Brillouin scattering in thinfilm waveguides

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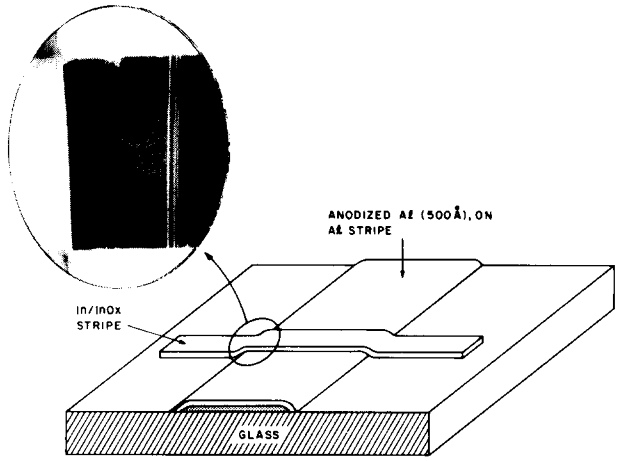

FIG. 3. Cross stripe geometry and writing results (inset) for the ablation test experiment discussed in the text. The In/InO_x film on glass is light gray and transparent, but where it crosses the anodized aluminum stripe the resulting trilayer structure appears dark blue.

Fig. 3. The indicated cross-stripe geometry was passed through a 38-mW laser beam at a velocity of 3.8 m/s. The resulting exposure, both pulsed and continuous, cutting across the 1-mm-wide In/InO_x stripe (inset of Fig. 3) did not cause any appreciable change ($\sim 1\%$) in the resistance of five such stripes. These results suggest a recrystallization of the composite amorphous phase at B in Fig. 1 to a predominantly polycrystalline phase with approximately equal resistivity (D of Fig. 1) may have occurred. Ablation did not occur even with 10-μs writing pulses at 300 nJ/μm^2 thus indicating a high dynamic range of writing energies for this material.

The situation, however, appears to be more complex as indicated by our preliminary observations that written information can be reliably and repeatedly erased. These experiments were performed on an $Al\text{-}Al_2O_3\text{-}In/InO_x$ trilayer with a 25-mW laser beam (numerical aperature = 0.6) operated under both pulsed and cw conditions. After writing with 200-ns or 1 μs-long pulses it was found that very slow (~ 30 min) and sometimes incomplete erasure could be obtained with the focused cw read beam (~ 0.25 mW). Partial erasure with various pulse lengths (200 ns–10 μs) could be obtained with the focused write beam. Most significantly, when the written spots were exposed for 10 μs to the 25-mW writing beam, defocused as much as 100 μm out of the focal plane, the erasure was complete and reproducible. As many as 10 write-erase cycles at a given spot showed no noticeable degradation in the contrast ratio. We have yet to examine other composites for erasability.

Although these results are not completely understood at this time, it is clear that such a write-erase capability is important with regard to applications. We anticipate the need for much additional detailed characterization before we can hope to understand the nucleation, growth, and kinetic accessibility of the metastable phases which must certainly play a critical role in this interesting behavior.

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Brillouin scattering in thin-film waveguides

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Brillouin component is observed for the first time along the backscattered *m* lines in the anisotropic film waveguides. Each order of the forward as well as the backscattered *m* lines is found to be split into two components and are attributed to the presence of TE and TM modes. Temperature conditions under which the films are made and the thickness of the films are found to be critical. Polystyrene films are used in the investigations as waveguide materials due to their compatibility.

PACS numbers: 78.35. + c, 42.80.Lt, 42.10.Qj, 42.60.Kg

Many authors[1–4] have reported the propagation of guided waves in isotropic layered media in connection with integrated optics. The discussion has been extended from isotropic layered media to layered crystalline anisotropic media.[5–9] It has been indicated that the extraordinary refractive index of an uniaxial crystal is direction dependent and

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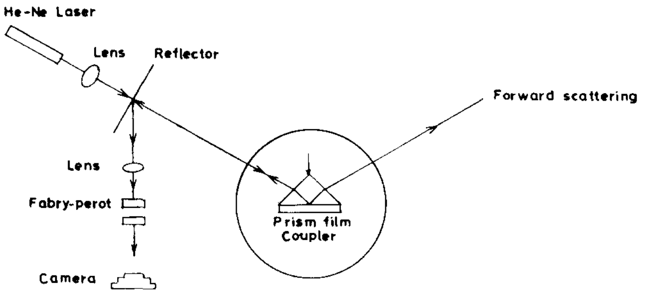

FIG. 1. Experimental arrangement for the observation of backscattered m line and Brillouin component.

hence the guided modes that contain extraordinary wave components should exhibit directional property. Also the property of anisotropic media requires the condition of non-coincidental Poynting and wave vectors resulting in a change of the constant phase surfaces in the substrates thus leading to the generation of backward waveguided mode components.

Backward m-line scattering was reported[10] in solution deposited polystyrene thin films using prism couplers to measure the mode angles of thin-film optical waveguides.

In this letter we report our observations of Brillouin components for the first time along the intense backscattered m lines in the thin-film waveguides using polystyrene films as the waveguide material and prism coupling arrangement to couple the beam into the film. Each order of the back scattered m lines is found to be clearly split into two distinguishable components due to the presence of TE_e and TM_e the transverse electric and transverse magnetic components sensitive to the direction of the extraordinary refractive index of the birefringent polystyrene medium. Films with different thicknesses prepared at different temperatures have been investigated and it is found that these two parameters are critical for the observation of intense backscattered radiation and hence Brillouin component along the m lines.

We have made films of polystyrene material on microscopic glass substrate of refractive index 1.513 by dip coating[11,12] technique. Commerically available polystyrene 666 of Polychem is dissolved in GR grade toluene to prepare the solution. Ultrasonically cleaned glass slides are immersed in the solution by a mechanical device. The film with the substrate is pulled after constant thickness is reached.[11,12] The

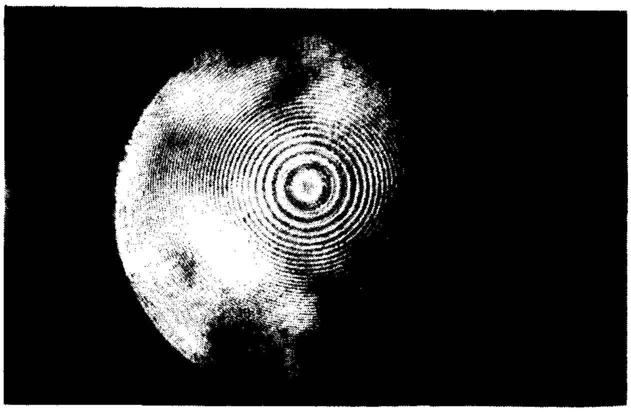

FIG. 2. Fabry–Perot interferogram of Brillouin scattering. The faint one is the Brillouin component and the bright one Rayleigh component.

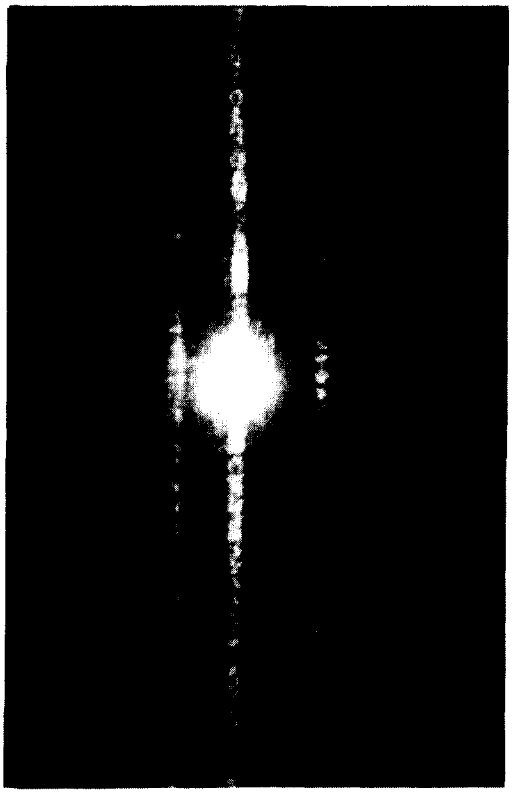

FIG. 3. Backscattered m lines at a distance of 30 cm from the prism film coupler.

thickness of the film is varied by varying the temperature and concentration of the solution.

The experimental arrangement[10,13] is illustrated in Fig. 1. Light from a He-Ne laser of 5-mw output power is coupled onto the film by using a symmetric EDF prism coupler of refractive index 1.70. The angle of incidence is adjusted properly to couple the light into one of the modes. The intense backscattered m lines are collected by a reflector with a pinhole and directed to a Fabry–Perot interferometer through a lens. The Brillouin doublet has been recorded with a camera.

Figure 2 illustrates the Brillouin and Rayleigh components that are observed in a 3-μm-thick film prepared at 40 °C. We found that the Brillouin component is fully polarized whereas the Rayleigh line is partially polarized and the Brillouin shift is found to be 0.2 cm^{-1}. The Brillouin component is found to be very intense in films with thicknesses ranging from 2.5 to 3.5 μm and in the temperature range 35–40 °C.

Figure 3 shows the backscattered m lines and their clear splitting into two components for the above films. For temperatures above 40 °C it is observed that the intensity of backscattered m lines falls off and they are almost completely absent above 100 °C. Brillouin component is not present beyond 60 °C. By placing a polarizer in the laser beam and changing the direction of polarization it is found that there is an alternating change in the intensity of the split components. We attribute this change to the presence of the magnetic and electric modes of the extraordinary ray in the backscattered radiation. The forward m lines are also observed to be split up into two components.

We are under the impression that the mode mixing in the forward scattering is different from the backward scattering and as such experimental and theoretical investigations are now under progress in this laboratory.

From these experiments it is found that the backscattered radiation is totally absent beyond 120 °C. It has already been reported[14] that the films become isotropic after baking at 115 °C and only then are found to be suitable for use as low loss waveguides. One can reduce the loss due to backscattering, so as to have low loss thin-film waveguides by making them isotropic by controlling the temperature, thickness of the film, and selecting suitable solvents for making the film.

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New low dark current, high speed $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ avalanche photodiode by molecular beam epitaxy for long wavelength fiber optic communication systems

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We report a new $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ avalanche photodiode with separate absorption and multiplication regions (SAM APD) and an undoped spacer layer in the gain region. These devices grown by molecular beam epitaxy, have very low dark currents (4 nA at the onset of gain) which compare favorably with state-of-the-art $InP/Ga_{0.47}In_{0.53}As$ SAM APD's. Avalanche gains ≈ 60 and a high speed of response with a gain-bandwidth product ≈ 10 GHz are demonstrated. Receiver sensitivity measurements at 420 Mb/s and $\lambda = 1.3\,\mu$m with a Si bipolar transistor preamplifier yielded -36.0 dBm at a 10^{-9} bit error rate.

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Recently we reported the operation of a new $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ long wavelength avalanche photodiode (APD).[1] These devices, of the separate absorption and multiplication type (SAM APD), had high speed despite the abruptness of the heterojunction, due to the small value of the valence-band discontinuity.[2] The latter feature represents a potential advantage over $InP/Ga_{0.47}In_{0.53}As$ SAM APD's which require grading of the heterojunction[3] or an intermediate InGaAsP layer[4] to achieve high speed. However, the above devices[1] had large dark currents (≈ 20 μA at unity gain) which precluded its use in digital receivers for long wavelength fiber optic communication systems.

We demonstrate here for the first time a new high speed $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ APD with very low dark current, comparable to that of the best state-of-the-art $InP/Ga_{0.47}In_{0.53}As$ APD's. Receiver sensitivity measurements using this novel APD are also reported.

The structure (Fig. 1) is basically a SAM device with a $Ga_{0.47}In_{0.53}As$ 2-μm-thick undoped ($n = 5\times10^{15}$–10^{16}/

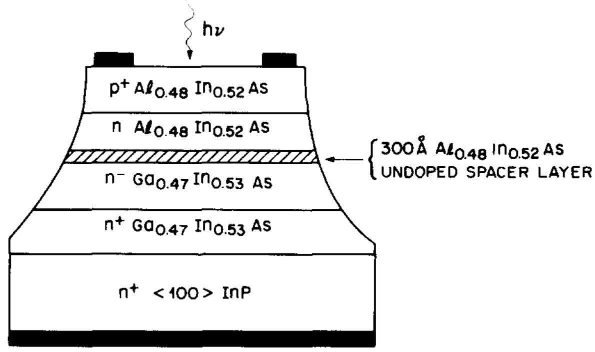

FIG. 1. Schematic of the $Al_{0.48}In_{0.52}As/Ga_{0.47}In_{0.53}As$ APD.

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