OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 8, No. 7-8, July – August 2014, p. 668 - 671

Manufacturing of selectively buried channel waveguide on glass substrate

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A process for selectively buried glass-based planar waveguide chip manufacturing is presented, which involves surface channel waveguide forming, and subsequent field-assisted ion-diffusion with aids of wedge-shaped masking film. Cross-section at different portion of channel waveguide is observed with optical microscope, and waveguide transition loss is characterized. Results show that smooth transition has been realized using wedge-shaped masking film with slope of 1/100, with transition loss of 2.8dB could be achieved.

(Received August 1, 2011; accepted July 10, 2014)

Keywords: Glass, Ion exchange, Waveguide

1. Introduction

Ion-exchange technology on glass substrate has long been applied in various fields, for example, tinting of glass for decoration, chemical strengthening of glass for engineering material, and various ion-exchanged gradient index (GRIN) optical elements. Application of ion-exchange technology for waveguide device fabrication begins in 1972, when T. Izawa and H. Nakagome demonstrated the first ion-exchanged waveguide of Tl^+ ions in silicate glass containing oxides of sodium and potassium [1]. From then on, glass-based integrated waveguide devices have been drawing intensive attention of many research groups over the world [2-9], due to its compatibility with optical fibers, low propagation loss, cost-effectiveness, and most distinguishingly, flexibility. Up to present days, glass-based integrated optical splitters have been batch produced for application in optical communication network. Besides this, glass-based waveguide technology is expected to be an enabling integrated optic device fabrication technology, for application in other realms, such as optical sensing and optical interconnection.

Glass-based waveguide falls into two categories, surface waveguide and buried waveguide, depending on location of waveguide core with respect to the glass substrate surface. Surface waveguide, in which waveguide core locate at glass substrate surface, enables effective interaction between guided wave and upcladding layer, is regularly used for optical chemical and biochemical sensing, and functional waveguide construction; Buried waveguide, in which waveguide core locate beneath glass substrate surface, possesses low propagation loss, low coupling loss with fibers, and immunity to environment disturbance, and hence suitable for coupling with fiber and conducting light. Selectively buried waveguide is a novel optical structure that integrates both surface and buried waveguide onto a single substrate, taking advantages of these two kinds of waveguides: surface waveguide facilitate modulation of guided wave with upcladding layer, while buried waveguide shows low coupling and propagation loss. Therefore, selectively buried waveguide manufacturing technology becomes a promising technology, for both optical sensor chip and optical functionality integration.

In recent years, selective buried glass-based waveguide have been proposed and experimentally attempted by several research teams [2-7]. But up to present days, Information on manufacturing process and device characterization results is not adequate. In our laboratory, studies on glass based selectively buried channel waveguide devices manufacturing technology have recently been conducted, aiming at realization of chemical sensing using glass based waveguide chip. In this letter, we demonstrate the manufacturing process of selectively buried channel waveguide.

2. Experiments

Silicate glass of system SiO_2-B_2O_3-Al_2O_3-R'O-R_2O (R'=Ca, Mg; R=Na, K) is specifically designed and melted for ion-exchanged integrated optical waveguide chip. Glass wafers are disk-shaped substrates of dimension Φ 75mm×1.2mm, with double-side polished.

Fig. 1 shows selectively buried channel waveguide manufacturing by a two-step process: surface waveguide formation, and subsequent field-assisted ion-diffusion with aids of wedge-shaped masking film. In the fist step, surfaced channel waveguides are formed by thermal ion-exchange at elevated temperature in melted salt mixture. The salts mixture is composed of $AgNO_3/NaNO_3/Ca(NO_3)_2$, $n[AgNO_3]:n([NaNO_3]:n[Ca(NO_3)_2]$ being 3:500:500. The waveguide structure is delineated by photolithgraphically defined "windows" in the vacuum evaporated aluminum masking film. After ion-exchange step, aluminum masking film on glass substrate is chemically etched-off.

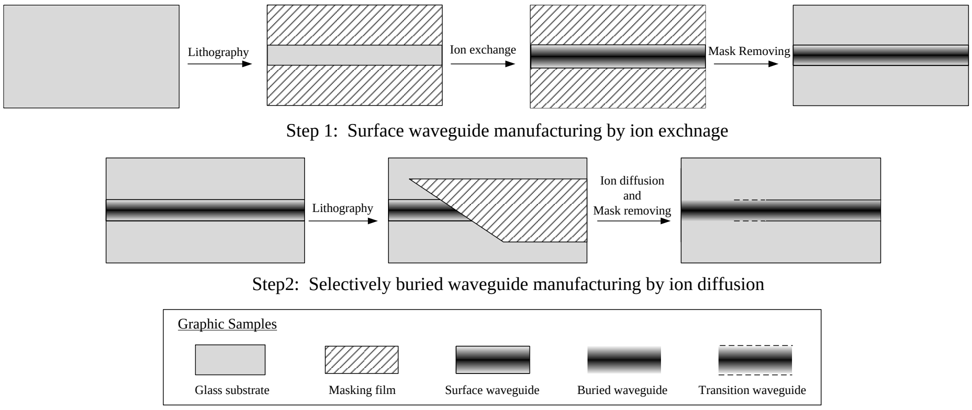

Fig. 1. Selectively buried channel waveguide manufacturing process.

In the second step, Wedge-shaped mask aluminum masking film, is fabricated, slope of inclined edge being 1/100, with respect of the waveguide formed in the fist step. Field-assisted ion-diffusion is performed at 220℃, with assisted voltage 300V applied. In field-assisted ion-diffusion process, waveguide covered by the masking film remain in surface after the field-assisted ion-diffusion while waveguide exposed to melted salt are buried into beneath the glass substrate surface, and waveguide partially covered by masking film provide smooth transition between surface waveguide and buried waveguide.

The experimental instruments for field-assisted ion-diffusion are schematically depicted in Fig. 2. The glass substrate is glued to a quartz barrel using temperature resistant silicone sealant to hold cathode melted salt mixture, a quartz container is used to hold anode melted salt mixture, both cathode and anode melted salt mixture are $NaNO_3/Ca(NO_3)_2$, with $n([NaNO_3]:n[Ca(NO_3)_2]= 1:1$, two platinum disk-shaped electrodes are immersed in the melted salt mixture and connected respectively to the cathode and anode of a DC power supply.

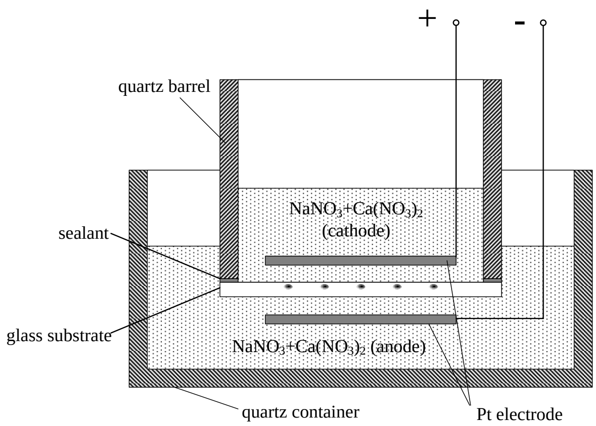

Fig. 2. Configuration of field-assisted ion-diffusion.

After ion-diffusion and dicing, end surfaces of glass chip is lapped and polished for observation and testing. Optical microscope is used for morphologic observation of channel waveguide diffusion zone at different portion, i.e. surface waveguide portion, buried waveguide portion, and transition waveguide portion. Standard integrated optical testing system is used to characterize loss properties of glass waveguide chip.

3. Results and discussions

Channel waveguides of width 10 μm have been manufactured and tested. Cross-section and top view images of channel waveguide at different portion is shown in Fig. 3, with A at the buried portion, B at the transition portion, and C at the surface portion. From these pictures we know that smooth transition between buried and surface waveguide is achieved, which enables low transition loss between buried portion and surface portion in channel waveguide. From which we know that transition with slope of 1/100 produce smooth transition between buried and surface waveguide.

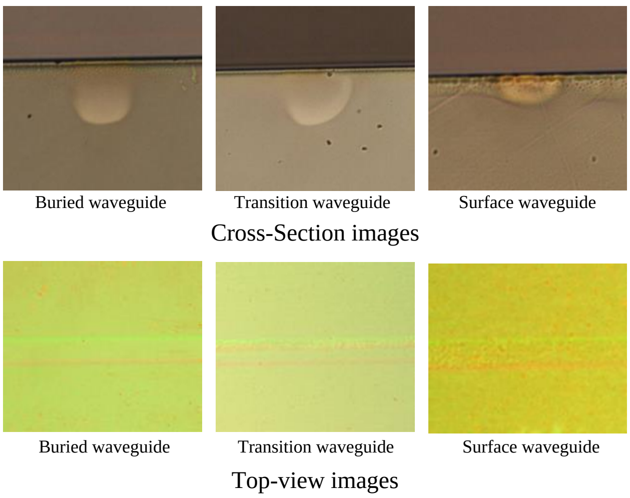

Fig. 3. Cross-section and top view of selectively buried channel waveguide at different portion.

To characterize optical loss of selectively buried waveguide, buried and surface waveguide, as shown in Fig. 4, are fabricated on the same glass chip. Insertion loss of buried and surface waveguide of different length is given in Fig. 5. For buried and surface channel waveguide as shown in Fig. 4, Insertion loss L_{insert} could be given as:

$$L_{insert} = 2L_{Coup} + \alpha L$$

Where L_{Coup} is coupling loss of waveguide with optical fiber, α is propagation loss of channel waveguide in dB/cm; L is waveguide length. Using linear fitting method, coupling and propagation loss of surface and channel waveguide could be acquired, as given in Table 1.

Table 1. Loss Characteristics of surface and buried waveguide.

	Coupling loss (dB)	Propagation loss (dB/cm)
Buried waveguide	0.40	0.42
Surface waveguide	3.08	1.82

For selectively buried waveguide of structure shown in Fig. 4(A) could be given as

$$L_{insert} = 2L_{Coup,B} + \alpha_B L_B + \alpha_S L_S + 2L_{Trans}$$

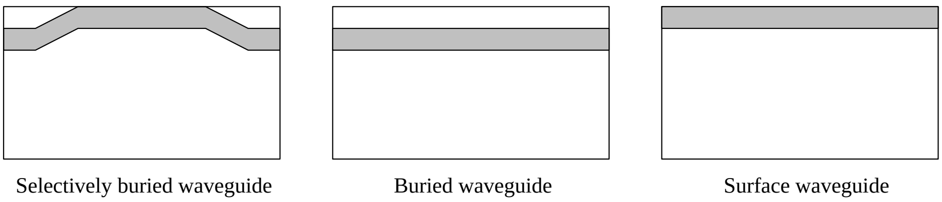

Fig. 4. Three types of waveguides fabricated on glass chip.

Where subscript B and S represent buried and surface waveguide, and L_{Trans} is transition loss. Typical value of selectively buried waveguide is measured to be 10.5dB. Given surface waveguide, surface waveguide, transition waveguide portion are 2.2 cm, 1.2 cm and 0.2 cm, respectively, L_{Trans} is estimated to be 2.8dB.

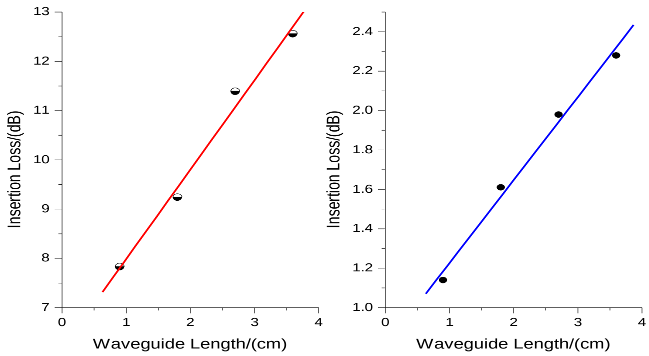

Fig. 5. Dependence of insertion loss of surface waveguide (left) and buried waveguide (right) on waveguide length.

4. Conclusions

In summary, using ion exchange and subsequently field-assisted ion-diffusion process, with aids of wedge-shaped masking film, selectively buried planar waveguide in glass substrate is manufactured. Analysis results show that using transition slope of 1/100, transition loss of 2.8dB between buried and surface waveguide could be realized.

Acknowledgement

The Project Supported by Zhejiang Provincial Natural Science Foundation of China Y1100665, in part by UNESCO/KeizoObuchi Research Fellowship Program, in part by National Natural Science Foundation of China under Grant 60977043, and in part by the Major State Basic Research Development Program under Grant 2007CB613405, in part by “Zijin Project” of Zhejiang University, in part by “Interdisciplinary Research Project” of Zhejiang University.

References

[1] T. Izawa, H Nakagome, Appl. Phys. Lett., **21**, 584 (1972).
[2] O. Bertoldi, J.-E. Broquin, G. Vitrant, V. Collomb, M. Trouillon, V. Minier, Proc. SPIE **5451**, 182 (2004).
[3] Jérôme Grelin, Davide Bucci, Elise Ghibaudo, Jean-Emmanuel Broquin, Proc. SPIE **6475**, 64750A (2007).
[4] Jean-Emmanuel Broquin, Proc. SPIE **6475**, 647507 (2007).
[5] J. Frantz, J. Carriere, Y. Enami, R. Kostuk, S. Honkanen, D. Mathine, N. Peyghambarian, OFC, 318-319 (2003).
[6] Raymond K. Kostuk, Jesse Frank, James Carriere, S. Scott Saavedra, Proc. IEEE 0-7803-7888-1 (2003).
[7] Brian R. West, Pratheepan Madasamy, N. Peyghambarian, S. Honkanen, Journal of Non-Crystalline Solids, **347**, 18 (2004).
[8] Yunqiang Ti, Feng Qiu, Yinghui Cao, Linghua Jia, Weiping Qin, Jie Zheng, Gerald Farrell, Journal of Materials Science, **43**, 7073 (2008).
[9] Hao Yin-lei, Zheng Wei-wei, Jiang Shu-hang, Gu Jin-hui, Sun Yi-ling, Yang Jian-yi, Li Xi-hua, Zhou Qiang, Jiang Xiao-qing, Wang Ming-hua, Journal of Inorganic Materials, **24**, 1401 (2009).

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