Challenges of temperature-dependent emission spectra measurement of thulium-doped fibers around 2 µm

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Abstract: Understanding temperature's impact on spectroscopic properties in high-power thulium-doped fiber lasers is crucial for accurate numerical modeling. Our study discusses influence of thulium concentration and temperature-induced bend losses on emission spectra measurement.

Thulium fiber amplifiers and lasers (TDFLs) are important sources of radiation around 2 um. They have a wide range of applications e.g. in industry, medicine, or defense [1]. However, their output power potential is still an order of magnitude higher than the current record of 1.15 kW [2]. The main limiting factors are associated with thermal effects in the fibers, while the temperature of more than 500 K can be reached in the fiber core during TDFL operation [3]. The laser power is affected by the increasing temperature due to the spectroscopic properties changes, which were presented in [4]. Estimating heat distribution in high-power fiber lasers is crucial for designing an efficient cooling system and predicting temperature-induced changes in relevant spectroscopic properties. Therefore, investigating the temperature dependence of spectroscopic parameters is important. However, the correct measurement of the emission spectra around the wavelength of 2 µm presents a complex problem that has to be address properly to obtain precise values that are subsequently utilized in numerical models.

The series of in-house prepared thulium-doped silica fibers with different compositions, geometry, and thulium concentrations were used for the experiments. In our study, we tested fibers fabricated using nanoparticles doping as well as solution doping techniques with single or double-clad structures. The samples, on the order of millimeters, were core-pumped by means of erbium-doped fiber laser (EDFL), by laser diode (Thorlabs, FPL1054S), or TDFL emitting at the wavelengths of 1560 nm, 1625 nm, and 1700 nm, respectively. The emission signal was collected in the backward direction using a broadband optical fiber coupler (TAP) and filters (FWDMs) together with FC/APC connectors to reduce the back-reflected pump radiation and recorded by an optical spectral analyzer (OSA). The experimental setup is illustrated in Fig. 1. Spectra were measured at various temperatures spanning from 300 K to 675 K while the active fiber was positioned on a hotplate and fixed by a Kapton tape. Additionally, measurements were taken in a liquid nitrogen bath at the temperature of 77 K. Moreover, the measurement was provided for different fiber lengths and pump powers. The obtained data were corrected to spectral dependence of used fiber components and normalized with respect to spectra measured at room temperature to provide mutual comparison.

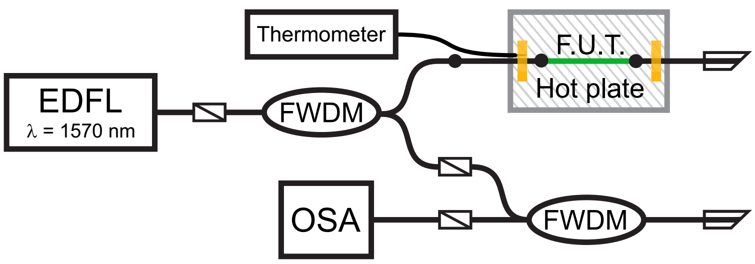

Figure 1: Setup of the temperature-dependent emission spectra measurement.

Measurement of the active fibers samples was provided with various lengths, but in all cases short enough to minimize the reabsorption effect, shows comparable results. The same situation cames unexpectedly also for the different pump wavelengths since the absorption varies for each wavelength with the temperature differently. The pump power was chosen to excite sufficiently the whole length of the sample, however as low as possible to reduce the potential heating effects. The samples with higher thulium concentration exhibited an unexpected increase in peak values during measurement. This could be surprising, however, it can be explained using a numerical model as will be shown in the presentation. The rising trend is shown in Fig. 2a). Normalized spectra for two selected fibers at the temperatures of 77 and 300 K are shown in Fig. 2b). It's worth noting to mention that the variation for higher temperatures, which is more important for laser operation, is not as significant as for the temperature of the liquid nitrogen. The peak position shift for various temperatures is in good agreement with already presented measurements [4]. Comprehensive results from our measurements for all variables mentioned will be presented alongside simulations, and their impact on accurate emission spectra measurements will be discussed.

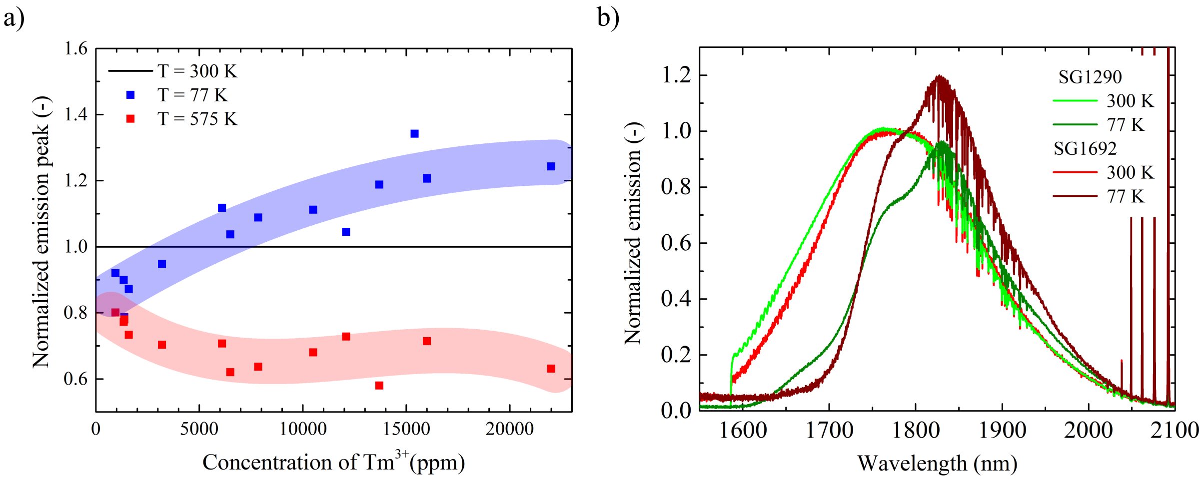

Figure 2: a) The emission peak values at 77 K and 575 K for fibers with different concentration, all values are normalized with respect to the measurement at room temperature; b) Emission spectra for two selected fibers.

The parameters of active fiber are important, but also the passive fibers need to be focused on. While the samples were spliced together with standard single-mode fibers, that were also partially cooled and heated, their transmission could be affected by the temperature change. For that reason in our contribution, we will discuss also the effect of LP_{01} mode band losses increase with decreasing temperature [5].

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