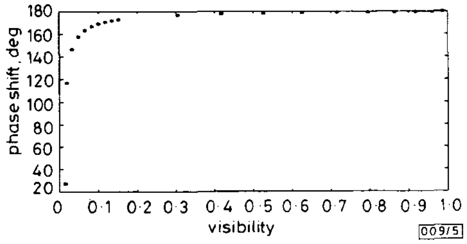

Fig. 5 *Numerical simulation of experiment which leads to results depicted in Fig. 4*

Calculations have been carried out for an ideal 3dB coupler with an additional polarisation mode coupling factor of 0.5%

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References

1 HERETH, R., and SCHIFFNER, G.: 'Broad-band optical directional couplers and polarisation splitters', *J. Lightwave Technol.*, 1989, **LT-7**, pp. 925–930

2 SCHLIEP, F., and HERETH, R.: 'Phase sensitive measurement technique for singlemode fibre directional couplers', *Electron. Lett.*, 1992, **28**, (16), pp. 1538–1541

3 SANZ, I., and MURIEL, M.A.: 'Measurement technique for characterization of 2 × 2 couplers', *Electron. Lett.*, 1992, **28**, (14), pp. 1301–1305

4 SCHLIEP, F., HERETH, R., and SCHIFFNER, G.: 'Phase sensitive investigations of 3 × 3 singlemode couplers', *Electron. Lett.*, 1993, **29**, (1), pp. 68–71

Polysilicon Fabry-Perot cavities deposited with dichlorosilane in a reduced pressure chemical vapour deposition reactor for thermal sensing

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Indexing terms: Chemical vapour deposition, Temperature measurement, Silicon

The thermo-optical effect of a polysilicon Fabry-Perot thermal sensor, deposited in a reduced pressure pancake reactor using dichlorosilane, has been evaluated theoretically and experimentally. The polysilicon deposition rate was much faster than that deposited by the low pressure chemical vapour deposition (LPCVD) technique using silicon.

Microsensors based on polysilicon are currently being widely investigated because of their potential for low cost and high performance [1]. Besides the usual thermal-electrical sensing mechanism, applying the thermal-optical characteristics of the polysilicon film can be simple, repeatable, and radio-frequency interference free. Previously, silicon wafers were used for fibre-optic tactile sensors [2]. This Letter reports using the large change in refractive index of deposited polysilicon films with temperature to form the basis of a highly integrated poly-Si thermal sensor. A surface-normal reflection type polysilicon Fabry-Perot (FP) thermal sensor, illustrated in Fig. 1, was fabricated. Polysilicon films were deposited in a reduced pressure epitaxial reactor using dichlorosilane because of its fast deposition rate and large crystallites instead of the silane in a LPCVD tube.

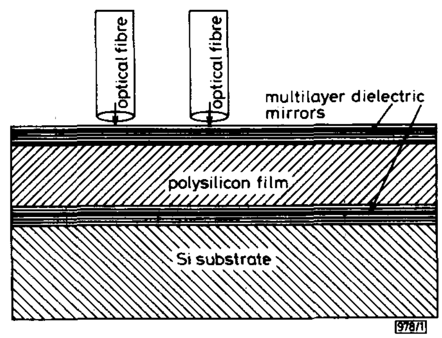

Fig. 1 *Device layout and geometry*

The thickness of polysilicon for microsensor applications is usually between 1 and several micrometres [3], and the deposition rate in an LPCVD tube is only ~25Å/min at 580°C, 50sccm of SiH_4, and 150mtorr. Thus the time needed for deposition would be more than 6h as compared to an epitaxial reactor of 0.6µm/min at 1015°C, atmospheric pressure, and 45sccm of dichlorosilane (SiH_2Cl_2). The natural chemical reaction of SiH_2Cl_2 not only generates the Si but also releases HCl which prevents silicon from nucleating on top of the insulation surface by etching. As observed from the experiments, if the ambient temperature is lower than 1000°C, the wafers do not become thoroughly covered by polysilicon. This should be attributed to the HCl etching rate being higher than the poly-Si deposition rate. As the temperature was raised above 1000°C, the poly-Si deposition rate was higher than the HCl etching rate, and the whole-wafer poly-Si silicon-on-insulator (SOI) structures were obtained. The thickness for a 15min deposition was measured to be 9.3µm with a standard deviation of 300Å. The poly-Si grown in the epitaxial reactor did not show a shiny silver mirror surface. Because the FP cavity length needed to be reduced to a certain thickness, subsequent chemical and mechanical polishing (CMP) was necessary. With an etch stop the CMP had a measured surface irregularity of less than 50Å[4].

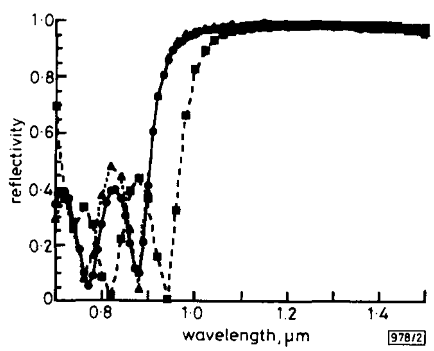

Fig. 2 *Measured reflectivity spectra of mirror with three stack plus cap oxide layer*

○ measured (three stack + cap oxide)
■ theory (0.2µm oxide + 0.1µm poly-Si)
▲ theory (0.22µm oxide + 0.08µm poly-Si)

One key step towards increasing the finesse (sensitivity) of the Fabry-Perot cavity is using multi-dielectric layers as the top and embedded high reflection mirrors. Amorphous silicon (a-Si) and SiO_2 were chosen as the high and low index dielectric materials so that fewer dielectric pairs were needed to obtain a high reflectance. The a-Si films were prepared by LPCVD and the oxide layers were then obtained by oxidising the a-Si films at 1000°C for 25min in order to obtain a stack with 1000Å polysilicon and 2000Å of SiO_2. The designed centre Bragg wavelength was 1.3µm. The normal reflectivity spectra of a stack of three dielectric mirrors plus an oxide cap layer prepared by LPCVD system and furnace tube is shown in Fig. 2. Note that the mirror presents a very smooth and high reflectivity response. Although, the desired centre wavelength appears slightly shifted, the reflectivity is still at its maximum at a wavelength of 1.3μm.

The thermo-optical effect of a semiconductor can be described by the energy bands of semiconductors, various absorption edges, and interband critical points exhibiting large shifts with temperature at constant pressure. Thus a model showing the relationship of the refractive index and the energy bandgap is essential for representing the thermo-optical effect. A modified single-effective oscillator (SEO) model was proposed by Afromowitz [5], for the refractive index below the band edge:

$$n^2 - 1 = \frac{E_d}{E_0} + E^2\frac{E_d}{E_0^3} + \frac{E^4 E_d}{2E_0^3(E_0^2 - E_g^2)} \ln\left[\frac{2E_0^2 - E_g^2 - E^2}{E_g^2 - E^2}\right] \quad (1)$$

where E_0 and E_d are the oscillator energy and the strength from the SEO model and E_g is the energy bandgap. For a-Si, the E_0 and E_d values are chosen to be 3.308 and 34.56eV [6]. Differentiating eqn. 1 with respect to temperature, and taking into account the shift of the oscillator and bandgap energies with temperature yields

$$\frac{\partial n}{\partial T} = \frac{\partial n}{\partial E_g}\frac{\partial E_g}{\partial T} + \frac{\partial n}{\partial E_0}\frac{\partial E_0}{\partial T} \quad (2)$$

For the indirect bandgap Si, $\delta E_g/\delta T = -1.7 \times 10^{-4}$eV/°C was equated with the rate of change of the lowest indirect gap. For the SEO oscillator energy, $\delta E_0/\delta T = -4.7 \times 10^{-4}$eV/°C was assumed to move at the same rate as the transition at $k = (0,0,0)$ [6]. Fig. 3

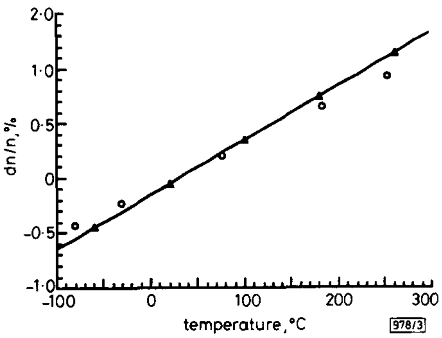

Fig. 3 *Variation of refractive index with temperature*

Thermal refraction of c-Si at λ = 6μm
○ empirical data
▲ calculated

shows the good agreement of the values calculated from eqn. 2 compared with the empirical data of Wolf [7], which predicts that the refractive index should increase with temperature. Fig. 4 shows the measured results of the thermal shift of the resonance wavelength for an FP structure with 2μm of cavity length and three stacks of films as top and bottom mirrors. The reflectivity of the resonance wavelength varied at a rate of 2.4Å/°C. By pointing two optical fibres normal to the sensor carried with two different light wavelengths, one is at the resonance wavelength and the other can be a smaller or larger wavelength. The relationship between the reflectivity and the ambient temperature is easily calibrated.

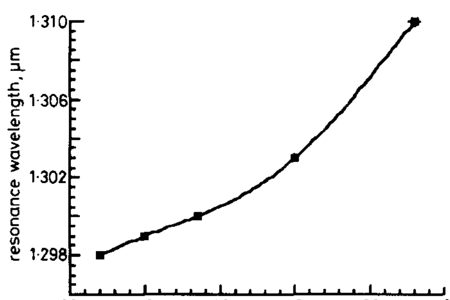

Fig. 4 *Temperature dependence of resonance wavelength*

In summary, the deposition time for poly-Si films is reduced from 6h to only several minutes. After CMP, the wafers have mirror like surfaces with controllable cavity thickness. The reflectivity of the FP mirror was greatly improved by applying multilayers of polysilicon and SiO_2 films to act as the high and low index materials. Experiments show that three stacks (six layers) of quarter wavelength thick films provide a 98% reflectivity, hence the finesse of the FP cavity will be greatly increased. The thermal response of the structure was measured to be 2.4Å/°C.

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References

1 ZUCKER, O., LANGHEIRICH, W., and MEYER, J.: 'The effect of process parameter variation on polysilicon temperature transducer characteristics', *Sensors and Actuators*, 1992, **32**, pp. 419–422
2 CHAO, H., and SNIEGOWSKI, J.J.: 'Optical fibre microbending sensor by micromachining techniques', *Electron. Lett.*, 1990, **26**, (8), pp. 513–515
3 GUCLE, H., SNIEGOWSKI, J.J., CHRISTENSON, T.R., MOHNEY, S., and KELLY, T.F.: 'Fabrication of micromechanical devices from polysilicon films with smooth surfaces', *Sensors and Actuators*, 1989, **20**, pp. 117–122
4 SUBRAMANIAN, C.K., and NEUDECK, G.W.: 'Large area silicon on insulator by double-merged epitaxial lateral overgrowth', *J. Vac. Sci. Technol.*, 1992, **10**, (2), pp. 643–647
5 AFROMOWITZ, M.: 'Refractive index of $Ga_{1-x}Al_xAs$', *Solid State Commun.*, 1974, **15**, (1), pp. 59–63
6 DUDLEY, J.J., CRAWFORD, D.L., and BOWERS, J.E.: 'Temperature dependence of the properties of DBR mirrors used in surface normal optoelectronic devices', *IEEE Photonics Technol. Lett.*, 1992, **4**, (4), pp. 311–314
7 WOLF, H.F.: 'Silicon semiconductor data' (Pergamon Press, New York, 1969)

High speed GaAs optoelectronic exclusive-OR gate

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Indexing terms: Photoconducting devices, Logic gates

An optoelectronic exclusive-OR gate has been demonstrated in high speed GaAs photoconductive switches. Optical output was achieved by gain-switching an auxiliary semiconductor laser from the electrical output of the logic device. Signal pulses shorter than 400ps were obtained with an on-off contrast ratio better than 19dB.

Computing and signal processing with optical beams have the advantages of high speed and inherent parallelism. Different optoelectronic logic devices have been proposed for this purpose. Among them, the exclusive-OR (XOR) gate has received the greatest attention owing to its usefulness in binary addition and binary comparison. Several groups have demonstrated optical-input optical-output XOR gates using phototransistors for light detection [1–3]. Their highest speed attained is of the order of microseconds, and is being limited by the large emitter junction capacitance. Another approach to realising the logic gates is to adopt high speed photoconductive switches. Their advantages include simple fabrication, fast response, large dynamic range and lack of jitter [4]. An optoelectronic AND gate for time-division demultiplexing has been demonstrated which is based on GaInAs photoconductive switches [5]. The devices proved to have a high speed response with a relatively low switching energy. Kamiyama *et al.* have