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The Status of Research on Integrated Optics in China

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Abstract *In this article, some aspects reflecting the status of the Chinese research on integrated optics are briefly reviewed.*

At the moment in China, twenty institutions or more are involved in researches on different topic areas of integrated optics. Among these institutions, the Changchun Institute of Physics has made intensive research work since its earliest founding in China in the middle 1970s. The Shanghai Jiao Tong University has also made great efforts in the field of integrated optics since 1979. In this paper, no attempt will be made to give a comprehensive account of the Chinese integrated optics over the past years, because it is beyond the scope of the paper. However, it is our aim to present a survey of the work being carried on in some major institutions in China, including in particular the two institutions mentioned above of comparatively long background in the art.

Guided Wave Optics

For an optical waveguide with index profile of second-order polynomial, the Helmholtz equation is solved, and exact solutions of mode profile and mode equation are derived [1]. The results can be used to deal with relevant problems such as the glass waveguide fabricated by Ag^+ ion exchange technique.

Multiple quantum well (MQW) stripe waveguide is a 2-D problem, and it is difficult to solve the problem by using the finite element method only. A new algorithm for fast and accurate analysis of stripe MQW waveguides was reported [2]. The technique is based on a combination of effective index and finite element methods. The stripe MQW structure is first replaced by an equivalent planar waveguide, using the effective index method to derive the refractive index profile of the planar guide from the original problem. Then the propagation constants and field intensity profile for the equivalent structure are calculated with the finite element method.

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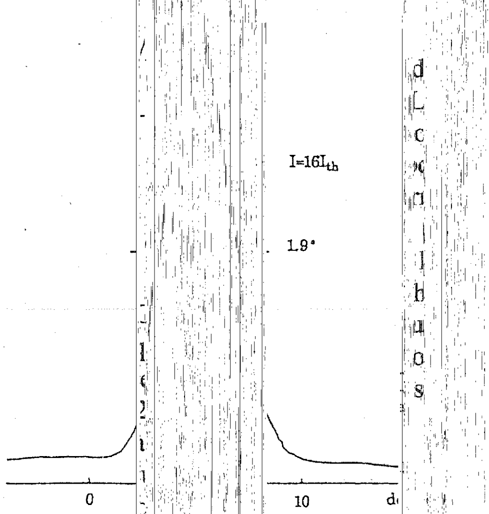

Figure 1. The ... d pattern of a

Semiconductor Devices

High-power diffraction limited GaAs/(... ; phase-lock ... iconductor laser arrays are developed and fabricated by the li ... ase epitaxy ... technique, the standard photolithographic technique, the wet ... , and the p ... bombardment [3]. The optical power per facet of 300 mW at ... the single m ... eration, and the single-lobe far-field pattern with FWHM 1.9 ... ined for an ... vith six lasers, as shown in Fig. 1 and Fig. 2. Theoretical calc ... of threshol ... ent density is made for InGaAsP/InP surface emitting laser di ... ELD) with ... spherical resonator [4]. The results indicate that in the case ... cavity leng ... more than 10 μm, the InGaAsP/InP SELD with a hemispheri ... onator is fea ... y having lower threshold current density J_{th} than the case wit ... e parallel re ... r and will be possible in room temperature continuous wave(s) ... operation, as ... n in Fig. 3.

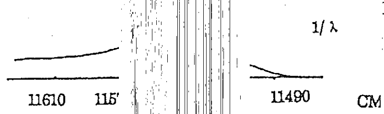

Figure 2. ... ectra of array.

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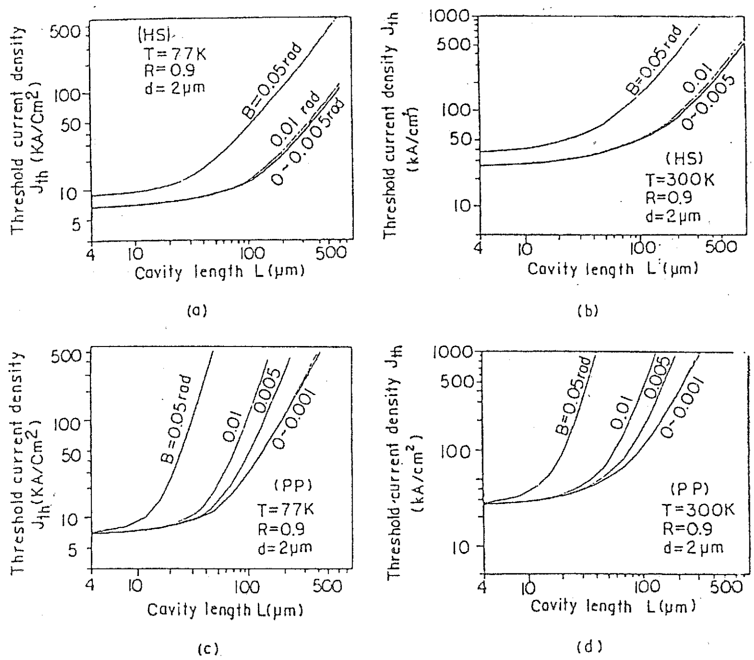

Figure 3. Curves of threshold current density J_{th} versus cavity length L with parameter B. B = 0.0001, 0.0005, 0.001, and 0.05 rad. (a), (b) for HS resonator at 77K and 300K. (c), (d) for PP resonator at 77K and 300K.

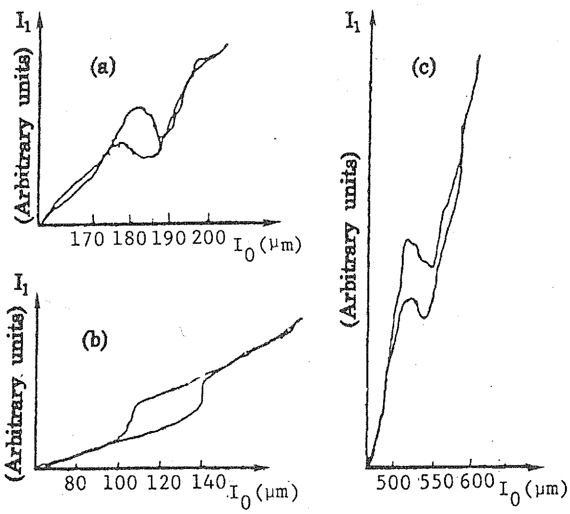

Figure 4. Measured curve of optical bistability by three beam coupling methods between prism and nonlinear waveguide: (a) prism input and wave output, (b) prism input through waveguide and then prism output, and (c) waveguide input and prism output.

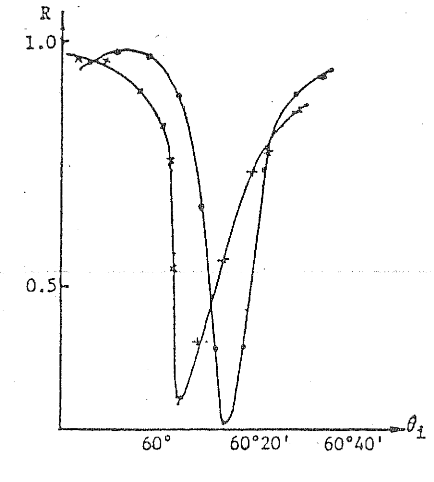

Figure 5. Angular scans of the reflectance around the long-range surface plasmon excitation angles.

Semiconductor Doped Glass and Glass Waveguides

Single-mode waveguides have been fabricated in glass doped with CdS_x Se_{1-x} by K/Na ion exchanging [5]. Prism optical nonlinear waveguide intrinsic bistability was observed by using three different coupling methods. Fig. 4 shows the measured curves of optical bistability. The bistability is also observed in devices with internal F-P cavity structure [6], in distribution feed back grating (DFBG) structure [7], and in a structure of attenuated total reflection (ATR) excitation of a surface plasmon (SPW) [8]. Both magnitude and sign of the third-order nonlinear refractive coefficients associated with thermal effect in semiconductor doped glass have been measured using the intensity-dependent dispersion relation of long-range surface plasmon [9]. Fig. 5 shows angular scans of reflectance around the long-range surface plasmon excitation angles.

In optical waveguides, low losses and the capability of supporting high-power densities can be achieved with the use of glass as the basic material, with the further advan-

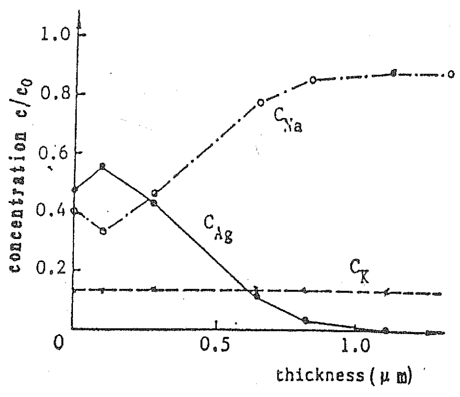

Figure 6. Ag, K, and Na profiles in the prism area after second exchange.

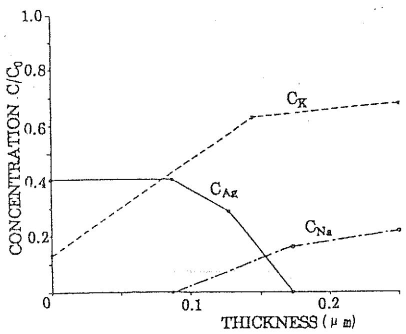

Figure 7. Ag, K, and Na profiles in the waveguide outside the prism area after second exchange.

tage of a very good matching in coupling passive components to optical fibers [10]. The fabrication method of glass waveguide with Ag^+-Na^+ and K^+-Na^+ ion exchange on Soda-Lime glass substrates and the analyses of their characteristics have been reported [11, 12]. The double ion-exchange is introduced, which can be used to fabricate surface refractive components such as prism and lens. The profiles of various ions on top layers of ion-exchanged glasses have been analyzed using Rutherford backscattering spectrometry (RBS). Fig. 6 and Fig. 7 shows the profiles of Ag^+, K^+, and Na^+ inside and outside of the prism area after the second exchange. As is well known, ion exchange produces graded-index waveguides, and the knowledge of the value of the surface index and the index profile is essential for a proper design of the waveguide components. Some experimental data referring to waveguides fabricated by double ion-exchange are presented in [13]. Also presented in this reference is a comparison of the results relating to the surface index and the index profile obtained through the use of two different numerical techniques, both based on the WKB approximation. The refractive index profile of a 5-mode K^+-Na^+ ion-exchanged waveguide is shown in Fig. 8.

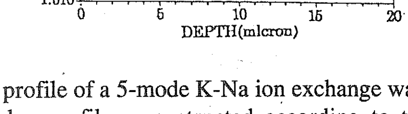

Figure 8. Refractive index profile of a 5-mode K-Na ion exchange waveguide (exchange time 720 minutes). Dashed curve index profile reconstructed according to the Chiang method. Dashed curves with shorter pads = index profile reconstructed according to the dispersion-curve method. Continuous line = Gaussian curve best fitting the Chiang profile indices are indicated by dots.

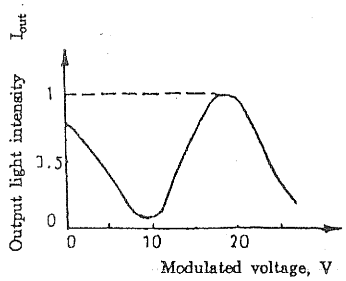

Figure 9. Relation curve of output light intensity with modulation voltage.

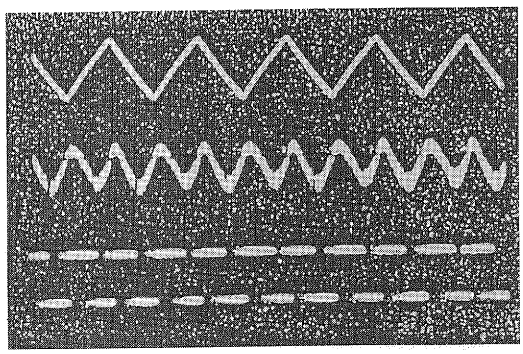

Figure 10. The response of optical A/D converter to an analog signal.

Devices Fabricated in Lithium Niobate Substrates

An 1.5 μm Ti:$LiNbO_3$ E-O waveguide intensity modulator has been fabricated by using the Ti-indiffusion technique and normal photolithography [14]. It consists of a symmetric Mach-Zehnder interferometer and a three-section coplanar waveguide electrode. A 9.5 V half-wave voltage and a 0.7 GHz modulation bandwidth were achieved, as shown in Fig. 9. The integrated-optic A/D converter consists of an array of $LiNbO_3$ guided-wave interferometric modulators that function as an analog amplitude analyzer, pulsed

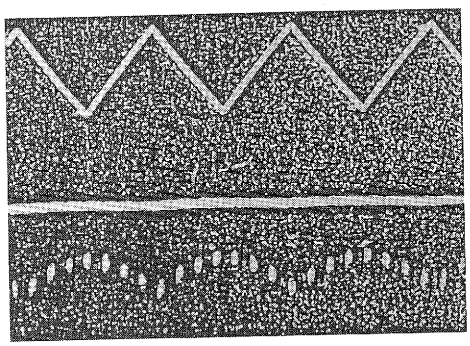

Figure 11. The optical sampling of the optical A/D converter.

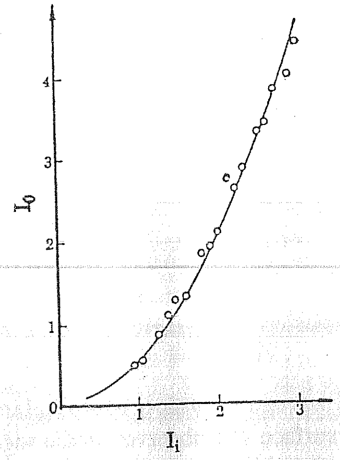

Figure 12. The relation between Io and Ii.

lasers for optical sampling, and high-speed monolithic comparators/demultiplexers to generate the digital levers and slow the data to ECL-compatible rates. The design parameters and fabrication procedure of the integrated-optic A/D converter are reported in [15], and the results of measurement of the performance of the sample are presented in Fig. 10 and Fig. 11. The half-wave voltage from 5 V to 20 V, 3-dB bandwidth of more than 100 MHz, and a total insertion loss of less than 30 dB were achieved.

Nonlinear-Guide Wave Optics

An experiment on nondegenerate four-wave mixing was demonstrated with proton-exchanged $LiNbO_3$ planar waveguide [16, 17]. By exciting counterpropagating guided

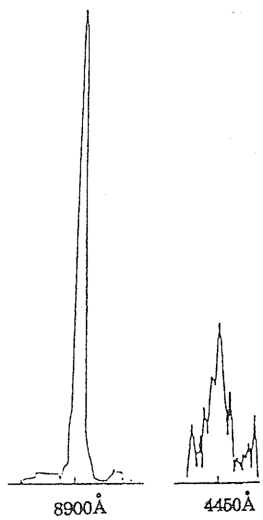

Figure 13. Spectra of fundamental and harmonic waves.

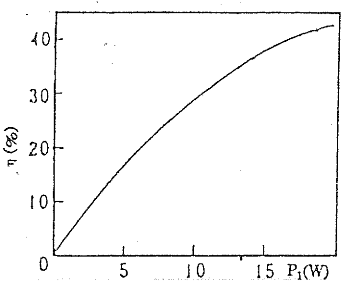

Figure 14. The conversion efficiency curve according to optical input power.

waves at opposite ends of the waveguide with prism couplers, second harmonic g tion radiating normally to the surface was observed in the region where the guided overlap. Fig. 12 shows the relations between the output and input optical inten Emission at 445 nm was generated by continuous-wave frequency doubling in nealed proton-exchanged MgO doped $LiNbO_3$ channel waveguide [18, 19]. In the iment, a maximum conversion efficiency of 42% was realized. Fig. 13 shows the s of fundamental and harmonic wave. The conversion efficiency is given in Fig. 1

During recent years, the interest of the Chinese scientific workers in the fi integrated optics has been directed to optical signal processing, optical communic optical computing, and nonlinear-guided wave optics. Some key devices and tec gies have been developed in this direction. However, few optical integrated devi yet are put in practical use. It will take many more years to achieve the end of pr applications of integrated optics in China.

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