Crystal silicon 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, Fabry-Perot resonators, Silicon-on-insulator

A surface-normal Fabry-Perot (FP) thermal sensor with embedded multiple QW dielectric mirrors, was fabricated and evaluated using a single crystal merged silicon epitaxial lateral overgrowth (MELO) technique. The sensitivity of the sensor has been improved owing to the higher finesse.

Silicon based microsensors are currently being widely investigated because of their potential for low cost and high performance [1]. Application of the thermal-optical characteristics of the crystal Si or polysilicon films can be simple, repeatable, radio-frequency interference free, and is compatible with well developed monolithic silicon processing. Previously, silicon wafers deposited with polysilicon were used for thermal sensing [2]. This Letter reports that instead of using the large change in refractive index of polycrystal silicon films with temperature, crystal silicon also can be used to form the basis of a highly integrated Si thermal sensor. The MELO processes and the device structure are shown in Fig. 1.

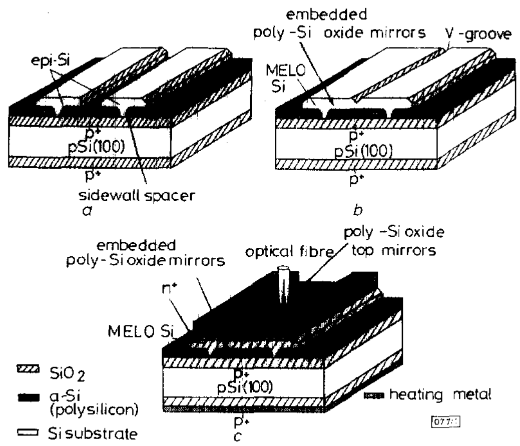

Fig. 1 *Schematic diagrams showing device structure and processing*

a ELO Si film from two seeds
b Merged ELO Si film from two seeds
c Fabricated Fabry-Perot thermal sensor

Once the thickness of the silicon epitaxy growth (SEG) silicon epilayer exceeds the edge of the masking level, single crystalline Si starts to grow both vertically and laterally over the oxide mask as shown in Fig. 1*a*. A local silicon on insulator (SOI) structure is obtained through this process by continuous epitaxial growth from seed windows on each side of oxide islands as shown in Fig. 1*b*. The coalesced Si film is called merged ELO (MELO) [3]. The V-groove on top of the MELO film can be eliminated either by continuous epitaxy growth or by subsequent chemical and mechanical polishing (CMP). With an etch stop, the CMP had a measured surface irregularity of <50Å [4]. A test structure device is shown in Fig. 1*c*. The MELO standard deviation of the thickness of the MELO films was measured to be 0.5μm for a9 μm film [4]. To maintain the epitaxial c-Si grown from seed windows during the MELO process, sidewall spacers were employed to protect the c-Si from contacting those dielectric high reflectivity mirrors as shown in Fig. 1*a*. This process preserves the c-Si characteristic of the growth film so that this cavity can not only be used in sensors but also in optoelectronic devices. The silicon deposition rate is 0.115μm/min at 970°C, 40torr. Thus the time needed for deposition is <1h.

To increase the finesse (sensitivity) of the Fabry-Perot cavity, multidielectric layers have been used for 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 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 an LPCVD system and furnace tube are shown in Fig. 2.

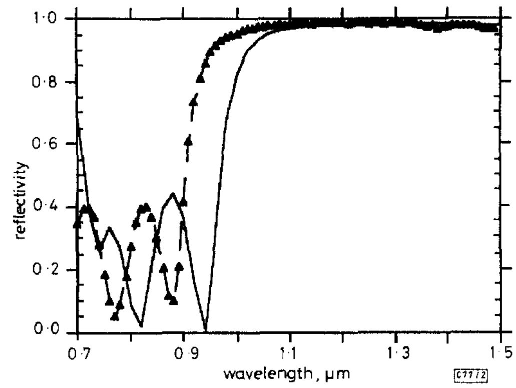

Fig. 2 *Measured reflectivity spectrum of three-stack mirror*

——— theory
—▲— measured

The thermal optical effect of a semiconductor can be described by a modified single-effective-oscillator (SEO) model proposed by Afromowitz [5]. The refractive index below the band edge is

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

where E_0 and E_d are the oscillator energy and strength from the SEO model and E_g is the energy bandgap. For c-Si, the E_g, E_0 and E_d are 1.11, 4.0, and 44.4eV, respectively [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, $\partial E_g/\partial T = -1.7 \times 10^{-4}$eV/°C was equated with the rate of change of the lowest indirect gap. For the SEO oscillator energy, $\partial E_0/\partial T = -4.7 \times 10^{-4}$eV/°C was assumed [7]. From this model, the change of refractive index at $\lambda = 6$μm, $T = 100$°C is calculated to be 0.3%.

The cavity length of the MELO film after the CMP process was measured to be 2.5μm and the mirrors are composed of three layers of dielectric films. The fabricated device was measured by connecting it to a PC current source as the heat source. The device n^+ area is 1.5 × 2.5mm². The wavelength was fixed at 1.3μm to measure the intensity of the reflective light and the results are shown in Fig. 3. The reflectivity of the resonant wavelength was shifted at the rate of 17.5nm/A.

In summary, the use of MELO to bury multilayer QW dielectric islands and CMP to form a controlled thickness of local silicon-on-insulator film, enabled us to implement a high finesse FP c-Si thermal sensor. 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. Three stacks (six layers) of quarter wavelength thick films provide a 98% reflectivity and hence the finesse of the FP cavity will be greatly increased. The thermal response of the structure was measured to be 17.5nm/A. This structure can be applied to thermal sensing and optoelectronic devices such as intensity modulators.

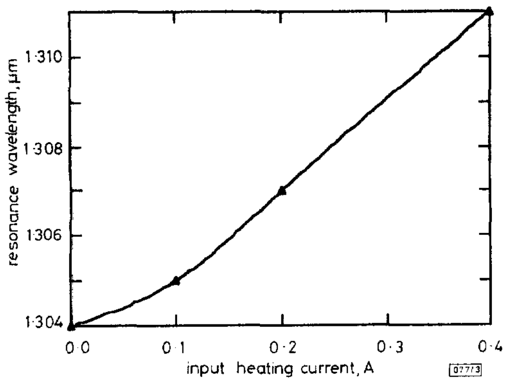

Fig. 3 *Resonance wavelength against heating current*

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Effect of atmospheric pressure MOCVD growth conditions on UV band-edge photoluminescence in GaN thin films

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Indexing terms: Photoluminescence, Chemical vapour deposition

Strong band-edge luminescence in GaN films grown by atmospheric pressure MOCVD is observed. The effect of the growth temperature and V/III ratio on the band-edge to deep level luminescence ratio (I_b/I_d) indicates that a large supply of active nitrogen is essential for obtaining excellent optical properties. GaN grown under optimised conditions exhibits an I_b/I_d ratio of 10.9 at 300K and 1300 at 22K.

Introduction: Recent progress in the heteroepitaxy of device quality wide bandgap nitride semiconductors and their successful implementation for light emitting diodes [1, 2] has revived intensive research activities into nitride materials. Currently, metal organic chemical vapour deposition (MOCVD) and molecular beam epitaxy are the most promising techniques for nitride growth. Prior work has demonstrated that initiation of the growth by deposition of a low growth temperature GaN or AlN nucleation layer is indispensable [3, 4]. However, few reports exist that correlate MOCVD growth conditions with luminescence properties of epitaxial GaN films. A broad luminescence band at ~2.2eV (550nm) dominating the room temperature photoluminescence is commonly reported for GaN films, and is caused by a vacancy complex assisted recombination [5].

We report the growth and optical properties of GaN grown by atmospheric pressure MOCVD. Alter optimisation of the nucleation layer growth for high crystallographic quality of GaN overlayers, we studied the effect of the V/III ratio and deposition temperature on the GaN luminescence. We found that both parameters greatly affect near band edge and deep level recombination.

Experimental conditions: The MOCVD GaN layers were grown on (0001) sapphire in a horizontal flow reactor operated at atmospheric pressure. The substrates were heated in the growth chamber at 1050°C in a hydrogen atmosphere. The GaN precursors used were trimethylgallium (TMGa) and ammonia (NH_3). The precursor injection was varied between 11.8 and 23.6 µmol/min for TMGa and 0.03 and 0.12mol/min for NH_3. Nitrogen was used as the carrier gas during the nucleation layer growth and hydrogen was used during the deposition of the GaN overlayer. The total gas flow into the reactor was 6.3l/min. The growth temperature was 600°C for the GaN nucleation layer and between 1000 and 1080°C for growth of the 1.2µm thick GaN layer. The layers were analysed by double crystal X-ray faction using the (0002) reflection of GaN. Room temperature and 22K photoluminescence (PL) measurements were performed using the 325nm line of an He-Cd laser. The pump level was 1 mW (excitation density = 220mW/cm²) and was varied between 0.01 and 2mW for power dependent measurements. Hall measurements were performed at 300K using the standard van der Pauw technique.

Results and discussion: The growth rate of GaN was found to be mass transport controlled in the temperature range 600 – 1080°C. No indication of prereaction in the upstream parts of our system was found. This accounts for the high growth rate per TMGa input partial pressure of 1.28 × 102nm/min/Pa, comparable to the standard GaAs process [6].

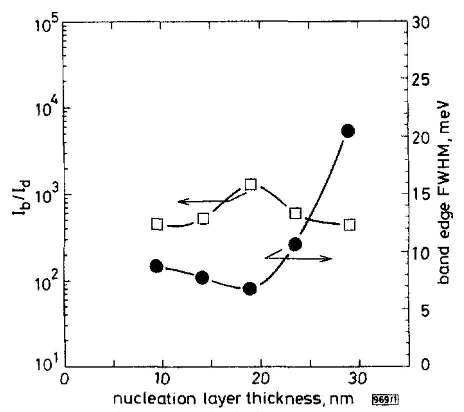

Fig. 1 *22K band-edge to deep level photoluminescence intensity ratio (I_b/I_d) and FWHM of (D°X) bound exciton peak as against nucleation layer thickness*

Photoluminescence excitation density p_{exc} = 220mW/cm², T_{gr} = 1050°C, V/III = 5145

Fig. 1 shows the effect of the nucleation layer thickness on the 22K PL properties of 1.2µm thick GaN layers. All layers were grown at 1050°C. The intensity ratios of the near band edge and