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Temperature and emissivity measurements at the sapphire single crystal fiber growth process

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ABSTRACT

We present a new method for evaluation the absorption coefficient of the crystal melt around the phase transition zone for the spectral range of semitransparency. The emissivity distribution across the crystallization front of the sapphire crystal fiber was measured at the quasi-stationary laser heated pedestal growth (LHPG) process (Fejer et al., 1984; Feigelson, 1986) and the data for solid state, melt and phase transition zone (melt-solid interface) were obtained. The sapphire melt absorption coefficient was estimated to be 14 ± 2 cm^{-1} in the spectral range 1–1.4 μm around the melt point. It is consistent with data, obtained by different other methods. This method can be applied to determine the absorption coefficient for other materials.

1. Introduction

The aim of this study was to find characteristic features of the spatial temperature and the spectral emissivity distribution over the phase transition zone when a single crystal fiber was grown in the LHPG process [1,2]. The crystal of leucosapphire was taken as the model material because more information about its material and optical data is known in comparison with other optical crystals [3,4]. In the review [4] the recent data for the sapphire absorption coefficient value are analyzed. These data were obtained in two types of the experiments: the absorption coefficient measurement of molten aluminum oxide particles and of molten layers (including the melting top of sapphire fiber filament [5]). Unlike [5] we used in our measurements the axial symmetry heating of the sample in the steady state growing process. In the measurement process the rates of the source rod feeding, crystal fiber pulling, laser power, fiber diameter and molten zone size should be maintained constant. So the spatial position of the melt and phase transition zones and the temperature distribution did not depend on time. To provide conditions for stable growth of single crystal fibers it is useful to have a set of characteristic properties, specific to the particular crystal growth. Our experimental findings will serve as additional parameters to control the growing process of single crystal fibers.

The thermal radiation spectra were measured in 1–1.4 μm spectral domain. In this spectral range sapphire is transparent at the room temperature. However, high radiation absorption appears in this range when the temperature increases [3,4]. The melting point of sapphire is about 2327 K. Nevertheless, even at the melting point the sample cannot be considered as a common black body, because it absorbs radiation only partially. Radiation spectra of the semi-transparent sample supply information not only about the sample surface, but also about its central part. Fig. 1A displays the photo of the sapphire growth zone under investigation. The crystal fiber diameter is 650 μm. The melt area height along Z axis (the pulling direction) is about 1.5 mm, the melt volume is about 1–2 mm^3. The molten zone shines brightly in the visual range. The light intensity decreases towards the growing fiber and also towards the source rod. It seems that the only available technique to determine the temperature of so small hot sample is the method based on the emission spectral pyrometry. We measured the thermal emission spectra and then compared them to the spectra of the black body radiation [6,7]. In a similar process while fiber drawing from the vitreous SiO_2 the temperature is measured at the surface of the preform heating zone with the use of a pyrometer operating at 5–6 μm wavelength. Fused silica possesses very high absorption coefficient at 5–6 μm and is not transparent.

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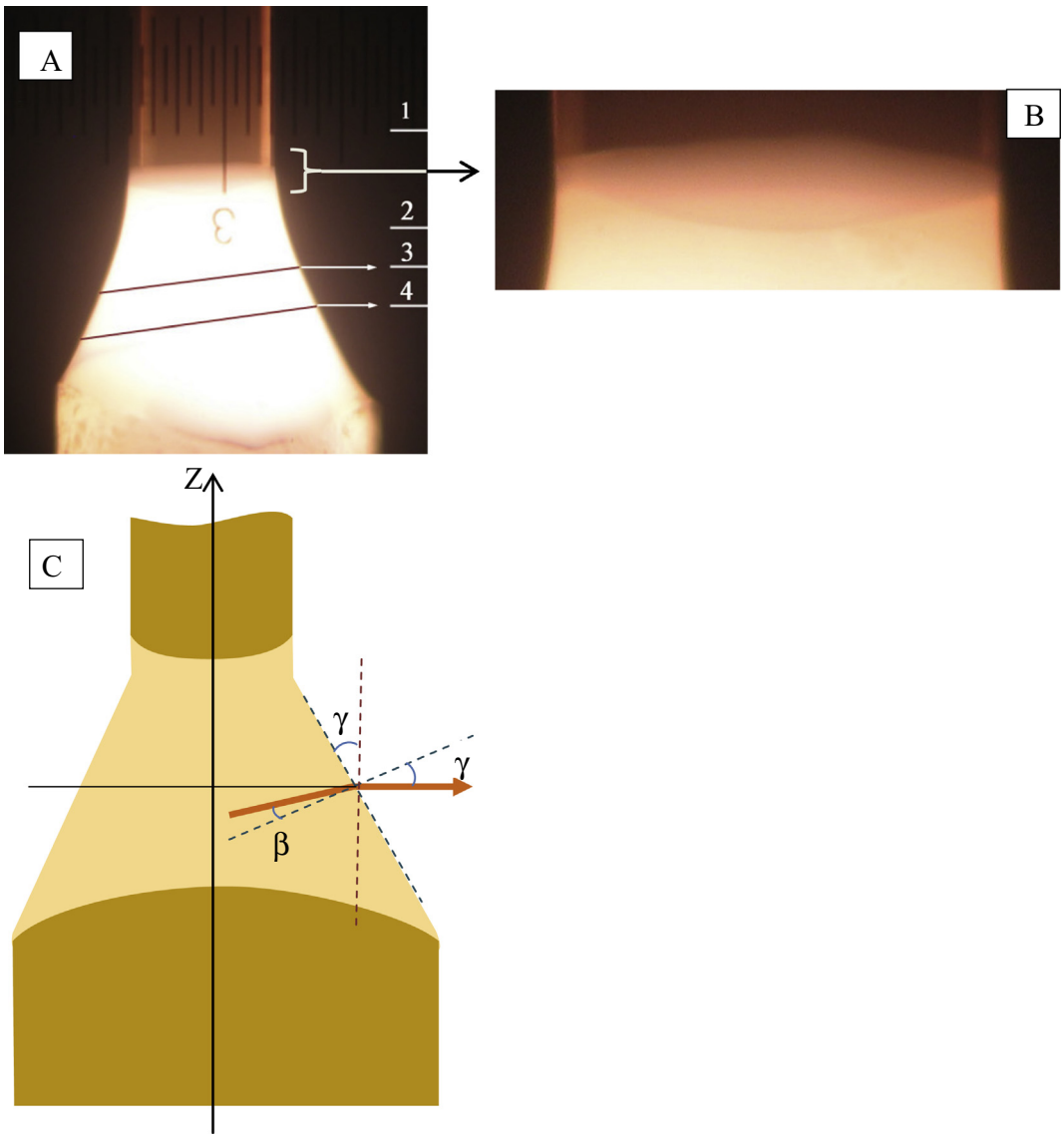

Fig. 1. (A) Photo of the sapphire single crystal fiber growth area. The scale division is 50 μm. The single crystal sapphire source rod with diameter of 1.3 mm is at the bottom and the crystal fiber is at the top, the melt zone is in the middle. The ray tracks are schematically drawn. Characteristic positions of measurements being used in other figures and discussion are marked at the right side; (B) Enlarged image of the melt-solid interface; (C) Schematic of the beam propagation in the sample at the measurements.

Unlike glass, the crystal fiber growth zone includes two different phase transitions: (1) the crystallization front between the growing fiber and the melt and (2) the boundary between the melt and the source rod (Fig. 1A). For the crystal growth the shape of the crystallization front is one of characteristic parameters of the process (see e.g., [8,9]). A more detailed photo of sapphire fiber crystallization front is shown in Fig. 1B. We used spectral pyrometry [6] to determine the temperature distribution over the growth zone of the sapphire single crystal fiber.

2. Experiment

Our experimental setup for single crystal fiber growth involved the LHPG method with CO_2 laser heating source. As a source rod we used sapphire single crystals square shaped in cross section (1.3 mm $*$ 1.3 mm) with smoothed edges. The fiber was pulled out by oriented seed crystal (along C axis) from the molten tip (pedestal) of a source rod. This setup was described in detail in the Ref. [10]. The measurement arrangement was similar to that in our previous experiment [11]. However, in [11] the optical aberrations of the image system substantially restricted the spatial resolution of the system. In order to understand the peculiarities of the temperature profile along the melt zone we need the sharp image in NIR range; it should be as free from chromatic aberrations as possible. Therefore, in the present paper we have reduced the effect of the aberrations of the optical system by reducing the numerical aperture of the optical system to use the paraxial radiation rays and by limiting the spectral measurement range. In addition (compared to [10]), in the present study we analyzed not only the shape of the spectrum, but its intensity also.

Using the optical system we formed the magnified (x 1.7) image of the sample (Fig. 2). Thermal radiation spectra were measured with the spectrometer Sol 1.7 (BWTEK Inc.). The spectrometer multimode fiber pigtail delivered the radiation from the image of the growth area to the spectrometer. The radiation flux always passed through the same area (d = 100 μm). This area was formed by the end face of the pigtail being placed in the image plane. The spectra were measured in different spatial points of the sample image.

As it was mentioned above the operational spectral range was restricted to avoid the influence of the chromatic aberrations. We