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Citation: *Journal of Applied Physics* **58**, 2441 (1985); doi: 10.1063/1.335917

View online: <http://dx.doi.org/10.1063/1.335917>

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# Brillouin scattering in polystyrene thin-film waveguides

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(Received 16 January 1985; accepted for publication 19 March 1985)

An account of Brillouin scattering on thin dip-coated polystyrene waveguides has been given. The behavior of the waveguide near the Bragg region is discussed. The Brillouin scattering observed in dip-coated polystyrene films is attributed to the corrugations in the waveguide due to stress birefringence.

## INTRODUCTION

Using a prism film coupler, it is possible to direct a laser beam into a thin dielectric film which acts as an optical waveguide. Because the film can be made very thin, light energy can be highly concentrated in thin films (e.g., 150-mW absolute power in a 3 by 5- $\mu\text{m}$ -thick film yields a power density of  $10^6$  W/cm<sup>2</sup>). This high power density makes it attractive for nonlinear optical experiments at relatively low absolute power levels. Another advantage is that one can change the transverse wave number  $k_x$  simply by varying the thickness of the film. Since the longitudinal wave number  $k_z$  is related to  $k_x$  through  $k_x^2 + k_z^2 = k_0^2 n_f^2$  where  $k_0$  is the free-space wave number and  $n_f$  is the film refractive index, one can control the phase velocities of the waves inside the guide simply by varying the thickness.

Stimulated Brillouin scattering in optical fiber waveguides with milliwatt and submilliwatt power lasers have been reported in literature.<sup>1-5</sup> Brillouin scattering in thin-film waveguides from backscattered  $m$  line were reported for the first time in 1984<sup>6</sup> by T. P. Janaky *et al.* A spontaneous amplified Brillouin shift of  $0.2\text{ cm}^{-1}$  in dip-coated polystyrene film was reported. We attribute the Brillouin scattering to the corrugations of the waveguide arising from the stress birefringence. The propagation characteristic of a perturbed passive optical waveguide has been given by many authors.<sup>7-9</sup> The behavior of the waveguide near the Bragg region is characterized by strong evanescence of the incident wave due to backward coherent scattering. For a given wavelength one can adjust the corrugation by changing the thickness, temperature of coating, etc., so that most of the incident light is backscattered.

One can give a clear picture of how the dip-coated polystyrene films of different thicknesses prepared at a given temperature act as corrugated waveguides using electron microscopic photographs. We have reported<sup>6</sup> that only films of thickness at about  $2.5\ \mu$  prepared at  $40^\circ\text{C}$  gave strong Brillouin scattering which disappears totally after baking at  $120^\circ\text{C}$ . Figures 1(a) and 1(b) are the electron microscope photographs of the film which gave strong Brillouin component shift  $0.2\text{ cm}^{-1}$ .<sup>6</sup> Figure 1(a) shows that the chains are closely packed, and Fig. 1(b) shows the individual chain structure. Figure 1(c) shows the chain structure of a film of  $1.15\text{-}\mu$  film, and it is clear that chains are not closely packed. Figure 1(d) shows the situation in a film of  $4\text{-}\mu$  thickness

where the chains are more closely packed than Fig. 1(b), showing an amorphous nature. Figure 1(e) represents the case with the film which gave strong Brillouin scattering and

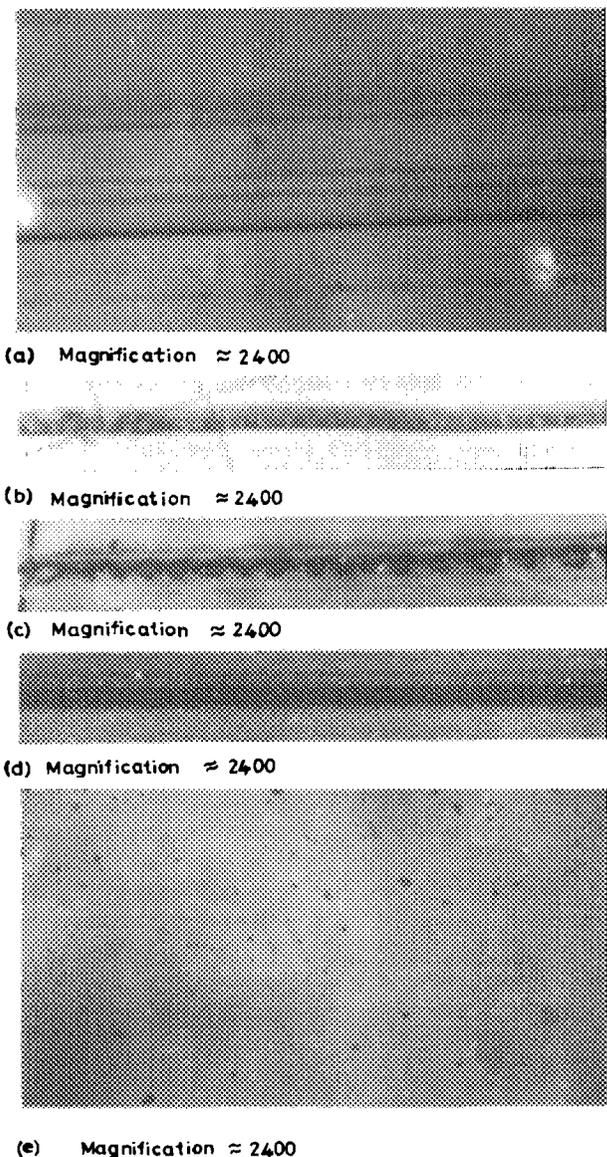


FIG. 1. Electron microscope photos of polystyrene films prepared at  $40^\circ\text{C}$  with varying thickness. (a) is film at the critical thickness which shows closely packed chains. (b) is the individual chain structure of the film at critical thickness. There is a regular periodic structure. (c) is a film of thickness of  $1.15\ \mu$ . The chains are not closely packed. (d) is a film of thickness of  $4\ \mu$ . No regular periods, shows amorphous nature. (e) is a film at the critical thickness after baking at  $120^\circ\text{C}$  for 12 h.

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which disappeared after heating the film at 120 °C for about 12 h.

It is clear from the photographs that the corrugation changes with thickness, and it disappears and the film becomes almost isotropic after heating to 120 °C. The chain structure is totally absent in these films. Since the chains are very closely packed, an accurate determination of corrugation period is difficult. The electron microscope photographs show only a gross structure. X-ray studies done on these films confirm that the films are polycrystalline in nature and the crystallinity varies with thickness. The estimated interplanar separations for the critical thickness film are around 1.93, 1.87, 1.64, 1.40, 1.19, and 0.67 Å.

A detailed discussion of the growth characteristics of polymer film is given in Refs. 1 and 10. The solubility of the polymer depends on the relative strength of the polymer forces of attraction between the atoms in the chain, between the molecular chains, and between polymer molecules and solvent molecules. It is hence evident that the process should be strongly temperature dependent. Moreover, the polymer molecules undergo enormous change in shape and dimension during film formation. The chains can be elongated only when good solvents are used. A good solvent is one in which the polymer is easily soluble and the solvent is not highly volatile. It is evident from the above explanation that stress due to the orientation of polymer molecules on glass substrate is the origin for the observed birefringence.<sup>11</sup> By heating above the softening point, stress is released, and the film becomes isotropic. It is understood that the stress birefringence which is acting as the periodic perturbation depends on (1) temperature, (2) solvent, (3) substrate, and (4) method of film making.

In Ref. 6 we have reported a Brillouin shift of the order of 0.2 cm<sup>-1</sup>. Here, the deposition involves the immersion of a glass substrate under isothermal conditions into a polymer solution of suitable concentration kept at a particular temperature. Since the backscattering is in the form of very sharp *m* lines and the Brillouin shift is observed along the *m* line, one can be sure that the backscattering is due to Bragg scattering and not due to any roughness effect.

In this paper we report another Brillouin shifted component of 0.445 cm<sup>-1</sup>. Here, the method of preparing film is different from that in Ref. 6. The films were prepared at lower temperatures, keeping the pulling rate very slow and uniform. In these films the backscattering is totally absent initially, but on annealing them from 50–100 °C, they also start giving backscattered *m* lines. Films of thickness 2–3 μ show very intense backscattered *m* lines on annealing them at about 70 °C. These films show a Brillouin shift of 0.445 cm<sup>-1</sup>. Films below and above 2–3 μ do not give any Brillouin shifted components, even though Rayleigh lines are present on annealing them above 50 °C. The Fabry Perot interferogram is given in Fig. 2. The Fabry Perot used is just a silver-coated one with 3-mm spacing. One very interesting property here is that only the TE modes show very intense Brillouin shift. The TM modes do not show a Brillouin component in most of the films. Very rarely one could observe a very feeble Brillouin component of the same shift 0.445 cm<sup>-1</sup> for TM modes. After 24 h of preparation of the film

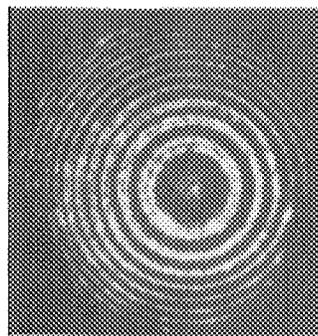


FIG. 2. Fabry Perot interferogram of Brillouin scattering in polystyrene waveguides. Outer one is Rayleigh, and the inner one Brillouin. The spacer distance is 3 mm.

the intensity of backscattering is found to decrease considerably, and the Brillouin component totally disappears. This may mean that the structure is highly unstable.

## INTERPRETATION

A possible interpretation for the generation of stimulated Brillouin scattering in guided media using low power lasers can be given on a similar basis of the analysis given by Smith for fiber wave guides,<sup>1</sup> since films are only just a two-dimensional analog of optical fiber. The critical power for stimulated Brillouin scattering can be given by

$$P_{\text{crit}}^{\text{Brillouin}} \approx \frac{21A\alpha}{\gamma_0}$$

*A* is the core area,  $\alpha$  is the attenuation constant, and  $\gamma_0$  is the Brillouin gain. The critical power for stimulated Brillouin scattering in polystyrene thin-film waveguides can be estimated to a good approximation to the order ranging from 0.5 to 5 mW, corresponding to the propagating mode area ranging from 10<sup>-9</sup> to 10<sup>-8</sup> cm<sup>2</sup> for the values of  $\alpha \approx 0.5$  dB/cm and  $\gamma_0 \approx 5 \times 10^{-9}$  cm/W.<sup>12</sup> One can control the mode area even to less than 10<sup>-9</sup> cm<sup>2</sup> using a prism film coupler.<sup>13,14</sup> This shows that the critical power for stimulated Brillouin scattering through polystyrene films is very much within the limits of the power of the He-Ne laser. We used in our experiment a 5-mW He-Ne laser. We did not observe any Brillouin component with a 2-mW laser. One can perhaps get an idea of the coupling area using different power sources.

## EXPERIMENT

The experimental arrangement is illustrated in Fig. 3. Light from a He-Ne laser of 5-mW output power is coupled into the film by using a symmetric extra dense flint prism coupler of refractive index 1.70. The angle of incidence is adjusted properly to couple the light into one of the TE modes. The intense backscattered *m* lines are collected by a reflector with a hole and directed to a Fabry Perot interferometer through a lens. The Brillouin doublet is recorded with a camera.

## CONCLUSION

In general we have described how a dip-coated polystyrene film acts as a corrugated waveguide due to the stress birefringence. The critical power calculation for stimulated Brillouin scattering in polystyrene films is made assuming

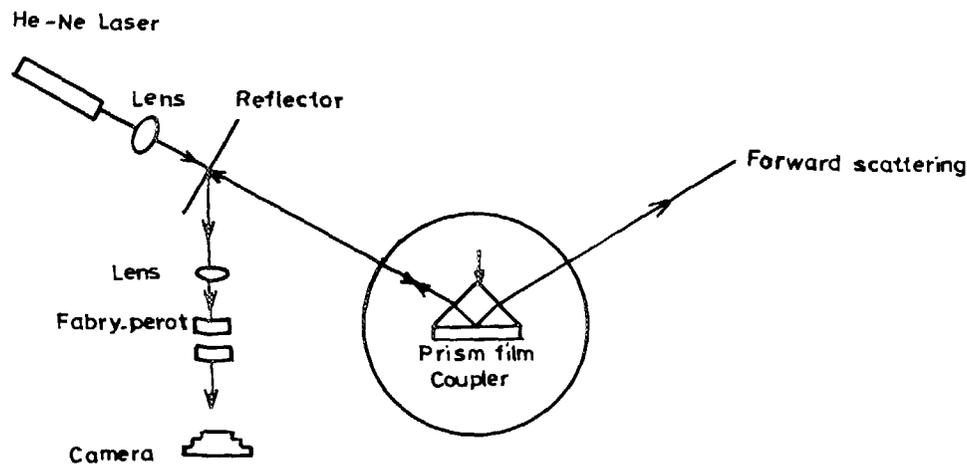


FIG. 3. Experimental arrangement for the observation of Brillouin scattering.

single pass amplification of spontaneous emission.

Our thanks are due to Dr. R. S. Sirohi for his kind interest in this work. One of the authors, Mrs. T. P. Janaky, is indebted to the U. G. C. for financial assistance.

<sup>1</sup>R. G. Smith *Appl. Opt.* **11**, 2489 (1972).

<sup>2</sup>L. F. Stokes, M. Chodorow, and H. J. Shaw, *Opt. Lett.* **7**, 288 (1982).

<sup>3</sup>L. F. Stokes, M. Chodorow, and H. J. Shaw, *Opt. Lett.* **7**, 509 (1982).

<sup>4</sup>D. R. Ponikvar and S. Ezekiel, *Opt. Lett.* **6**, 398 (1981).

<sup>5</sup>P. Labudde, P. Anliker, and H. P. Weber, *Opt. Commun.* **32**, 385 (1980).

<sup>6</sup>T. P. Janaky, T. A. Prasad Rao, D. V. G. L. Narasimha Rao, and C. K. Narayanaswamy, *Appl. Phys. Lett.*, **44**, 1025 (1984).

<sup>7</sup>A. Yariv and H. W. Yen, *Opt. Commun.* **10**, 120 (1973).

<sup>8</sup>A. Yariv and M. Nakamura, *IEEE J. Quantum Electron.* **QE-13**, 233 (1977).

<sup>9</sup>N. Bloembergen, *Appl. Phys. Lett.*, **17**, 483 (1970).

<sup>10</sup>A. C. Restogi and K. L. Chopra, *Thin Solid Films* **18**, 187 (1973).

<sup>11</sup>T. P. Sosnowski and H. P. Weber, *Appl. Phys. Lett.* **21**, 310 (1972).

<sup>12</sup>D. R. Dietz and T. A. Wiggins, *J. Appl. Phys.* **43**, 3631 (1972).

<sup>13</sup>T. Tamir, *Integrated Optics* (Springer, Berlin, 1975), pp. 83-139.

<sup>14</sup>D. Marcuse, *Light Transmission Optics* (Van Nostrand Reinhold, New York, 1972), pp. 286-417.