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Study of laser induced temperature variation in silica nanofibers

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Abstract. After presenting a theoretical modelling based on the heat equation, we show two different experiments to measure the laser induced temperature variation in silica nanofibers in air, a direct one and an indirect one based on Brillouin scattering, leading to an estimated value of the convective parameter h.

1 Introduction

Optical tapered nanofibers are fabricated by heating and stretching standard silica fibers until reaching diameters comparable or smaller than the light wavelength which are homogeneous over several cm lengths. At such diameters, the optical mode is very strongly confined in the silica leading to the enhancement of optical non linearities. The mode can also exhibit an intense evanescent tail that can be used for optical sensing or traps in the vicinity of the nanofiber. One other strong advantage of tapered nanofibers compared to bulk components is their ability to be inserted in fibered networks with very low losses. All these properties make them significantly exploited for an increasing number of applications. One limitation of nanofibers that can lead to instabilities, degradation of the performances or even their destruction is their temperature increase due to the coupling of an intense laser light inside them. Only a few studies exist in the literature about these thermal effects and are limited to vacuum [1,2]. Controlling these thermal effects can also be used to propose self-cleaning of nanofibers [2]. Our aim in this paper is to study laser induced thermal effects in nanofibers, in different fluids such as air. Indeed, thermal exchanges with air at the micro and nanoscales are not well known, for example the convective coefficient (h) is still debated [3]. In our work, we propose a theoretical modelling based on the heat equation, that can be used for different gas and pressures. We take into account not only the nanofiber part but also its tapers shape. Preliminary experimental measurements of the temperature of nanofibers by two different methods (direct method and method based on Brillouin scattering) show good agreements with our simulations.

2 MODELLING

Our simulations are based on the differential heat equation valid for a cylindrical symmetry [1]:

$$c_p\rho\partial_t T\pi a^2 = -\partial_z H_{rad}(T) + \partial_z H_{rad}(T_0) + \lambda_c \partial_z^2 T\pi a^2 + \partial_z P_{heating} + dP_{gas}$$

∂_t and ∂_z are the derivative versus t (time) and z (direction of propagation), c_p and ρ are the specific heat and density of silica, λ_c is the heat conduction of silica. a is the radius depending on z. H_{rad} represents the radiative heat transfer between the nanofiber at temperature T and the environment at temperature T_0 and is calculated from the fluctuational electrodynamics [4].

$P_{heating}$ is the heat source, which in our case is due the laser propagation and is written:

$$dP_{heating} = kI(a)2\pi a dz$$

k is an absorption coefficient due to the presence of pollutants at the surface of the nanofiber [1], $I(a)$ is the intensity of the laser at the surface.

dP_{gas} represents the thermal exchanges with the surrounding gas. For pressures smaller than 1µbar, dP_{gas} is proportional to the pressure [1]. For higher pressures, we use a linear approximation to compute this term:

$$dP_{gas} = h(T - T_0)2\pi a$$

h is the convective coefficient in W/m²K and is our single adjustable parameter.

Fig 1 shows the evolution of the temperature of the nanofiber and its tapers in the stationary regime and in air (nanofiber radius r_{NF} = 450 nm, nanofiber length L_{NF} = 2 cm, pump power = 53 mW, pump wavelength λ_p = 760 nm, h = 7.2 W/m²K). The maximum temperature is achieved in the nanofiber part, with an increase of 50 K with respect to the room temperature.

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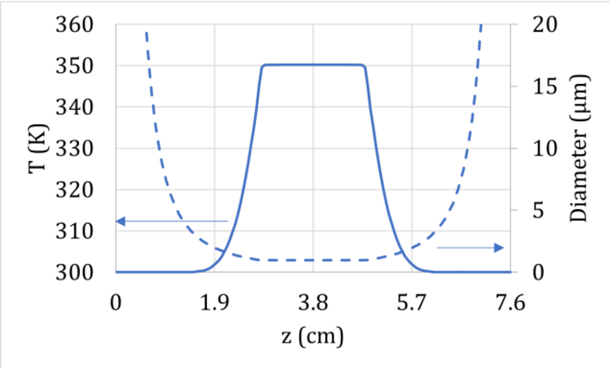

Fig. 1. Solid curve (left scale): temperature profile along the nanofiber and its tapers. Dotted curve (right scale): profile of the nanofiber and its tapers.

3 Direct method

In Fig. 2, we have represented the experimental setup for the direct measurement of the temperature of the nanofiber. The pump source is a cw laser emitting at 780 nm, which is injected in the nanofiber with a microscope objective. The nanofiber is drawn from a standard telecom fiber and preceded by a single mode filter to excite the fundamental mode only. We used a thermistor (diameter of 400 µm) that we put in contact with the nanofiber.

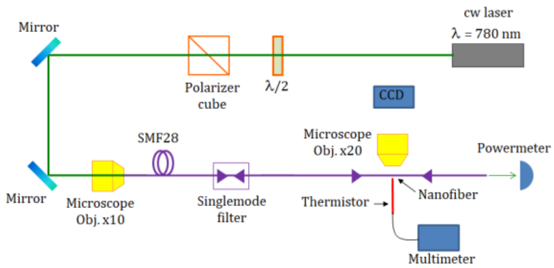

Fig. 2. Experimental setup for the direct measurement of the laser induced temperature of the nanofiber.

In Fig. 3, we have plotted the nanofiber temperature versus h which is our single fitting parameter and superposed experimental datas. The best fits give a value for h which is between 2.6 and 7.2 W/m²K.

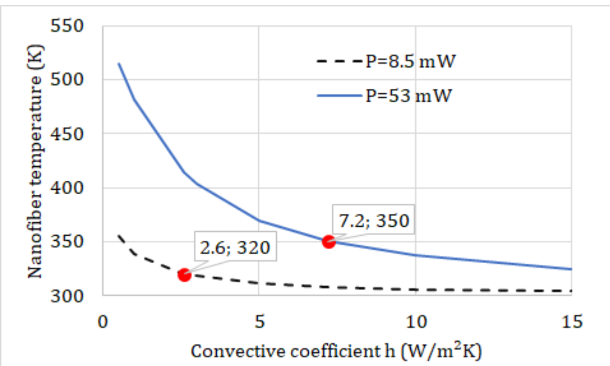

Fig. 3. Simulated nanofiber temperature versus the convective coefficient h for two different pump powers. Red points are experimental data.

4 Brillouin scattering

We have experimentally investigated the laser induced heating in nanofiber by monitoring the Brillouin scattering. In heterodyne detection, a small part of the laser pump source used to generate Brillouin scattering in nanofiber is absorbed to heat the nanofiber. We observe a linear dependence of Brillouin resonance from compression elastic wave as a function of input pump power for a nanofiber diameter of 940 nm (see Fig. 4). The slope is 0.85 MHz/°C, giving a temperature variation of 10°C between 20 mW and 40 mW, corresponding to a value of h around 5 W/m²K.

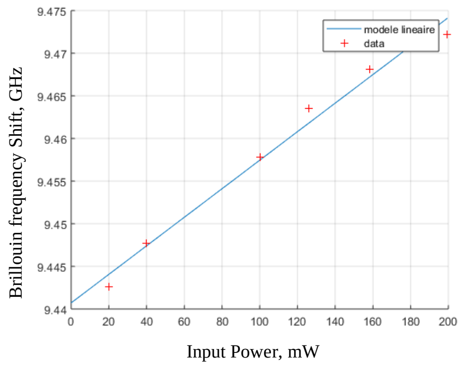

Fig. 4 Brillouin frequency shift measurement as a function of cw input power at 1550nm for a diameter of nanofiber of 940 nm and a length of 40 mm.

5 Conclusion and perspectives

We have presented a numerical model of the laser induced temperature variation of nanofiber and its tapers in air. Two different methods are used to measure the temperature. The results are consistent by fitting the experimental data with the model, which gives a range for the convective parameter h between 2.6 and 7.2 W/m²K. Further experiments will be conducted to confirm and precise these values.

References

1. P. Anderson, S. Jalnapurkar, E.S. Moiseev, D. Chang, P.E. Barclay, A. Lezama, and A.I. Lvovsky, AIP Advances 8, 055005 (2018).
2. C. Wuttke and A. Rauschenbeutel, Phys. Rev. Lett. 111, 024301 (2013).
3. X. J. Hu, A. Jain and K. E. Goodson, Intern. J. of Thermal Sciences, 47 820-824 (2008).
4. A. Vladyslav, M. Golyk, M. Kardar, Phys. Rev. E, 85, 046603 (2012).