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Acousto-Optic Light Deflection in an Al_2O_3 Optical Waveguide Structure

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Abstract *The total deflection of an optical guided wave by a surface acoustic wave (SAW) in a silicon-based $SiO_2/Al_2O_3/SiO_2$ optical waveguide structure is reported. The SAW is generated by an interdigital transducer with piezoelectric ZnO deposited on top of the optical waveguide structure.*

Introduction

Acousto-optic deflection by surface acoustic waves (SAWs) is a very well-known item in integrated optics. Since the first demonstration of acousto-optic deflection in a thin film given by Kuhn et al. [1] the acousto-optic effect has been reported in many other optical waveguide structures [2–4]. To our knowledge, however, no results of the acousto-optic effect in a silicon-based Al_2O_3 waveguide have been reported so far.

Al_2O_3 is an attractive material for fabrication of silicon-based optical circuits [5]. Its low attenuation (~0.5 dB/cm at 780 nm) is favorable, and its refractive index ($n = 1.69$) is low enough to apply glass prisms for prism-coupling. On the other hand, the refractive index is high enough to provide good optical contrast with SiO_2 or glass as cladding layer. Such large refractive-index contrasts are, for example, necessary to make components like low-loss bends [6,7].

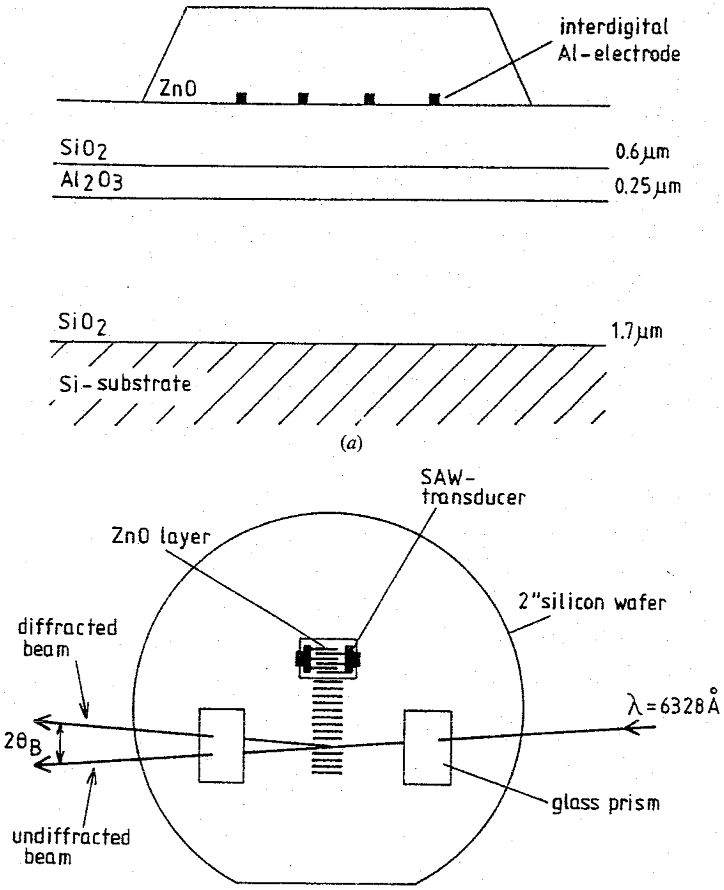
In this paper, we report SAW-generation in an $SiO_2/Al_2O_3/SiO_2$ slab waveguide by a piezoelectric overlay film of ZnO in order to investigate the acousto-optic properties of that structure. This is done by measuring the Bragg deflection efficiency of the optical guided waves of the waveguide.

In a Bragg deflector, light at Bragg incidence will be diffracted away by twice the Bragg angle given by $\Theta_B = \arcsin(\lambda/2N_{eff}\Lambda)$, where Θ_B is the Bragg angle, N_{eff} the effective refractive index of the waveguide structure, and λ and Λ are the optical and acoustic wavelength, respectively [1]. Operation in the Bragg regime is assured when the diffraction parameter $Q = L\lambda/N_{eff}\Lambda^2$ is much bigger than one, where L is the aperture of the acoustic wave. Theoretically, the fraction of light which is diffracted by a Bragg deflector will have a $\sin^2 x$-shape dependence on the square root of the input power.

Device Fabrication

A planar optical-waveguide structure is obtained by RF sputtering of a 0.25-μm thick Al_2O_3 film ($n = 1.69$) and a 0.6-μm thick SiO_2 film ($n = 1.46$) on top of a thermally oxidized silicon(111) substrate (oxide thickness 1.7 μm).

On top of this waveguide structure an aluminum transducer electrode consisting of 100 fingerpairs, having a period of 16 μm and an acoustic aperture of 3 mm, is fabricated by photolithographic methods. The transducer is positioned in such a way that the SAW will travel along the Si(111)[112]-orientation. Then a C-axis–oriented ZnO overlay film is deposited by DS-C–gun magnetron sputtering through a mechanical shadow mask. The mask is used to ensure that the ZnO film only covers the transducer electrode (Figure 1). This is done because the high refractive index of ZnO ($n \simeq 2.0$) will cause stripping



(*a*)

(*b*)

Figure 1. Schematic configuration of the acousto-optic deflector. (*a*) Cross section and (*b*) top view.

of the light propagating in the waveguide structure if ZnO is used as a top layer. The thickness of the ZnO layer is about half an acoustic wavelength in order to obtain optimal piezoelectric coupling [8].

The transducer is driven by an RF-signal generator with amplifier and operated at a center frequency of 170.6 MHz. No matching network is used, since only a fraction of the input power (~2%) is reflected back from the transducer. The bandwidth of the device has been measured to be 1.7 MHz.

Experimental Setup

A parallel He-Ne laser beam ($\lambda = 633$ nm, $w = 0.3$ mm) is coupled in the waveguide by prism-coupling. Prisms are made of SF-10 glass ($n = 1.72$). By varying the angle of incidence of the optical guided wave with respect to the acoustic wavefronts, the most suitable angle of incidence (i.e., the Bragg angle) for obtaining the maximum intensity of the diffracted light of the first order is determined. At Bragg incidence some higher orders are also detected, which indicates that the diffraction also involves some Raman-Nath diffraction.

The diffracted and undiffracted lightbeams were coupled out and detected by a CCD camera. With an oscilloscope one video line of the camera, corresponding with the maxima of the spots, was displayed for measurements.

Results

The maximum intensity of the diffracted first order was obtained at a Bragg angle of 0.66° (in air). Using the previously mentioned formula for the Bragg angle, the acoustic wavelength in the optical waveguide structure is calculated to be $\Lambda = 27.5$ μm, corresponding with an acoustic velocity of 4691.5 m/s. This is close to the SAW velocity of 4740 m/s in pure Si(111) along the [112] orientation, calculated with a computer program solving the wave-equation for a SAW. This means that the penetration depth of the SAW is much bigger than the thickness of the optical waveguide, so the overlap between the optical and acoustic wave will be small.

With the calculated value of Λ it follows that the diffraction parameter $Q = 1.6$, which implies that the diffraction is reasonable Bragg diffraction. This is in agreement with our observation that only a small percentage of the optical guided wave was diffracted into higher orders. The diffraction efficiencies of both the TE_0 and the TM_0 modes of the waveguide structure are measured. At a continuous electrical input power of 5.0 W, a diffraction efficiency of 66.4% of the TM_0 mode is obtained. At the same power a diffraction efficiency of only 9.1% for the TE_0 mode was found. Since a further increase of the continuous electrical power could damage the device, the input power was pulsed with a duty cycle of 5%. It appeared to be possible to completely extinguish the zero diffraction order of the TM_0 mode at a peak power of about 15 W, almost 98% of the light being diffracted into the first order. At the same peak power a deflection of 25% for the TE_0 mode was obtained. The difference in diffraction efficiency between the two modes implies the coupling for the TM_0 mode with the acoustic wave to be a factor of 3 larger than for the TE_0 mode. The reason for this difference is a difference in the acousto-optic-induced change in refractive index for the two modes given by $\Delta n_m = -(n^3/2)P_{mn}S_n$, with n being the refractive index of the medium, P_{mn} the photoelastic tensor, and S_n the strain caused by the acoustic field. Since the strain components S_n are the same for both optical modes the difference in diffraction efficiency can be explained

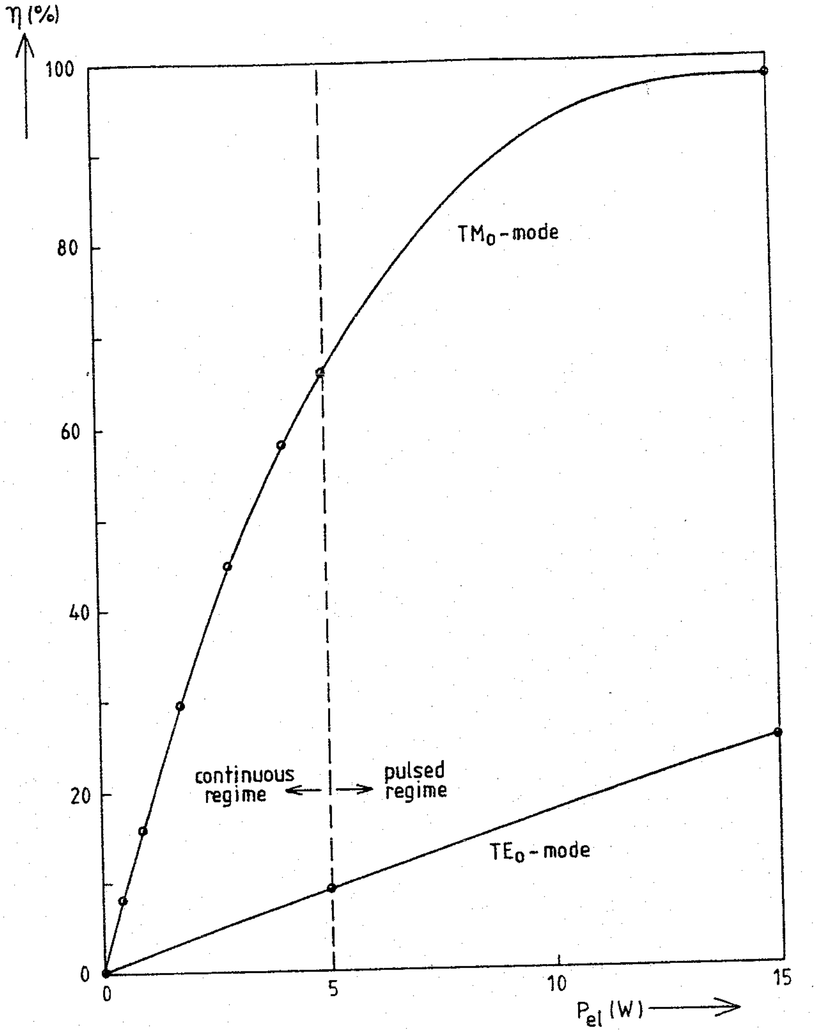


Figure 2. Dependence of the diffraction efficiency η of the TE_o and the TM_o mode on electrical input power P_{el}. The dots represent the experimental results.

by different photoelastic tensor components of the waveguide structure which contribute to the index change of the two different modes.

In Figure 2 a plot is shown of the diffracted light intensity versus the electrical input power of both optical modes. Also plotted are the best fits of the experimental values with theoretical predictions of a $\sin^2 x$-shape of the diffraction efficiency at Bragg incidence [3,9].

Conclusion

The acousto-optic deflection of light in a $SiO_2/Al_2O_3/SiO_2$ waveguide structure is demonstrated. A piezoelectric ZnO film is used to generate a surface acoustic wave with a

wavelength of 27.5 μm. Total deflection of the TM_0 mode at an electrical peak power o
15 W is obtained. At the same conditions 25% of the TE_0 mode is diffracted.

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References

1. L. Kuhn, M. L. Dakss, P. F. Heidrich, and B. A. Scott, ''Deflection of an Optical Guided Wave by a Surface Acoustic Wave,'' *Appl. Phys. Lett.* **17,** 265–267, 1970.
2. R. V. Schmidt, I. P. Kaminow, J. R. Carruthers, ''Acoustic-Optic Diffraction of Guided Optical Waves in $LiNbO_3$,'' *Appl. Phys. Lett.* **23,** 417–419, 1973.
3. Y. Ohmachi, ''Acousto-Optical Light Diffraction in Thin Films,'' *J. Appl. Phys.* **44,** 3928–3933, 1973.
4. D. A. Wille, M. C. Hamilton, ''Acousto-Optic Deflection in Ta_2O_5 Waveguides,'' *Appl. Phys. Lett.* **24,** 159–160, 1974.
5. M. K. Smit, G. A. Acket, and C. J. Van der Laan, ''Al_2O_3 Films for Integrated Optics,'' *Thin Solid Films* **138,** 171–181, 1986.
6. E. C. M. Pennings, G. H. Manhoudt, M. K. Smit, ''Low-Loss Bends in Planar Optical Waveguides,'' *Electron. Lett.* **24,** 998–999, 1988.
7. E. C. M. Pennings, J. van Schoonhoven, J. W. M. van Uffelen, M. K. Smit, ''Reduced Bending and Scattering Losses in New Optical 'Double-Ridge' Waveguide,'' *Electron. Lett.* **25,** 746–748, 1989.
8. G. S. Kino, ''Theory of Interdigital Couplers on Nonpiezoelectric Substrates,'' *J. Appl. Phys.* **44,** 1480–1488, 1973.
9. C. S. Tsai, ''Guided-Wave Acoustic-Optic Bragg Modulators for Wide-Band Integrated Optic Communications and Signal Processing,'' *IEEE Trans. Circuits Syst.* **CAS-26,** 1072–1098, 1979.