Simple technologies for fabrication of low-loss silica waveguides

Citation for published version (APA):

Document status and date:
Published: 01/01/1992

Publisher 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:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.
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,N$_x$/SiO$_2$ and the Si/SiO$_2$/doped SiO$_2$/SiO$_2$ multilayer waveguides [1-2]. Whereas the silica waveguides with Si$_3$N$_x$ as guiding layer have large refractive index contrast (≈5) and are suitable for matching to semiconductors, waveguides with doped SiO$_2$ as guiding layer have small index contrast (≈5 x 10$^{-3}$) and are suitable for matching to optical fibres.

We propose a PECVD-based technology which uses only N$_2$, SiH$_4$ and SiO$_2$ to form the SiO$_2$, guiding layer. The refractive index profile of the guiding layer is controlled by the SiH$_4$/N$_2$O 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. Second, the refractive index contrast in using this technology can be varied from 5 x 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:

$$\text{SiH}_4 + 2\text{N}_2\text{O} \xrightarrow{\text{PECVD}} \text{SiO}_2 + 2\text{N}_2 + 2\text{H}_2$$

It is found that by controlling the flow ratio of SiH$_4$ and N$_2$O in the PECVD the structure of the deposited SiO$_2$ layer can be changed to SiO$_2$. This change will affect the refractive index of the deposited layer. The change of the refractive index is proportional to the SiH$_4$/N$_2$O flow ratio.

Fig. 1 shows the dependence of the refractive index of the deposited layers on the ratio SiH$_4$/N$_2$O 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$_2$O < 0.025. From the Figure it is seen that the refractive index of the deposited layers varies linearly with the SiH$_4$ flow.

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$_2$ 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$_2$ layer with BHF is dependent on its composition. Fig. 2 shows the dependence of the etching rate from the SiH$_4$/N$_2$O flow ratio. It is seen that oxygen content reduces the etch rate.

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 using a x20/0.45 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$_2$O in the PECVD, the refractive index contrast can be varied between 5 x 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
Q. Lai, J. S. Gu, M. K. Smit, J. Schmid and H. Melchior (Institute of Quantum Electronics, Swiss Federal Institute of Technology Zurich, CH-8093 Zurich, Switzerland)
References


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


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 quantum layer, has enabled the grating coupling constant k 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 k which is also a very important parameter in making analog 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 InP buffer layer, a 1.25 μm wavelength InGaAsP (1.25 Q) grating section. However, each laser can be easily tuned to its Bragg band centre to obtain better mode behaviour. Fig. 2 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 k of the laser structure employing