Control of the ice ball formation during tissue cryosurgery using sapphire shaped crystals

Zotov A.K. [1,2*], Dolganova I.N. [1,2], Shikunova I.A. [1] and Kurlov V.N. [1]

[1] Institute of Solid State Physics of the Russian Academy of Sciences,
[2] Bauman Moscow State Technical University
**E-mail: akzotov@hotmail.com*

Cryoablation is the method of living tissue removing by their freezing. This method has several advantages; among them are relative painlessness, hemostatic effect, minimal damage to healthy tissues, and shorter patient rehabilitation [1]. This method implies special cryoprobes that are in contact with tissue to be removed. Such probes must possess a number of features for effective performance, such as biocompatibility, chemical inertness and high thermal conductivity for achieving rather high cooling rate that is essential for tissue cryonecrosis. Despite the advantages of cryosurgery, the process of cryoablation is associated with certain risks of damage to surrounding healthy tissues, as well as incomplete cell death. To increase the effectiveness of this method, it is important to control the tissue freezing depth [1-3].

Due to high transparency in a wide spectral range, chemical resistance and high thermal conductivity at cryogenic temperatures sapphire crystals provide a favorable material platform for cryosurgical instruments [4-8]. To monitor the cryoablation process, the developed sapphire probe enables measurement of the intensity of diffuse reflection for non-invasive detection of tissue freezing depth [7]. In this work, we demonstrate the developed sapphire cryoprobe and experimentally confirm the possibility of monitoring of the ice ball formation in tissues. In addition, we compare the performance of the most commonly used metal probes with the sapphire one. The results reveal the benefits of sapphire for cryosurgical applications.

The work was supported by the Russian Science Foundation Project No. 19-79-10212-P.

References

[1] Tumor ablation. Principles and practice. Ed. by E. van Sonnenberg et al. Springer-Verlag New York; (2005).
[2] J. Bischof, K. Christov, B. Rubinsky, “A morphological study of cooling rate response in normal and neoplastic human liver tissue: Cryosurgical implications,” Cryobiology 30, 482–492 (1993).
[3] W.B. Bald and J. Fraser, “Cryogenic Surgery,” Reports on Progress in Physics, 45, 1381 (1982).
[4]. I. Shikunova et al., “Sapphire capillary interstitial irradiators for laser medicine,” Proc. SPIE 10716, 1071605 (2018).
[5] G. Katyba et al., “Sapphire shaped crystals for waveguiding, sensing andexposure applications,” Prog. Cryst. Growth Charact. Mater. 64(4), 133–151 (2018).
[6] V.N. Kurlov et al., Crystal Growth Processes Based on Capillarity: Czochralski, Floating Zone, Shaping and Crucible Techniques. Chapter 5. Shaped Crystal Growth (pages 277-354), John Wiley & Sons, United Kingdom (2010).
[7] E.N. Dubyanskaya, et al. “A concept of cryoapplicator based on sapphire shaped crystal enabling control of the ice ball formation using spatially resolved elastic backscattering of light,” Proc. SPIE, 10685, 1068529 (2018)
[8] Arsen K. Zotov, Arsenii A. Gavdush, Gleb M. Katyba, Larisa P. Safonova, Nikita V. Chernomyrdin, Irina N. Dolganova, "In situ terahertz monitoring of an ice ball formation during tissue cryosurgery: a feasibility test," J. Biomed. Opt. 26(4) 043003 (2021)