Simple technologies for fabrication of low-loss silica waveguides

SIMPLE TECHNOLOGIES FOR FABRICATION OF LOW-LOSS SILICA WAVEGUIDES

Q. Lai, J. S. Gu, M. K. Smit, J. Schmid and H. Melchior

Indexing terms: Optical waveguides, Glass, Integrated optics

A simple and reproducible technology is developed for the fabrication of low-loss silica waveguides on silicon substrates. The guiding layer is formed by changing the Si–O ratio composition of the SiO_2 layer. The waveguides can be made to have a good match to either optical fibres or guided-wave devices in III-V compound semiconductors.

Introduction: Silica-based optical waveguides have received much attention in recent years in guided-wave optical circuits owing to the advantages of low-cost, low propagation loss, hybrid optical packaging and good match to optical fibres [1–2]. A variety of circuits and components based on silica waveguides have been developed by AT&T Bell Laboratories and NTT Opto-Electronics Laboratories [3–7]. Most published work on silica waveguides refers to two technologies: the $Si/SiO_2/Si_3N_4/SiO_2$ and the Si/SiO_2/doped SiO_2/SiO_2 multilayer waveguides [1–2]. Whereas the silica waveguides with Si_3N_4 as guiding layer have large refractive index contrast (~ 0.5) and are suitable for matching to semiconductor lasers, waveguides with doped SiO_2 as guiding layer have small index contrast ($\sim 5 \times 10^{-3}$) and are suitable for matching to optical fibres.

We propose a PE-CVD-based technology which uses only N_2O and SiH_4 to form the SiO_2 guiding layer. The refractive index profile of the guiding layer is controlled by the SiH_4 flow rate during deposition. There are two advantages in using this technique. First, the use of poisonous gas such as PH_3 and GeH_4 for the doping of the SiO_2 is avoided in the entire process. The process is therefore very safe even with simple equipment.* Secondly, the refractive index contrast in using this technology can be varied from 5×10^{-3} to 0·5. The waveguide design is therefore very flexible to meeting different requirements for the refractive index and optical field profiles.

Waveguide fabrication and loss measurements: SiO_2 can be formed with plasma enhanced chemical vapour deposition (PECVD) using the following chemical reaction:

$$SiH_4 + 2N_2O \xrightarrow{\text{plasma}} SiO_2\downarrow + 2N_2\uparrow + 2H_2\uparrow$$

It is found that by controlling the flow ratio of SiH_4 and N_2O in the PECVD the structure of the deposited SiO_2 layer can be changed to SiO_x. This change will affect the refractive index of the deposited layer. The change of the refractive index is proportional to the SiH_4/N_2O flow ratio.

Fig. 1 shows the dependence of the refractive index of the deposited layers on the ratio SiH_4/N_2O as measured with an ellipsometer at a wavelength of 0·6328 μm. A refractive index of $n = 1.46$ is achieved for ratios $SiH_4/N_2O < 0.025$. From the Figure it is seen that the refractive index of the deposited layers varies linearly with the SiH_4 flow.

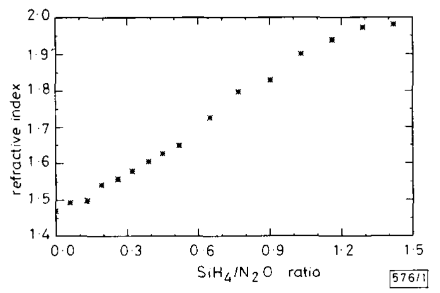

Fig. 1 *Refractive index deviation of deposited layer against SiH_4/N_2O flow ratio in PECVD*

Pressure = 360 mtorr, power = 25 W and substrate temperature = 300°C

Silica waveguides based on this technology were fabricated as follows. First, a 9 μm thick SiO_2 is obtained by thermal oxidation of the Si substrate. The guiding layer is then formed by depositing an SiO_x layer with PECVD. The core ribs are formed by wet etching the guiding layer with BHF at room temperature. Finally, the processed wafer is covered with a PECVD SiO_2 layer. The inset of Fig. 3 shows a cross-section of the waveguide structure.

The etch rate of the deposited SiO_x layer with BHF is dependent on its composition. Fig. 2 shows the dependence of the etching rate from the SiH_4/N_2O flow ratio. It is seen that oxygen content reduces the etch rate.

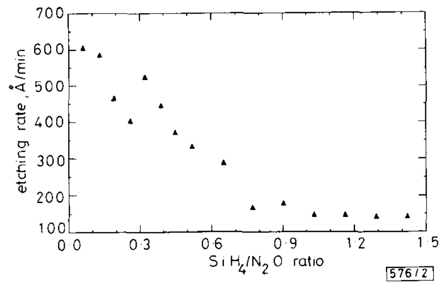

Fig. 2 *Etch rate of deposited layer in BFH at room temperature against SiH_4/N_2O flow ratio*

The propagation losses of the waveguides were measured by the cut-back method. The light beam from a 1·3 μm semiconductor laser was coupled into the front facets of the waveguides by means of a ×20/0·45 microscope objective. The losses of the waveguides were determined by measuring the light intensities at the output facets of the waveguides. The measured propagation losses of the waveguides are of the order of 0·2 dB/cm. Because optical absorption associated with OH^- in the deposited layers contributes to the loss, it can be reduced by annealing the waveguides at a high temperature. After annealing at a temperature of 1100°C for 30 min in an N_2 atmosphere, the propagation losses are reduced to <0·1 dB/cm. The propagation losses of the waveguides after 30 min annealing at different temperature are shown in Fig. 3.

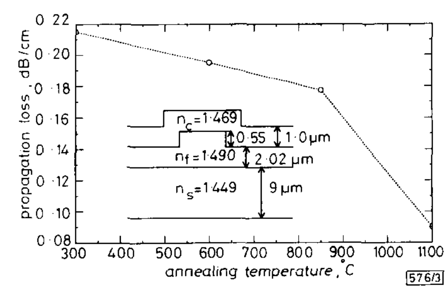

Fig. 3 *Propagation losses of waveguides against annealing temperature at wavelength of 1·3 μm, TE mode*

Conclusions: The technology for fabrication of silica waveguides presented in this Letter is simple and reproducible. Use of poisonous gases is avoided. Waveguides with propagation losses less than 0·1 dB/cm are obtained. By controlling the flow ratio of SiH_4/N_2O in the PECVD, the refractive index contrast can be varied between 5×10^{-3} and 0·5, so that the waveguides can be designed to match to either optical fibres or photonic devices based on III-V compound semiconductors.

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* *Editor's note:* This is not so. There are hazards in the use of silane, which is therefore heavily regulated.

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VERY HIGH SIDEMODE-SUPPRESSION-RATIO DISTRIBUTED-BRAGG-REFLECTOR LASERS GROWN BY CHEMICAL BEAM EPITAXY

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Indexing terms: Lasers, Semiconductor lasers

The fabrication and performance of InGaAs/InGaAsP multiquantum well distributed-Bragg-reflector lasers grown by chemical beam epitaxy are reported. Use of a long and weak grating, which was made on a thin and uniformly grown quaternary layer, has enabled the grating coupling constant κ to be well controlled. For most of the lasers the measured linewidths are below 10 MHz. A record high sidemode suppression ratio of 58·5 dB was obtained.

Tunable distributed-Bragg-reflector (DBR) lasers [1–3] are key elements for both a coherent and an incoherent wavelength-division-multiplexed (WDM) communication system. The laser can be used as a transmitter, a local oscillator [4], and even an active filter [5]. Recently, it has also been considered as an ideal laser source for amplitude-shift-keying (ASK) transmission [6] owing to its high sidemode suppression ratio (SMSR) compared with the unpredictable performance of that of a distributed-feedback (DFB) laser. To increase the threshold gain difference between the main mode and sidemodes of a DBR laser, we can reduce the Bragg reflection bandwidth of the laser by using a weak and long waveguide grating and increase the longitudinal mode spacing by reducing the equivalent cavity length. In either case, the key parameter that needs to be well controlled is the grating coupling constant κ which is also a very important parameter in making analogue DFB lasers for CATV applications.

Recently we have succeeded in preparing 1·3 and 1·55 μm wavelength multiquantum well (MQW) Fabry–Perot [7, 8] distributed-feedback (DFB) [9], and gain coupled DFB [10] lasers by chemical beam epitaxy (CBE) [11] and found very good crystal growth uniformity across 2 inch wafers. Taking the growth advantages of uniformity and well controlled thickness by CBE, we report the fabrication of DBR lasers with a record high SMSR of 58·5 dB.

The CBE system used is a modified Riber CBE 32 system. It can be used to grow very uniform thickness layers across the whole two inch wafer. The growth layer structure of the DBR laser is shown in Fig. 1. After the growth of a 6000 Å thick

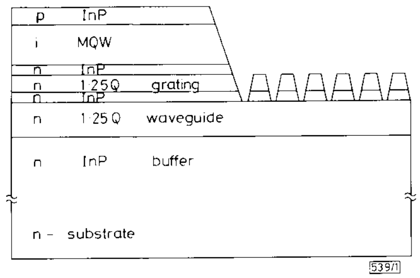

Fig. 1 *Growth layer structure of DBR laser*

InP buffer layer, a 1·25 μm wavelength InGaAsP (1·25 Q) waveguide layer with 2700 Å thickness is grown. Following growth of a thin InP etch stop layer, a 250 Å thick 1·25 Q grating layer and another InP etch stop layer are grown. The multiquantum well (MQW) gain medium is composed of six 50 Å thick InGaAs strained quantum wells and six 120 Å 1·25 Q barriers. Finally, a *p*-type InP protection layer is grown as the top layer.

The grown wafer is processed by a wet etching technique to remove the gain medium in the passive side. A holographic grating pattern is then generated and transferred to the grating layer through selective etching. Because the thickness of the grating layer is well controlled by the CBE growth time, the grating coupling constant κ is also well defined. Followed by stripe etching and semi-insulating and *p*-cap layer regrowths, the wafer is further processed for multi-electrode metallisation. The lasers are cleaved with a gain section ~225 μm long and a grating section ~360 μm long.

The fabricated lasers have thresholds of ~20 mA. The tuning range is 21 Å. The short tuning range may partly be caused by a reduction of current tuning effect caused by the 'counter wavelength shift' by heat generation in such a long grating section. However, each laser can be easily tuned to its Bragg band centre to obtain better mode behaviour. Fig. 2

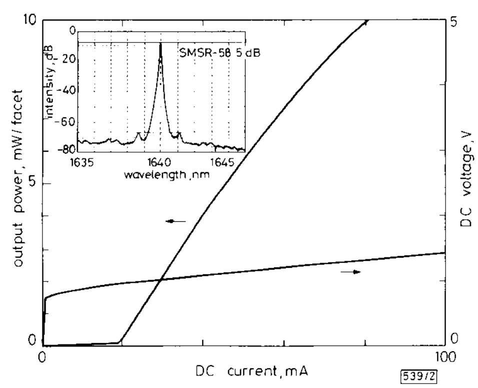

Fig. 2 *L–I and I–V curves of one of the DBR lasers*

Inset: output spectrum of laser at 87 mA bias

$l_{active} = 225\,\mu$m

$l_{grating} = 360\,\mu$m

$I_{th} = 19$ mA

shows the CW biased light-current (L–I) curve and current–voltage (I–V) curve of a laser and its SMSR at a bias of 87 mA. A record high SMSR of 58·5 dB has been achieved with these lasers. For most of the lasers, 10 mW output can be easily achieved and the measured output linewidths are below 10 MHz which is attributed to the effect of the narrow Bragg bandwidth produced by the long and weak waveguide grating. The theoretically calculated κ of the laser structure employing