Simple technologies for fabrication of low-loss silica waveguides

Citation for published version (APA):

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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Download date: 26. Jul. 2019
SIMPLE TECHNOLOGIES FOR FABRICATION OF LOW-LOSS SILICA WAVEGUIDES


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 x 10⁻⁴) and are suitable for matching to optical fibres.

We propose a PECVD-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 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: SiO₂ can be formed with plasma enhanced chemical vapour deposition (PECVD) using the following chemical reaction:

\[
\text{SiH}_4 + 2\text{N}_2\text{O} \rightarrow \text{SiO}_2 + 2\text{N}_2 + 2\text{H}_2
\]

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 SiO₂. 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 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 a SiO₂ 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 SiO₂ 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.

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 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 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.

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 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.

ELECTRONICS LETTERS 21st May 1992 Vol. 28 No. 11

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* Editor's note: There are hazards in the use of silane, which is therefore heavily regulated.

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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 6000Å thick InP buffer layer, a 1.25μm wavelength InGaAsP (1.25 Q) waveguide layer with 2700Å thickness is grown. Following the growth of a thin InP etch stop layer, a 250Å thick 1.25 Q barriers. Finally, a p-type InP protection layer is grown as a transmitter, a local oscillator. 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 laser structure employing high SMSR of 58.5dB has been achieved. The fabricated lasers have thresholds of 20mA. The multi quantum well (MQW) gain medium is composed of six 50Å thick InGaAs strained quantum wells and six 120Å 1.25 Q barriers. For most of the lasers, 10mW output can be obtained. The short tuning range may partly be caused by a reduction of current tuning effect caused by the coupled cavity. However, each laser can be easily tuned to its Bragg grating section. Inset: output spectrum of laser at 87 mA bias.