Ag^+-Na^+ exchanged channel waveguides in germanate glass

T. Luo, S. Jiang, G. Nunzi Conti, S. Honkanen,
S.B. Mendes and N. Peyghambarian

Singlemode and multimode Ag^+-Na^+ exchanged channel waveguides have been formed in germanate glass. The mode profiles and propagation losses of these channel waveguides at 1.55μm have been measured. The measured propagation loss is < 2dB/cm in channel waveguides.

Integrated waveguide lasers offer several advantages over others in terms of size, weight, on-chip integration and large geometrical tailoring possibilities. In particular, for direct evanescent-wave spectroscopic devices, ridge waveguides or surface waveguides exhibit a large interface between the waveguide and the chemically sensitive materials [1]. Integrated waveguide lasers at wavelengths of 2μm or longer are very desirable for a number of applications, due to the fact that the absorption bands of many gases and liquids are much stronger at 2μm than those at shorter wavelengths [2].

Germanate glass is one of the most promising glass hosts for integrated 2μm waveguide lasers due to its lower phonon energy and higher transmission near 2μm compared to fused silica, silicate glasses, and phosphate glasses. These are critical features in the efficient realisation of a 2.1μm holmium laser from the $^5I_7$-$^5I_8$ transition [3]. Germanate glasses also offer excellent chemical durability and physical strength. In addition, germanate glass is highly photosensitive, so Bragg gratings could be potentially directly written into waveguides [4].

In this Letter, we report the first demonstration of channel waveguides in germanate glass by the molten salt ion-exchange technique. The ion-exchange process has been characterised by measuring the refractive indices of slab waveguides. The mode profiles and propagation losses of the channel waveguides have been measured.

A germanate glass composition containing $65.5GeO_2$, $12Al_2O_3$, 4.5BaO $18Na_2O$ (mol %) was designed and fabricated. High purity chemicals GeO_2, Al_2O_3, Na_2CO_3 and $BaCO_3$ were used for glass fabrication. Chemicals were weighed and mixed before being loaded into a platinum crucible. The mixtures were melted at 1450°C in a nitrogen flowing atmosphere and then the glass melt was cast into a stainless steel mould. After annealing at 535°C, the glasses were optically polished to 2.5cm × 2.5cm × 2mm blocks for waveguide fabrication. The glass transition temperature was measured to be 530°C using a modulated differential scanner calorimeter. The refractive index of this germanate glass at 632.8, 830, 1300 and 1550nm is 1.6170, 1.6088, 1.6011 and 1.5985, respectively.

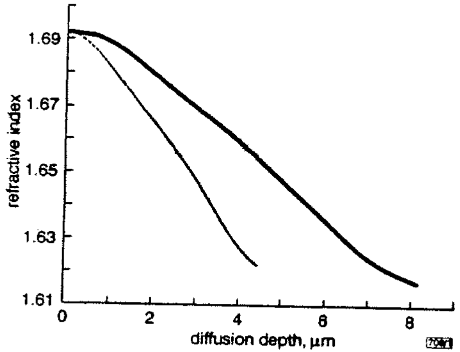

Fig. 1 *Index profiles of ion-exchanged planar waveguides*

——— 290°C, 100min
- - - - 290°C, 35min

Planar waveguides were fabricated by immersing the samples into a molten salt bath containing $2AgNO_3$, $49NaNO_3$, $49KNO_3$ (wt%). This mixture allows ion exchange at temperatures as low as 230°C. A variety of ion-exchange temperatures ranging from 230 to 330°C and ion-exchange times ranging from a few minutes to several hours were used to characterise the diffusion process. The effective mode indices at 632.8, 830, 1300 and 1550nm were measured using the prism-coupler technique. The index profile was calculated from the measured mode indices using the inverse WKB method [5].

Fig. 1 illustrates the index profiles of ion-exchanged samples at 290°C. The effective diffusion depth was determined from the index profile. The effective diffusion constant D_e was calculated using eqn. 1 [6]:

$$d = \sqrt{D_e t} \qquad (1)$$

where d is the effective diffusion depth and t is the ion-exchange time. The diffusion constants were calculated to be 1.82, 4.70, 7.27, 16.22 and 26.33μm²/h at diffusion temperatures 230, 250, 270, 290 and 310°C, respectively. The relationship between $\ln D_e$ and $1/T$ agrees very well with the Arrhenius equation [7].

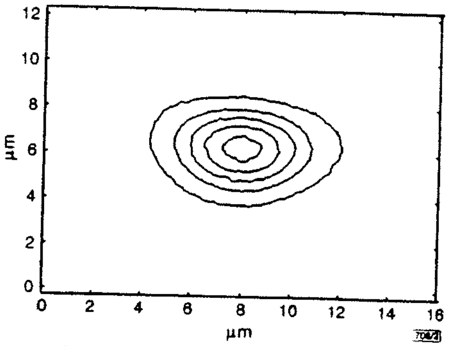

Fig. 2 *Intensity distribution of 4μm width channel singlemode waveguide*

Contour lines signify 10, 30, 50, 70 and 90% of maximum intensity

Based on the experimental results of slab waveguides, we have designed and fabricated singlemode and multimode channel waveguides. A 100nm thick metallic aluminium film was coated on fine polished germanate glass samples by e-beam evaporation. Photoresist was spin-coated on the sample and was pre-baked. After UV exposure in a mask aligner, the resist was developed and baked. 2–10μm channels were then opened by immersing the sample in an etching solution ($75gNaCO_3$, $35gNa_3PO_4.12H_2O$, $16gK_3Fe(CN)_6$, 0.5 litre H_2O). Finally, the photoresist left on the top of aluminium film was removed by an organic solvent. Channel waveguides were fabricated by immersing the glass sample in dilute silver nitrate salt ($AgNO_3$:$NaNO_3$:KNO_3 = 2:49:49) at 290°C for 35min. The aluminium mask was removed by the same etching solution used to make the channel openings. Light from a 1.55μm laser diode was directly butt-coupled into the waveguide by using a singlemode optical fibre. The transmitted near field pattern was recorded using an infrared camera. The image was then processed on a computer. Waveguides with 4μm or smaller channel opening are singlemoded at 1.55μm and waveguides with 4μm or greater channel opening are multimoded at 1.55μm. Fig. 2 shows the intensity distribution of a 4μm-width channel singlemode waveguide. Propagation losses at 1.55μm in these channel waveguides were measured using a technique described in [8]. The measured loss is < 2dB/cm. The loss is mainly caused by the relatively poor surface quality, which can be improved by optimising the process parameters.

In conclusion, singlemode and multimode channel waveguides in germanate glass have been demonstrated. The propagation loss of the channel waveguides at 1.55μm is < 2dB/cm.

Acknowledgment: We acknowledge support from BMDO through the Center for Optoelectronic Devices, Interconnects, and Packaging (COEDIP).

16 September 1998
Electronics Letters Online No: 19981513

T. Luo, S. Jiang, G. Nunzi Conti, S. Honkanen, S.B. Mendes and N. Peyghambarian (*Optical Sciences Center, University of Arizona, Tucson, AZ 85721, USA*)

T. Luo and S. Honkanen: Also with NP Photonic Technologies, LLC, Tucson, AZ 85747, USA

G. Nunzi Conti: Also with DEIS, Università di Bologna, 40136 Bologna, Italy

References

1 BOISDE, G., and HARMER, A.: 'Chemical and biochemical sensing with optical fibers and waveguides' (Artech House, Inc., 1996)

2 RAMEIX, A., BOREL, C., CHAMBAZ, B., FERRAND, B., SHEPHERD, D., WARBURTON, T., HANNA, D., and TROPPER, A.: 'An efficient, diode-pumped, 2μm Tm:YAG waveguide laser', *Opt. Commun.*, 1997, **142**, (4–6), pp. 239–243

3 JIANG, SHIBIN, MYERS, J., BELFORD, R., RHONEHOUSE, D., MYERS, M., and HAMLIN, S.: 'Flashlamp pumped lasing of Ho:germanate glass at room temperature'. OSA Proc. Advanced Solid-State Lasers, 1994, Vol. 20, pp. 116–119

4 HILL, K.O., FUJII, Y., JOHNSON, D.C., and KAWASAKI, B.S.: 'Photosensitivity in optical fiber waveguide: applications to reflection filter fabrication', *Appl. Phys. Lett.*, 1978, **32**, pp. 647–649

5 CHIANG, K.S.: 'Construction of refractive-index profiles of planar dielectric waveguides from the distribution of effective indexes', *J. Lightwave Technol.*, 1985, **LT-3**, (2), pp. 385–391

6 STEWART, G., MILLAR, C.A., LAYBOURN, P.J.R., WILKINSON, C.D.W., and DELARUE, R.M.: 'Planar optical waveguides formed by silver-ion migration in glass', *IEEE J. Quantum Electron.*, 1977, **QE-13**, (4), pp. 192–200

7 DOREMUS, R.H.: 'Ion exchange in glass' *in* MARINSKY, J.A. (Ed.): 'Ion exchange-A series of advances, Vol. 2' (Marcel Dekker, New York, 1969), Chap. 1

8 DERI, R.J., YASUOKA, N., MAKIUCHI, M., KURAMATA, A., and WADA, O.: 'Efficient fiber coupling to low-loss diluted multiple quantum well optical waveguides', *Appl. Phys. Lett.*, 1989, **55**, (15), pp. 1495–1497

Wavelength tunable optical add and drop multiplexer utilising coupled semiconductor waveguides and a striped thin-film heater

M. Horita, S. Tanaka and Y. Matsushima

A wavelength tunable semiconductor optical ADM is implemented which utilises coupled semiconductor waveguides and a striped thin-film heater. Stable optical characteristics over an 11nm tuning range, such as insertion loss variation, crosstalk and 3dB optical bandwidth are demonstrated. Through 5Gbit/s demultiplexing experiments it was confirmed that there were no inherent transmission problems due to the device even when the centre wavelength was tuned. Also the possibility of penalty-free tunable demultiplexing was demonstrated for the first time.

Introduction: Optical add and drop multiplexers (OADMs) [1, 2], having simultaneous functions of wavelength selection and routing of the selected signal, play an important role in wavelength division multiplexing (WDM) networks. Tunability of the selected wavelength is an important requirement for future OADMs in order to flexibly deal with changes in circuit demands and transmission line problems. We have proposed, and experimentally and theoretically studied, a vertically and contra-directionally coupled semiconductor waveguide type OADM (VECCS-OADM) from the viewpoints of narrowband wavelength selectivity, tunability and compactness [3 – 5]. An electrically tunable type VECCS-OADM utilising a striped thin-film heater was demonstrated, and a wide tuning range of > 10nm was confirmed [4]. Although stable optical characteristics during tuning are expected by this tuning scheme, a fairly large sidemode was observed due to a uniform grating. As the sidemode suppression ratio (SMSR) was improved dramatically by introducing a window function to the grating width [5], accurate measurement of the transmitted spectrum became possible. In this Letter, a detailed evaluation of the optical characteristics during the tuning operation of the VECCS-OADM is reported for the first time, and stable tuning operation was experimentally confirmed. A bit error rate (BER) of 5 Gbit/s signal was measured to investigate the influence of the VECCS-OADM on transmission performance, and penalty-free demultiplexing was successfully demonstrated.

Device structure and operational principle: A schematic view of the tunable VECCS-OADM with a trimmed grating and a striped thin-film heater in the InGaAsP/InP material system is depicted in Fig. 1. In a filter region, a central part of this device, a lower InGaAsP rib waveguide and an upper InGaAsP ridge waveguide, were vertically stacked, being separated by an InP separation layer. The grating was formed on the lower waveguide only in the filter region. The width of the grating was trimmed in order to improve the SMSR [5]. Both ends of the waveguides of the filter region were connected by bending waveguides to separate adjacent ports spatially. A striped thin-film heater was placed on the ridge waveguide in the filter region.

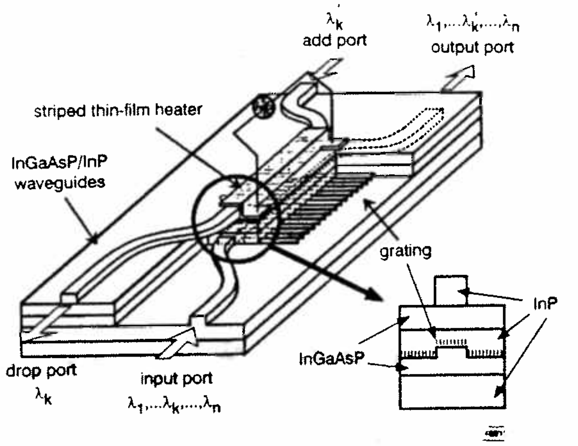

Fig. 1 *Schematic structure of VECCS-OADM with trimmed grating and striped thin-film heater*

For the drop operation, only light with a Bragg wavelength λ_k in the incident light from an input port is diffracted by the grating and selected from a drop port, and light of other wavelengths passes through to an output port. For the add operation, light with wavelength λ'_k, which is identical to λ_k, is inserted from an add port and diffracted to the output port to be mixed with light at other wavelengths. The Bragg wavelength can be tuned by a thermal effect produced in the striped thin-film heater.

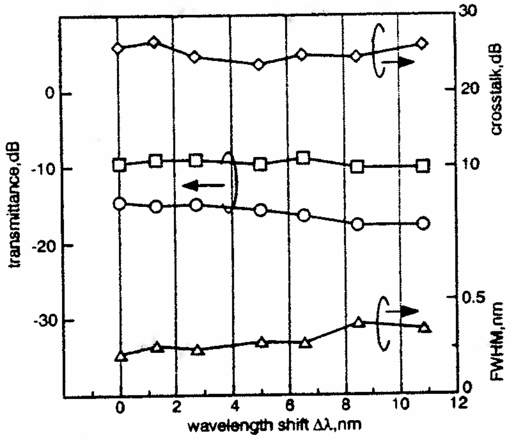

Fig. 2 *Variation of major optical characteristics of VECCS-OADM during tuning*

◇ crosstalk of dropped light
□ insertion loss between input port and output port
○ insertion loss between input port and drop port
△ FWHM of dropped light

Experimental results: Devices were fabricated by two step metal organic vapour phase epitaxy. The thickness of the lower and upper waveguides and the separation layer were 0.7, 0.5 and 0.4μm, respectively. The width and bandgap wavelength of both waveguides were 4 and 1.24μm, respectively. The period, depth and coupling length of the grating were 236nm, 500Å and 3mm, respectively. The total device length was 5mm, and the distance between two ports at the facets was 150μm. Both facets were AR-coated. A 0.25μm thick Cr/Au film was evaporated and striped by