Optica Applicata, Vol. XV, 2, 1985

Use of Brillouin–Mandelstam light scattering in optoelectronics*

ZUZANA CHORVÁTOVÁ

Department of Experimental Physics, Faculty of Mathematics and Physics, Komenský University, 842 15 Bratislava, Czechoslovakia.

The mode structure of planar optical waveguide is determined and the possibilities of simultaneous transmission of two light waves of the similar wavelengths generated by stimulated Brillouin–Mandelstam scattering (SBMS), are discussed. In optoelectronics, light scattering is, on the one hand, considered as a parasite phenomenon, but, on the other hand, a form of it – SBMS – may be used for generation and propagation of two light waves, transmitting thus a double amount of information by means of a given planar waveguide.

1. Brillouin–Mandelstam scattering (BMS)

BMS is a quasi-elastic scattering. It arises on the adiabatic density fluctuations, which are connected with pressure fluctuations and can be interpreted as the acoustic waves of hypersonic frequencies. The light stattered at these fluctuations has the frequency shifted with respect to that of the incident light. The value of the shift is responsible for the frequency of hypersonic wave ω_s therefore we have [1]

$$\omega_1 = \omega_2 + \omega_s$$

where ω_1, ω_2 correspond to the frequencies of scattered and incident light waves, respectively.

In the stimulated BMS, which is a non-linear optical phenomenon, the energy of incident electromagnetic wave due to electrostriction is transformed into the mechanical and scattered ones. The parametric amplification, which can be recognized as a rapid increase of the scattered light wave intensity, occurs when the power of incident laser radiation exceeds the threshold value, the latter being dependent upon the material, in which the scattering occurs.

The SBMS is studied in various liquids using the equipment, fully described in paper [2], which allows the SBMS occurrence under focused-laser radiation and the detection there of by means of Fabry–Pérot interferometer and camera.

Table 1 presents the frequency shifts of the scattered radiation.

---

* This paper has been presented at the VI Polish-Czechoslovakian Optical Conference in Lubiatów (Poland), September 25–28, 1984.

Our attempts at using the results obtained from SBMS in optoelectronics were due to the following reason: SBMS generates at the same time two waves with similar frequencies. After this generation occurs and one of the two waves is couples into the waveguide, the other one is also coupled simultaneously under the same conditions.

Table 1. The frequency shifts of the back-scattered light SBMS in some liquids

Sample	$\tilde{\nu}_S$ [cm^{-1}]
Enzym trypsin – the water solution	0.0926
Methanol	0.1328
Ethanol	0.1449
Acetone	0.1499
Water	0.1795
Benzene	0.2073
Liquid crystal MBBA, isotropic phase, 39.0°C	0.2580
Liquid crystal MBBA, isotropic phase, 37.6°C	0.2860

2. Light beam propagation in the planar waveguide

First, we investigate the propagation of the laser radiation alone, in the planar waveguide, then we discuss the propagation of two waves.

We use the well-known theory of radiation propagation through a dielectric film, described in detail, e.g., in [3]. The characteristic equation of film modes is to be solved. This equation determines the kind of modes which can propagate in the considered dielectric films. This equation, being the transcendental one, must be solved by numerical method. We have solved it for the given type of waveguide, it is the case of the so-called weakly guiding film. For this type of film the refractive indices of dielectric film (n_1) and substrate (n_2) range within 1.4–2.0, $n_1 \geqslant n_2$ and both the film and the substrate are situated in the air ($n_0 = 1$). The above type of waveguide is often used in practice.

In this case the characteristic equation of film modes can be simplified and be written as follows:

$$V^2 = u^2 \left(1 + \mathrm{ctan}^2 u\right) \tag{1}$$

where

$$V = \frac{2\pi}{\lambda} d(n_1^2 - n_2^2)^{1/2}$$

is a parameter of the film, the thickness of which is d.

As a result we gain the values of u, which are connected with the angle Θ_1

of a given mode propagation in the layer. We obtain

$$u = \frac{2\pi n_1}{\lambda} d \sin\theta_1.$$

The computer program [4] was elaborated for the solution of the Eq. (1). The needed values were taken for planar waveguide prepared from the solution of polystyrene in xylene. For this film $n_1 = 1.5864$, $n_2 = 1.5120$, $d = 1.599 \times 10^{-6}$ m and $V^2 = 58.048859$, radiation wavelength being $\lambda = 632.8 \times 10^{-9}$ m. The graph of function $V^2 = f(u)$ is represented by a noncontinuous curve. The noncontinuity points, where the function takes infinite values are $u = \pi$, 2π, 3π, ... To calculate the roots the method of half-cutting of the interval [5] was used.

The calculation has shown that in this polystyrene film 3 modes (there exist 3 solutions u_i and the corresponding θ_{1i}) can be generated. The calculated values are given in Tab. 2 for He-Ne ($\lambda = 632.8$ nm) and Rb ($\lambda = 694.3$ nm) laser radiation, respectively.

3. Film mode structure of radiation generated by SBMS

Our study was based on the experiences obtained from SBMS investigation and from studying the mode structure of the waveguide in which only single-wavelength light radiation propagates.

Then we have calculated the mode structure of a planar waveguide, in which both the laser and the scattered lights are propagating. The solution of the characteristic equation of film modes (1) yielded results given in Tab. 2 in which the values for the greatest (trypsin) and smallest (MBBA) change in frequency caused by the SBMS in the liquids, are given. The values of $\tilde{\nu}_s$ and thus those of $\lambda_{\text{Brill.}}$ for the other investigated samples are situated within this interval.

4. Results and conclusions

The SBMS was investigated experimentally and the values of the frequency shifts of incident and scattered radiation for several liquids were given. For the defined film the number of single-wavelength radiation modes was also calculated. From the gained results the mode structure of the film could be calculated for two waves of close frequencies.

From Table 2 it can be seen, that the synchron angle change at the generation of m-th mode and $(m+1)$-th one attains several degrees, whereas the angle change by the laser and scattered radiation in the same m-th mode is negligible (about 10^{-4}–10^{-6} degree).

Thus, in order to propagate the laser and scattered due to SBMS radiations

Table 2. Values of u and the generated mode propagation angles Θ obtained by solving the characteristic equation for polystyrene film modes

λ [nm]	Sample	V^2	u_1 [rad]	u_2 [rad]	u_3 [rad]	Θ_{11} [rad]	Θ_{12} [rad]	Θ_{13} [rad]	Θ_{11} [°]	Θ_{12} [°]	Θ_{13} [°]
$\lambda_{\text{He-Ne}}$ = 632.800000	–	58.048859	2.7695626	3.6396349	5.4803849	0.1099604	0.1445051	0.2175887	6.29972	8.27945	12.46667
λ_{Rb} = 694.300000	–	48.220566	2.7365268	2.7042535	5.3937226	0.1192080	0.1613640	0.2349604	6.83000	9.24527	13.46222
$\lambda_{\text{Brill.}}$ =											
694.304460	trypsin	48.219946	2.7365256	3.7042582	5.3937166	0.1192088	0.1613652	0.234961	"	"	"
694.306401	methanol	48.219676	2.7365238	3.7042606	5.3937161	0.1192090	0.1613658	0.2349623	"	"	"
694.306984	ethanol	48.219595	2.7365238	3.7042606	5.3937137	0.1192091	0.1613659	0.2349624	"	"	"
694.307225	acetone	48.219562	2.7365238	3.7042606	5.3937137	0.1192091	0.1613660	0.2349624	"	9.24555	"
694.308652	water	48.219364	2.7365220	2.7042636	5.3937102	0.1192093	0.1613665	0.2349628	"	"	"
694.309992	benzene	48.219178	2.7365220	3.7042636	5.3937102	0.1192095	0.1613668	0.2349633	"	"	"
694.312436	MBBA (39.0°C)	48.218838	2.7365196	3.7042666	5.3937036	0.1192099	0.1613675	0.2349638	"	"	"
694.313786	MBBA (37.6°C)	48.218651	2.7365196	3.7042684	5.3937036	0.1192101	0.1613678	0.2349642	"	"	"

in the waveguide, it is sufficient (from the practical point of view), that these two radiations be coupled into the waveguide at the same angle (with regard to the experimental fixing of angles as well as to non-zero laser beam divergence).

References

[1] Yariv A., *Kvantovaya Elektronika i Nelineinaya Optika*, Ed. Sov. Radio, Moskva 1973.
[2] Chorvátová Z., Heglas L., Czechosl. J. Phys. A, **31** (1981), 141–145.
[3] Unger H. G., *Planar Optical Waveguides and Fibres*, Clarendon Press, Oxford 1977.
[4] Pažúrová T., MSc. Thesis (in Czech), MFK UK, Bratislava 1984 (unpublished).
[5] Demidovič B. D., Maron I. A., *Základy numerickej matematiky* (in Czech), Praha 1966.

Received October 15, 1984

Применение рассеяния Бриллюэна–Мандельштама в оптоэлектронике

Определена модовая структура планарных оптических волноводов, а также обсуждены возможности получения двух волн, характеризующихся подобной длиной, генерированных стимулированным рассеянием Бриллюэна–Мандельштама (SBMS). В оптпэлектронике рассеяние света считают паразительным эффектом. Показано все-таки, что SBMS может применяться для генерирования и трансмиссии двух световых волн, а тем самым для трансмиссии двойного количества информации с помощью определенных планарных волноводов.