Numerical Study of Stimulated Brillouin Scattering in Optical Microcavities Made of Telecommunication Fibres

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Abstract— **We numerically studied stimulated Brillouin scattering processes up to the 5th order is microcavities with various realistic diameters and Q-factors made of standard telecommunication fibres. Pump power thresholds were simulated for different parameters of the system. The larger the microcavity and lower Q-factors, the higher pump power thresholds are. It is also shown that thresholds strongly depend on pump detuning. For a microcavity with a diameter of 200 µm and Q-factor of 5×10^7, threshold pump powers for the 1st order stimulated scattering are 0.3 and 30 mW for pump detunings 0 (exact resonance) and $20\times2\pi$ MHz, respectively.**

I. Introduction and Motivation

Microcavities made of different fibres are used for generation of frequency combs [1,2,3] based on a Kerr nonlinearity [4], Raman generation [5,6], Brillouin generation [7,8], laser generation (if a microcavity is doped with active rare-earth ions) [9,10,11], and many others. In the current work we contributed to the study of the cascade stimulated Brillouin scattering processes in optical microcavities made of telecommunication fibres. This may be important for the development of cost efficient micro-sensors [12]. Stimulated Brillouin scattering is a well-known process based on inelastic scattering on a hypersound wave [13]. Cascade processes are also often observed and can be used for development of optical gyroscopes [14]. The motivation of the current work is understanding of particularity of cascade stimulated Brillouin scattering processes and numerical optimization of their parameters in a scheme consisting of microcavities based of low-cost standard fibres and other telecommunication components.

II. Numerical Model

We considered the simplified schematic diagram for the cascade stimulated Brillouin scattering processes presented in Fig. 1. The continuous wave radiation generated by a standard telecommunication laser pumps a microcavity manufactured from a standard telecommunication fibre. Such a microcavity can be easily prepared using an optical fibre splicer with customized software. The technology is described in [15,16,17]. It is known that for cascade stimulated Brillouin scattering, odd-order waves travel in the backward direction relative to the pump wave, but even-order waves travel to the same direction as the pump wave [13]. Intracavity field amplitudes are E_k and output powers of Brillouin waves are P_k; E_0 and P_0 correspond to the wave at the pump frequency.

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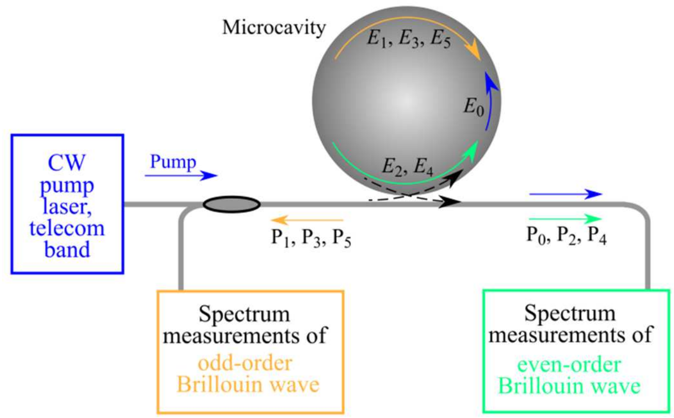

Fig. 1. Simplified schematic diagram for numerical study of cascade stimulated Brillouin scattering processes in microcavity made of telecommunication fibre.

To simulate cascade stimulated Brillouin scattering processes for a pump wavelength in the telecommunication C-band, we applied the numerical model for average slow-varying intracavity fields [7,8]. This model was successfully used for simulation of Brillouin scaterring processes and gave a good agreement with corresponding experimental measurements [7,8]. The model contains coupled time-dependent differential equations with nonlinear interaction between different scattering orders. The pump wave (0-th order) gives the energy to the 1st-order scattered wave. The k-th order wave takes the energy from the (k-1)-th order wave and gives the energy to the (k+1)-th order wave [7,13]. The parameters were calculated as in [7,8]. Constants describing material properties were taken from [13]. We successively enumerated the parameters of the system and numerically found the threshold pump powers for them.

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III. RESULTS AND DISCUSSION

We considered microcavities with realistic parameters: diameters d = 200, 300, 400, and 500 μm with typical Q-factors Q = 1×10^7–1×10^8. We calculated effective volumes of microcavity eigenmodes as in [18]. They are 1.0×10^4, 2.2×10^4, 3.8×10^4, and 5.7×10^4, respectively. Note that for microcavities with such diameters not only fundumenatal but high-order modes can also be excited. Since the frequency shift for stimulated Brillouin scattering is 10.9 GHz [13] significantly low than free spectral range (FSR), the generation is observed in various mode families. We set overlapping integrals 0.1 for modes in different cascades. We considered scattering processes up to 5th order and calculated threshold powers for them (Thr(1)-Thr(5) in Fig. 2 and Fig. 3.). The larger the microcavity and lower Q-factors, the higher pump power thresholds are (Fig. 2).

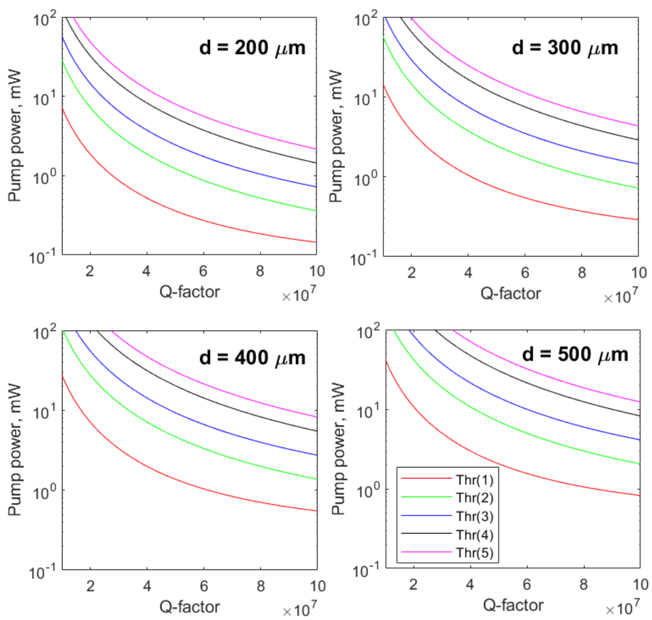

Fig. 2. Simulated threshold pump powers Thr(1)-Thr(5) for Brillouin waves up to the 5th order in microcavities with different diameters for pump detuning of 1x2π MHz.

It is also shown that thresholds strongly depend on pump detuning. The simulation results for a microcavity with a diameter of 200 μm are presented in Fig. 3. It is seen that for the 1st order scattering process, the thresholds differ in two orders when pump detuning changes from 0 (exact resonance) to 20×2π MГц. They are 0.3 and 30 mW for pump detunings 0 and 20×2π MHz, respectively. Thresholds are higher for higher order scattering processes.

Note that for effective management of eigenfrequencies one can use thermo-optical effects which observed due to refractive index changes and thermal expansion of a microcavity with temperature increasing [11,18,19]. This can help to shift eigenfrequinces for decreasing pump power threshold.

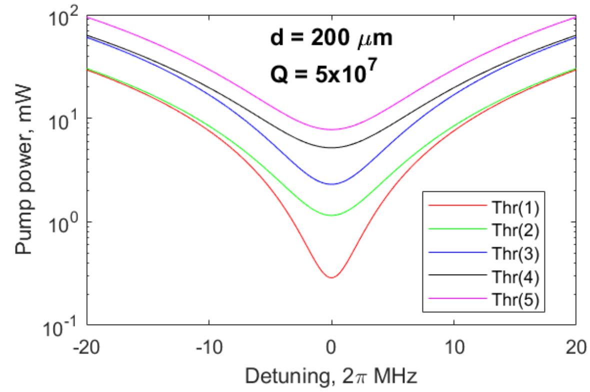

Fig. 3. Simulated threshold pump powers Thr(1)-Thr(5) for Brillouin waves up to the 5th order as function of pump detuning.

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