# Study of self-heated tapered silica microfibers by laser in air

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**Abstract:** We present measurements of the temperature of optical microfibers self-heated by a cw laser emitting at 1.48 µm. The experimental method we have implemented is simple and enables to perform for the first time to our knowledge spatially distributed measurements along the tapers and the microfiber part. Temperature rise of more than 20 °C is measured for moderate powers (200 mW) and relatively large radii (1.45 µm). The results are confronted to a numerical model we have developed and enable to determine range of values for the couple thermal transfer coefficient/surface absorption coefficient.

## 1 Introduction

Optical micro or nanofiber (ONF), i.e., the homogeneous section of a stretched and tapered silica optical fiber (micro or sub micrometer diameter on length of up to more than 10 cm) between two tapered transitions, has been presented a widespread use in science and engineering applications since more than thirty years as an elementary optical component easily integrated by its nature in an all-fibered network. The expanding use of ONF is due to its physical properties. The optical modes guided by the ONF have large intensities due to their strong transverse confinement and present very low losses. The modes can also exhibit an evanescent part outside the ONF with an intensity depending on the radius. Due to these intrinsic properties, ONF-based technologies present a large versatility of domains from fundamental to applications such as quantum information devices, nonlinear optics, remote sensor devices, detection, plasmonic-based sensor devices, devices for coupling light into micro-photonic components for the most active ones. However, despite all these attractive benefits, one limitation of the ONF has been identified. When a laser light is coupled into the ONF, it has been shown that the optical mode can be absorbed by surface pollution or defaults. This surface absorption, even low, can lead to an increase of the temperature of the ONF, which can in turn induce optical instabilities. Optical performances can also be degraded by this heating and the ONF can even be destroyed [1].

Only few works have studied laser self-induced temperature evolution along ONFs [2]. These works are focused on ONFs in vacuum, where temperatures above 1000 K leading to the destruction of the ONF are measured for low input powers (20-50 mW). The first measurement of self-heating ONF in nitrogen environment has been demonstrated recently [3]. However, the proposed methods give only a value of the temperature integrated on the ONF and the tapers. In this work we propose an experimental method that enables to measure the temperature increase of ONF under laser injection. This method presents several advantages: it is very simple to implement and enable to make spatially distributed measurements not only along the ONF part but also along both tapers. The experimental data are in good agreement with the simulation program we implemented.

## 2 Experimental setup

The experimental setup is shown on Fig. 1. The ONF are pulled from standard telecom fiber (SMF-28) by a classical "pull and brush" technique. After the fabrication, the input and output ends of the untapered fiber are connected to two pigtails. The two unstreched parts on both sides of the tapers are held on two separate supports fixed on a rectangular plate with the help of two magnets, keeping the ONF and the tapers tight and suspended in air between the two supports. Then the component, i.e. the ONF with the two tapers linked to the two pigtails is put on the experimental setup on a motorized translation stage. We use a cw fibered Raman laser emitting at 1.48 µm a maximum output power of 3 W. The fibered laser output is connected to the input pigtail of the component. The output pigtail is connected to a powermeter. The optical transmission (output power versus input power) is around 80%. A type K thermocouple with a diameter of 250 µm is used to measure the temperature of the ONF and its tapers.

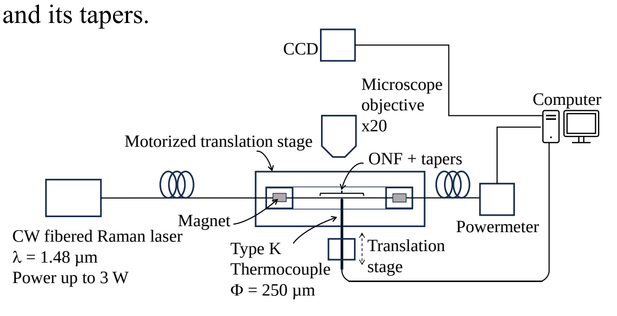

**Fig. 1**. Experimental setup.

We firstly image the unstretched beginning of the left taper having a diameter of 125 µm on the CCD camera with a microscope objective (Mitutoyo, x20). We approach the tip of the thermocouple in the field of the CCD and put its sensitive part in contact with the fiber. We check that the output power does not vary under the contact of the thermocouple, ensuring that the temperature which is measured is the one of the fiber and not induced by a leak of light. The motorized translation stage on which the ONF is put has a course of 15 cm, enabling to scan the two tapers and the ONF.

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## 3 Modelling

Our simulations are based on the differential heat equation valid for a cylindrical symmetry [2]:

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

$\partial_t$ and $\partial_z$ are the derivative versus t (time) and z (direction of propagation), $c_p$ and $\rho$ are the specific heat and density of silica, $\lambda_c$ 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.

$P_{heating}$ is the heat source, which in our case is due the laser surface absorption 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 ONF, $I(a)$ is the intensity of the laser at the surface.

$dP_{gas}$ represents the thermal exchanges with the surrounding gas. For pressures smaller than 1 µbar, $dP_{gas}$ is proportional to the pressure. 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 an adjustable parameter.

## 4 Results

We tested an ONF with a radius of 1.45 µm and a length of 1 cm and different injected powers (30 mW, 50 mW, 150 mW and 200 mW). We took a measurement point every mm. A representative result is presented in Fig. 2 at 150 mW. Fluctuations in the temperature are attributed to experimental difficulty to find for each point the best contact between the ONF and the sensitive part of the thermocouple with is not exactly at the extremity. They are also due to the presence of dust on the component.

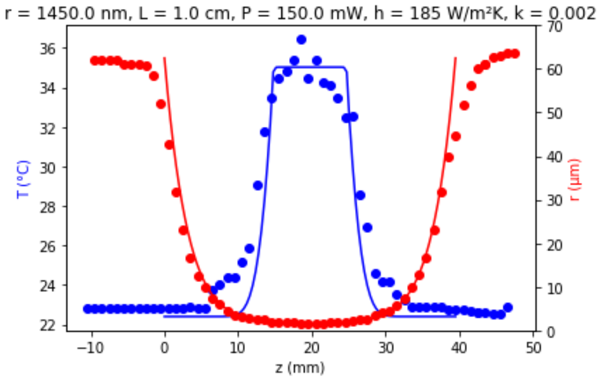

Figure 2. Temperature (blue, left) and radius (red, right), versus the position z. Rounds: experimental data, full line: theoretical model.

The temperature profile follows the diameter evolution, with a maximum temperature reached in the microfiber part. An adjustment with the theoretical model shows a good agreement with the experimental data with $k = 0.2\%$ and $h = 185\ W/m^2K$.

The maximum of temperature evolves linearly with the input power with a rate of 7.6°C/100 mW, as shown in Fig. 3. This property enables to predict the temperature rise for higher input powers. Indeed we have not exceeded an injected power of 200 mW to avoid damaging the connectors. For this power, we measured a maximum temperature rise of 20°C. We can also see on Fig. 4 that the output power does not vary during the measurement, showing that the contact with the thermocouple does not perturbate the propagation of the mode.

Other measurements with different radii and lengths will be presented during the conference as well as discussions on the modelling.

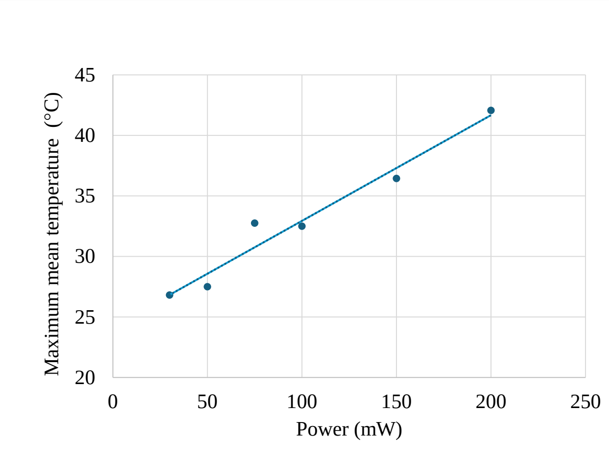

Figure 3. Maximum mean temperature versus input power.

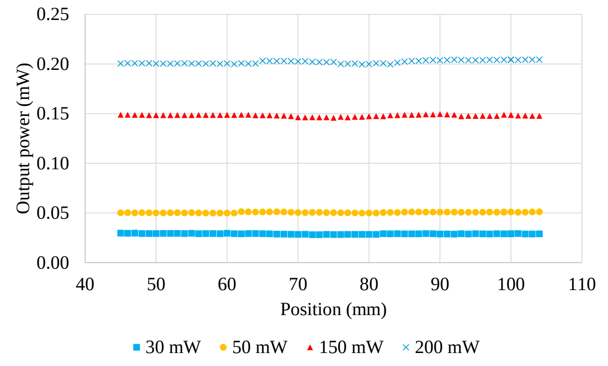

Figure 4. Output powers during the measurements.

## 5 Conclusions and perspectives

We have presented a simple method to measure the temperature of ONF versus the input powers. Data are in good agreement with the simulations.

## References

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