Simple technologies for fabrication of low-loss silica waveguides

Citation for published version (APA):

Lai, Q., Gu, J. S., Smit, M. K., Schmid, J., & Melchior, H. (1992). Simple technologies for fabrication of low-loss silica waveguides. *Electronics Letters*, 28(11), 1000-1001.

Document status and date:

Published: 01/01/1992

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

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- The final published version features the final layout of the paper including the volume, issue and page numbers.

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SIMPLE TECHNOLOGIES FOR FABRICATION OF LOW-LOSS SILICA WAVEGUIDES

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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 SiO₂ 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/SiO₂/Si₃N₄/SiO₂ and the Si/SiO₂/doped SiO₂/SiO₂ multilayer waveguides [1-2]. Whereas the silica waveguides with Si₃N₄ as guiding layer have large refractive index contrast (~0.5) and are suitable for matching to semiconductor lasers, waveguides with doped SiO₂ as guiding layer have small index contrast (~5 × 10⁻³) and are suitable for matching to optical fibres.

We propose a PE-CVD-based technology which uses only N₂O and SiH₄ to form the SiO₂ guiding layer. The refractive index profile of the guiding layer is controlled by the SiH₄ flow rate during deposition. There are two advantages in using this technique. First, the use of poisonous gas such as PH₃ and GeH₄ for the doping of the SiO₂ 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: SiO₂ can be formed with plasma enhanced chemical vapour deposition (PECVD) using the following chemical reaction:

It is found that by controlling the flow ratio of SiH₄ and N₂O in the PECVD the structure of the deposited SiO₂ 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 SiH₄/N₂O flow ratio.

Fig. 1 shows the dependence of the refractive index of the deposited layers on the ratio SiH₄/N₂O as measured with an

Fig. 1 Refractive index deviation of deposited layer against SiH₄/N₂O flow ratio in PECVD

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

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

ellipsometer at a wavelength of 0.6328 μm. A refractive index of *n* = 1.46 is achieved for ratios SiH₄/N₂O < 0.025. From the Figure it is seen that the refractive index of the deposited layers varies linearly with the SiH₄ flow.

Silica waveguides based on this technology were fabricated as follows. First, a 9 μm thick SiO₂ 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 SiO₂ 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 SiH₄/N₂O flow ratio. It is seen that oxygen content reduces the etch rate.

Fig. 2 Etch rate of deposited layer in BHF at room temperature against SiH₄/N₂O 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 N₂ 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 SiH₄/N₂O 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.

31st March 1992

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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 multi-quantum 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 multi-quantum 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 multi-quantum 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 $\sim 225 \mu\text{m}$ long and a grating section $\sim 360 \mu\text{m}$ long.

The fabricated lasers have thresholds of $\sim 20 \text{ mA}$. 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

$L_{\text{active}} = 225 \mu\text{m}$
 $L_{\text{grating}} = 360 \mu\text{m}$
 $I_{\text{th}} = 19 \text{ mA}$

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