Sapphire shaped crystals for medicine

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Abstract. The favorable combination of excellent optical and mechanical properties of sapphire makes it an attractive structural material for medicine. We have developed a new kind of medical instruments and devices for laser photodynamic and thermal therapy, laser surgery, fluorescent diagnostics, and cryosurgery based on sapphire crystals of various shapes with capillary channels in their volume.

1. Introduction
Sapphire has a high refractive index and a broad transmission band spanning the UV, visible, and IR bands. Sapphire also has high hardness, very good thermal conductivity, tensile strength, and thermal shock resistance. This favorable combination together with chemical inertness and biocompatibility, makes it an attractive structural material for medicine. A number of growth techniques have been developed to manufacture sapphire crystals of complex shapes directly from melt [1]. Sapphire shaped crystals holding multiple capillary channels with diameters are less than 600 microns in the crystal volume have been grown. This development has given rise to the emergence of essentially new areas of application.

In recent years we are developing new instruments and devices for laser treatment on the base of new sapphire shaped crystals:

- Sapphire needle capillary irradiators for laser radiation delivery for photodynamic interstitial therapy, laser thermotherapy and an ablation of tumors of a prostate, a liver, a thyroid gland, etc.
- Sapphire scalpels with possibility of coagulation and fluorescent diagnostics of malignancy of resected tissues in a vicinity of a cutting edge directly in the surgery process;
- Cryoapparatus for destruction with sapphire cryotips-lightguide;
- System for removal of brain tumors based on a sapphire probe with demarcation of borders of a tumor by fluorescent diagnosis and others.

Sapphire needle capillaries were developed as new laser waveguide introducers for delivery radiation into a tumour during interstitial laser photodynamic therapy, thermotherapy, and ablation of tumors [2]. These needles allow one to increase the irradiation volume substantially, to obtain an optimal temperature distribution, to simplify the design, and to eliminate a system for cooling the device. The high hardness of sapphire provides a stable point on the irradiator end for independent introduction of the irradiator into the tissue without using directors that lead to the increase in irradiator cross-section. The use of sapphire irradiators make it possible to improve the control over the dynamics of spatial photothermal distribution during the whole irradiation procedure, since the
effective redistribution of released heat by the sapphire decreases the possibility of formation of overheating nuclei, leading to the appearance of thrombi, nontransparent to laser radiation.

**Figure 1.** At the left: sapphire needle capillaries (external diameter of 1.2 mm, internal diameter of 0.5 mm): (a) as grown closed capillary; (b) capillary with a point formed by mechanical operation of the butt; (c) capillary with a point and diffuser formed by mechanical operation. At the right: sapphire needle combined with quartz fiber (the geometry of light field). The geometry of light field in sapphire needle (OD 1.2 mm, ID 0.5 mm) combined with quartz fiber.

Sapphire scalpsels with simultaneous incision and rapid real-time feedback analysis for on-line fluorescent diagnostics of tissues during surgery during surgical operation have been developed [3]. The principle of the new system is based on the use of isolated capillary channels in the volume of the sapphire scalpel for introducing of quartz waveguides, figure 2. One of the waveguides is used for delivering the laser radiation directly to the narrow region of the cutting edge and local excitation of photoluminescence. Another one is used for catching and transfer of photoluminescence to spectrometer. A laser optically coupled directly inside the edge, which acts as an optical wedge, allows obtain effective concentration of the laser energy in the area of the cutting edge of the scalpel for coagulation blood adjacent incision.

**Figure 2.** Sapphire scalpel for diagnostic and coagulation of incised tissue during a surgical operation (at the left). Fluorescent spectra in different position of scalpel edge: a – normal tissue, b – tumor (at the right).

The system for removal of brain tumors based on a sapphire multi-channel probe with demarcation of borders of a tumor by fluorescent diagnostics with simultaneous coagulation and aspiration was developed, figure 3. It carries out simultaneous laser coagulation for a hemostasis, tumor aspiration via the through channel of a sapphire probe, and also makes local optical measurements of properties of brain tissue for more exact and full removal of malignant tissue.
The new sapphire cryotips-irradiators made of shaped sapphire are developed. They could be used for cryodestruction of tumors, including big sizes of tumors and allow to carry out simple and convenient sterilization. Usage of the sapphire cryotips may give rise to creation of new techniques of tumors treatment by combination of cryosurgery with laser therapy fluorescent diagnosis due to direct delivery of light radiation to a biological tissue.

**Conclusions**
The development of sapphire shaping growth methods has given rise to the emergence of essentially new areas of application, including medicine. The application of sapphire can significantly help or completely overcome problems which slow down development of perspective and priority laser methods of treatment in oncology.

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