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Method for calculating SBS threshold in optical fibres

O.E. Nanii, E.G. Pavlova

***Abstract*. It is shown that the widely used method for calculating the SBS threshold in optical fibres yields erroneous results in a number of practically important cases. In particular, not all acoustic-antiwaveguide optical fibres demonstrate an increase in the SBS threshold. For the SBS threshold to increase, it is necessary to provide fast disruption of the acoustic wavefront due to refraction.**

Keywords: *optical fibre, stimulated Brillouin scattering, SBS threshold, high-power fibre lasers.*

Interest in the investigation of the methods for increasing the SBS threshold is due to a rapid progress in the development of high-power fibre lasers with a narrow radiation spectrum. In such fibre lasers, SBS becomes the chief factor limiting the maximum output power [1]. In addition, in the cable TV systems, SBS limits the maximum input signal power and, consequently, the operating distance of the cable TV system [2].

Recently, the principles of the creation of optical fibres with an increased SBS threshold have been proposed. These principles consist in using such dopants in the core and in the cladding that provide a significant reduction of the spatial overlap of the optical and acoustic modes [1, 3, 4]. The overlap coefficient of the optical and acoustic waveguide modes $I_{\rm ac}$ is determined by the expression [4]:

$$I_{\rm ac}=\frac{(\int E_0E_0^*\rho_{\rm ac}r{\rm d}r{\rm d}\theta)^2}{\int(E_0E_0^*)^2r{\rm d}r{\rm d}\theta\int\rho_{\rm ac}\rho_{\rm ac}^*r{\rm d}r{\rm d}\theta}, \qquad (1)$$

where E_0 is the complex amplitude of the electric field of the optical waveguide mode; $\rho_{\rm ac}$ is the complex amplitude of the acoustic waveguide mode. The SBS gain is proportional to the overlap coefficient, whereas the SBS threshold is inversely proportional.

According to the authors of [1 – 4], a relatively low SBS threshold in standard telecommunication fibres is due to a significant overlap of the optical waves and the excited acoustic waves. The latter is, in turn, due to the fact that the speed of the acoustic waves in the germanosilicate core of such a fibre is smaller than in the undoped-silica cladding. Therefore, the fibre constitutes a wavegude for the acoustic waves.

The purpose of this paper is to draw attention to the fact that calculation of the SBS threshold by the technique used at present (see [1, 3, 4]) yields an overestimated value in a number of practically important cases. It turned out that one should pay attention to the acoustic waves diverging as a result of diffraction or refraction. Our investigations showed that light scattering on such acoustic waves (i.e. on a continuum of leaking modes) should be taken into account in the case of weak overlapping of the acoustic and optical waveguide modes.

The necessity to allow for the diverging acoustic waves can be demonstrated by the example of an optical fibre, which has either a core refractive index lower than that of the cladding or equal acoustic refractive indices of the core and the cladding (the latter can be achieved by properly choosing the dopant). In this case, the acoustic waveguide modes do not exist, which must lead to the infinite growth of the SBS threshold, because the SBS gain must fall to zero. This conclusion, however, contradicts the results of experimental paper [5], in which the SBS threshold of undoped-silica-core fibres was shown to differ from that of standard fibres only slightly. We have shown that scattering on the continuum of leaking modes allows one to explain the low SBS thereshold in undoped-silica-core fibres.

We calculated the excited acoustic waves and the SBS gains for step-index fibres with the core diameter typical of the telecom fibres, ~ 9 μm, and a typical lifetime of an acoustic wave $T_{\rm B}=10$ ns. The SBS threshold was found to vary by no more than 10 % on varying the relative difference of the core and cladding acoustic refractive indices from $+0.65$ to -0.65.

The above result can be explained as follows. In fibres with the standard telecom refractive index profile, the diffraction length of an acoustic wave $L_{\rm d\,ac}=k_{\rm ac}r_0^2$ (where $k_{\rm ac}=2\pi/\lambda_{\rm ac}$ is the acoustic wave vector and r_0 is the acoustic beam radius) turns out to be larger than the attenuation length $L_{\rm B}=(V_{\rm ac}T_{\rm B})\approx 60$ μm (where $V_{\rm ac}$ is the acoustic wave speed). For $L_{\rm d\,ac}>L_{\rm B}$, the spatial structure of the acoustic beam is determined by the structure of the exciting optical beam. Therefore, the SBS threshold weakly depends on the acoustic waveguide properties of the fibre.

To lower the SBS threshold, the fibre acoustic properties should be such that the structure of the acoustic beam

O.E. Nanii, E.G. Pavlova Department of Physics, M.V. Lomonosov Moscow State University, Vorob'evy gory, 119991 Moscow, Russia; e-mail: nanii10@rambler.ru

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disrupts due to refraction within the refraction length $L_{\mathrm{rac}} < L_{\mathrm{B}}$. All the fibres with a significantly increased SBS threshold (by 6 – 10 dB) [1 – 4] do possess this property.

Our calculations show that the largest SBS threshold can be achieved in fibres with an acoustic refractive index profile depicted in Fig. 1, the optical refractive index profile being step-like as in standard fibres. Such a combination of the acoustic and optical refractive index profiles can be provided by co-doping silica with GeO_2 and Al_2O_3.

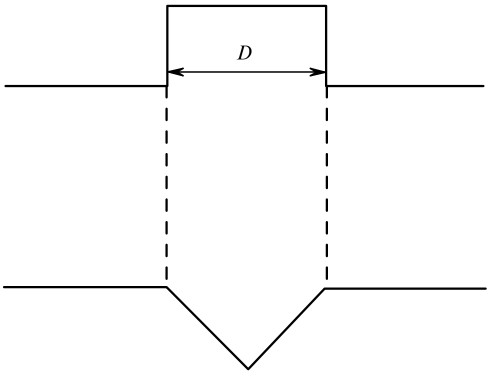

Figure 1. Optical (top) and acoustic (bottom) refractive index profiles of a telecom optical fibre with a high SBS threshold.

Thus, the widely used technique for calculating the SBS threshold proposed in [3, 4] yields correct results only for fibres with good acoustic waveguide properties. In important cases of acoustic-antiwaveguide fibres, this technique gives erroneous results, because the main contribution to the SBS gain in this case is made by diverging acoustic waves. In such fibres, it is necessary to calculate numerically the spatial structure of the excited acoustic wave and the scattering of the optical wave on this acoustic wave. In designing optical fibres with a high SBS threshold, it is of basic importance to provide fast disruption of the acoustic wavefront due to refraction.

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