Rayleigh and Brillouin scattering in metal-coated optical fibers at high temperatures

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This work discusses metal-coated optical fibers as a medium for adjustable Brillouin and Rayleigh backscattering. Attention is paid to high-temperature effects that can be used in Random fiber lasers to tune their properties, as well as, in distributed fiber sensors for measurements in extreme conditions.

Random lasers

Conventional lasers consist of active medium and mirrors (see figure 1-a). A random laser employs a highly disordered gain medium instead of mirrors. The random laser does not have optical cavity, but the principles of operation involves backscattering from many diffusing centers (see figure 1-b). Random lasing have been observed in many disordered active media, including semiconductor powder, nanostructured and non-nanostructured thin films, laser dyes, optical fibers [1], etc.

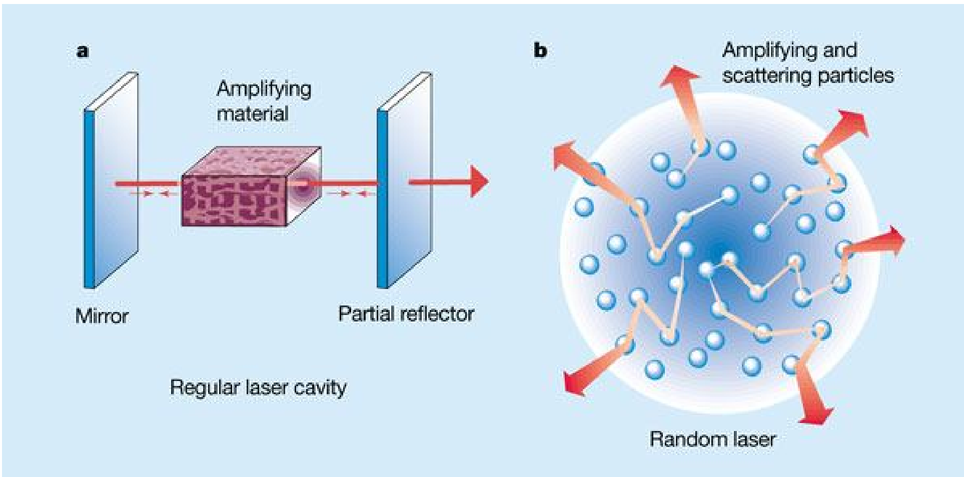

Figure 1. Construction of Random laser

In particular, the lasing can be achieved through the effects of Brillouin and Rayleigh backscattering in fibers [2]. Tuning of the refractive index irregularities along a beam propagation axe seems to be an interesting problem important for applications in Random lasers.

Metal Coated optical fibers

Metal-coated fibers can be employed as a medium for random lasing. Such fibers do not have conventional plastic coating, but they are covered by thin metal films (copper, aluminum, alloys) instead [3-4]. The main advantage of such fibers is that they can operate at high temperatures (up to 950^0C) and high pressure that is attractive, in particular, for applications in distributed fiber-optic sensors operating in extreme conditions.

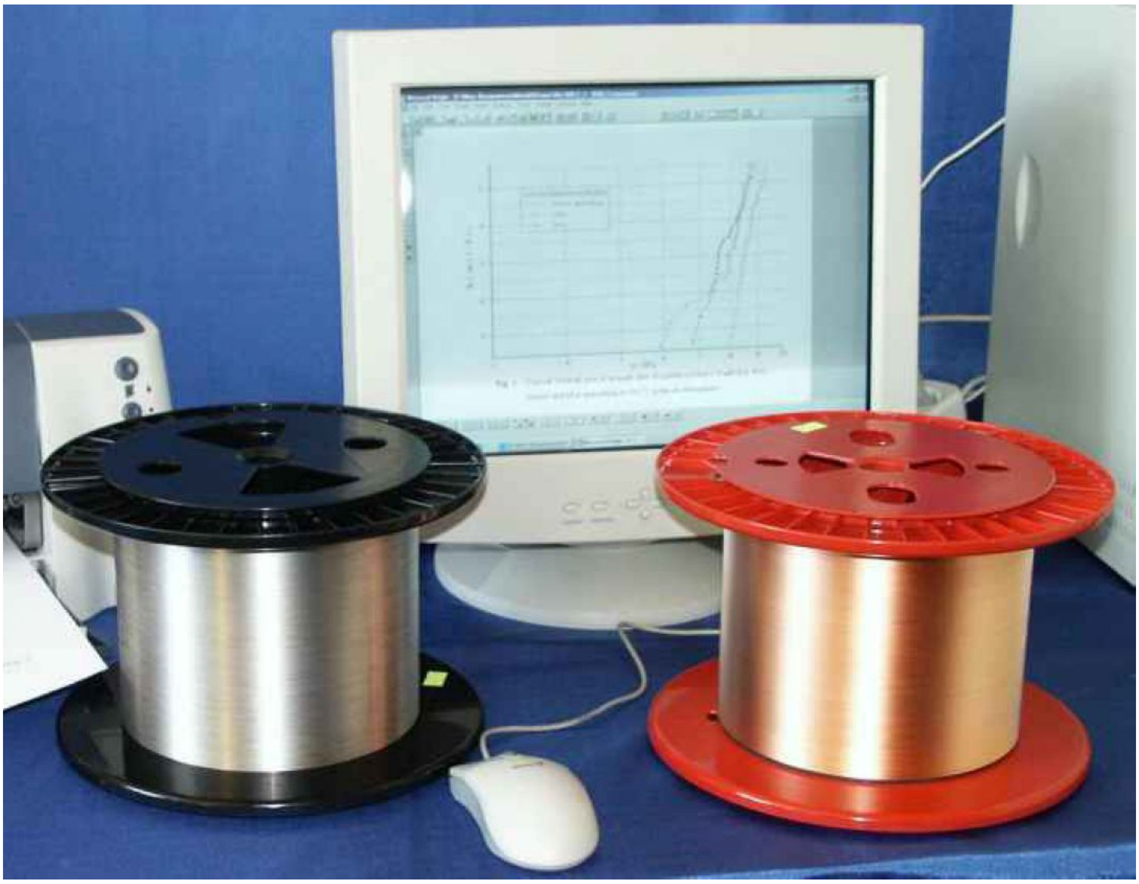

Figure 2. Metal coated optical fibers (aluminium and copper alloy).

Brillouin Scattering

Brillouin scattering is an effect that takes place in the optical media exposed by narrow-band laser radiation. The appearance of acoustic waves in optical media causes backscattered radiation (see figure 3). The frequency of the scattered signal is Stokes shifted from the frequency of the original signal. The frequency shift linearly depends on the temperature and fiber strain:

$$\Delta f = F_0 + \Delta T \cdot c_t + \varepsilon \cdot c_\varepsilon , \qquad (1)$$

where F_0 is the frequency shift (10.85 GHz for SMF-28 Corning fiber) at normal conditions; ΔT is change of the temperature; c_t is the thermal coefficient (1 MHz/K at λ=1550 nm); c_ε is the strain coefficient (490 MHz/% at λ=1550 nm); ε is the mechanical strain;

The coefficient of metal coating thermal expansion ($\sim 16.5 \cdot 10^{-6} K^{-1}$) differs from the one of the silica glasses ($\sim 0.57 \cdot 10^{-6} K^{-1}$). Therefore, heating of the coated fibers causes microbends in the optical fiber that in their turns increases optical losses. Figure 4 presents the dependence of optical losses on the temperature – an increase due to expansion of the metal coating and a decrease caused by fiber recrystallization due to coating annealing.

Microbends provoke stresses in the fiber core as well. The increase of stresses lead to increase of the silica glass density and increases the speed of sound at the same time followed by an increase of the Brillouin frequency shift. The behavior of optical fibers coated by a metal depends on a kind of the used coatings and alloys [3].

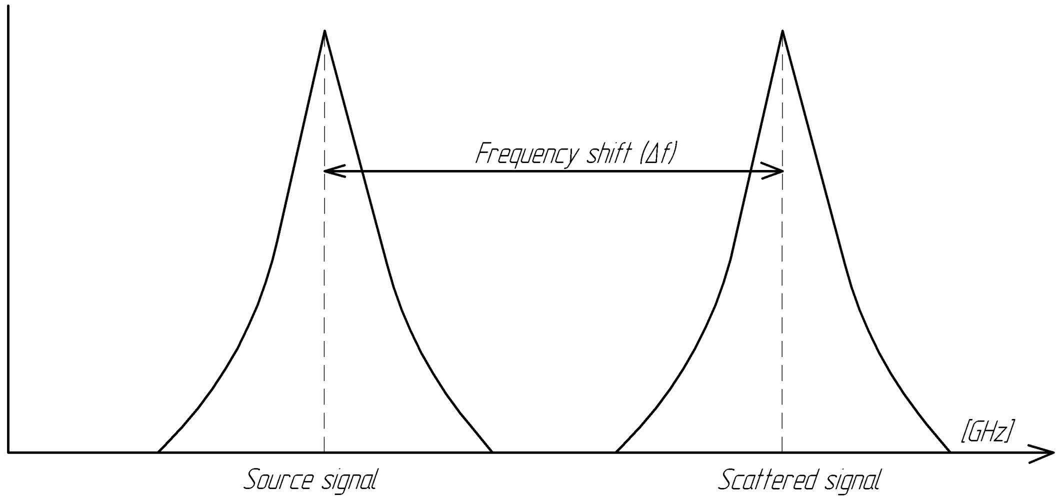

Figure 3. Brillouin frequency shift

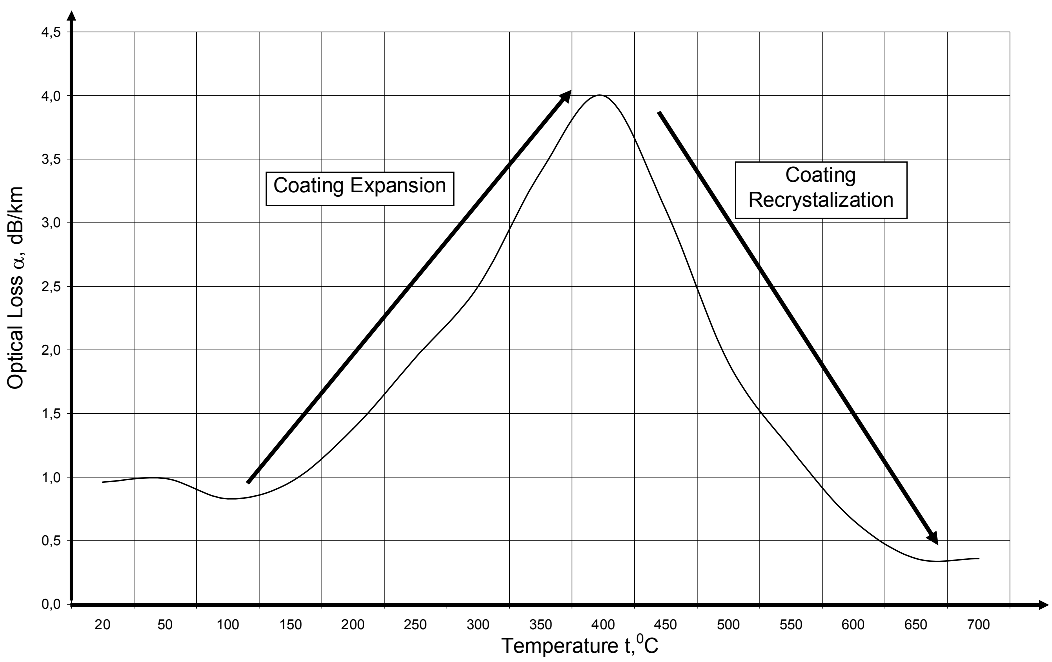

Figure 4. Dependence of optical fiber losses on temperature.

Thus, using metallized optical fibers as an active medium one can control the Brillouin frequency shift by adjusting the temperature.

Rayleigh scattering

Another well-known phenomenon observed in metal-coated optical fibers at high temperatures is an increase of the Rayleigh scattering signal with the temperature [4]. Optical fiber heating increases the speed of particle motion [5] within the fiber, increasing non-homogeneities in the optical fiber core. Changes in the scattering signal at temperatures up to 950^0C for multimode optical fiber are shown in figure 5.

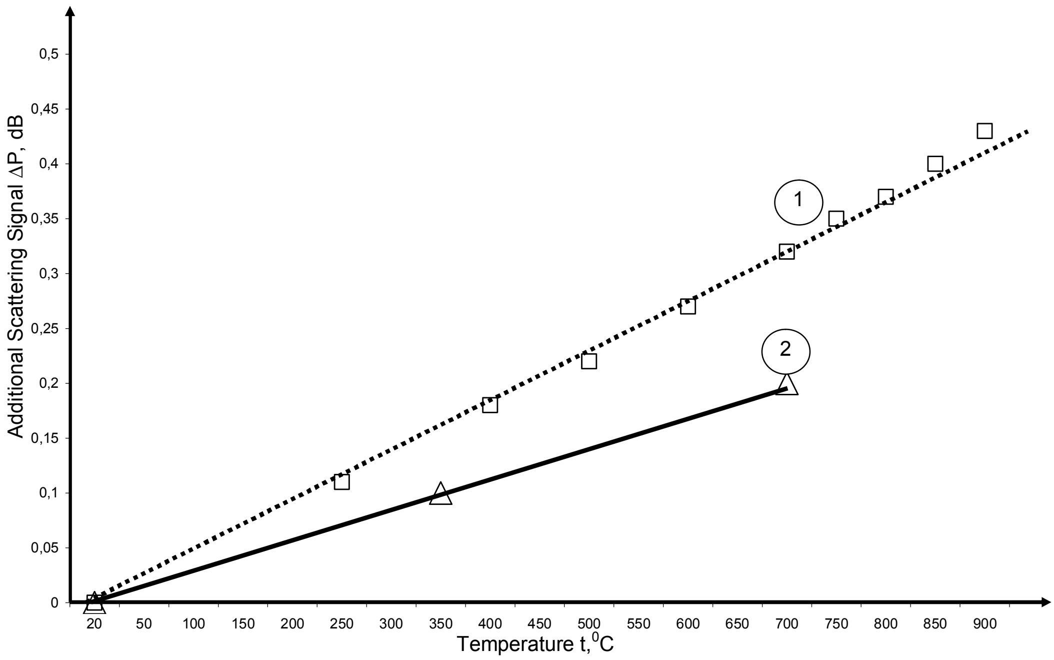

Figure 5. Additional Rayleigh scattering signal increase at temperatures up to 1000^0C . It as well depends on the doped level of GeO_2 (1 – 18 mol. %, 2 – 13 mol. %).

This phenomenon allows to decrease the length of the Random fiber laser and enables control of the active media gain by adjustment of the temperature.

Conclusion

Metal-coated optical fibers are a new kind of fibers suitable for operation with Random lasers. Their properties are still to be investigated. The authors thank Igor Vorobyov (IRE RAS) for provision of metal-coated optical fiber samples.

References

[1] S. K. Turitsyn, S. A. Babin, A. E. El-Taher, P. Harper, D. V. Churkin, S. I. Kablukov, J. Diego Ania-Castañón, V. Karalekas and E. V. Podivilov, "Random distributed feedback fibre laser," Nature Photonics, vol. 4, 231-235, 2010.

[2] A. A. Fotiadi "Random lasers: An incoherent fibre laser," Nature Photonics, vol. 4, 204-205, 2010.

[3] V. V. Voloshin, I. L. Vorob'ev, G. A. Ivanov, V. A. Isaev, A. O. Kolosovskii, B. Lenardich, S. M. Popov, and Yu. K. Chamorovskii, "Absorption Loss at High Temperatures in Aluminum- and Copper-coated Optical Fibers," Journal of Communications Technology and Electronics, vol. 56, 103-110, 2011.

[4] S.M. Popov, V.V. Voloshin, I.L. Vorobyov, G.A. Ivanov, A.O. Kolosovskii, V.A. Isaev, Y.K. Chamorovskii "Optical loss of metal coated optical fibers at temperatures up to 800 ºC," Optical Memory and Neural Networks (Information Optics), vol. 21, 45–51, 2012.

[5] I.L. Fabelinskii "Molecular Scattering of Light," New-York: Plenum, 1986.