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DEPARTMENT OF BIOMEDICAL SCIENCES

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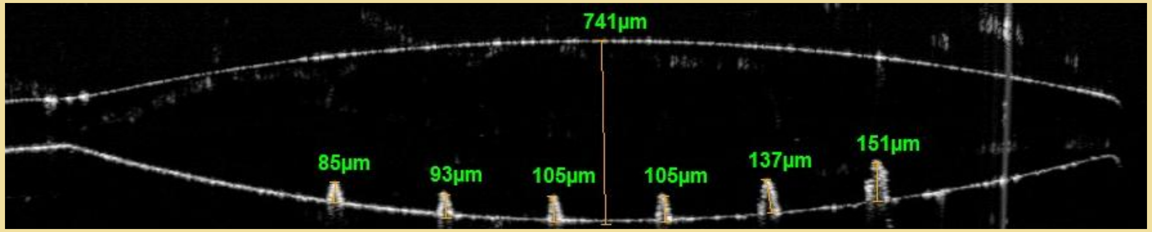
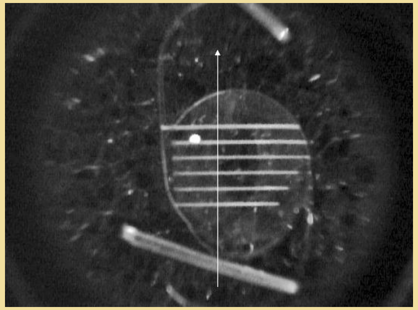
“Estimating Femtosecond Laser ablation depth on PMMA IOLs through OCT imaging”





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“Estimating Femtosecond Laser ablation depth on PMMA Intraocular Lenses Through OCT Imaging”

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Conflicts of Interest: The authors declare no conflicts of interest.

Abstract

Prosthetic lens implants, particularly intraocular lenses (IOLs), are the most effective solution for restoring vision after cataract surgery or in cases of severe refractive errors [1]. While IOLs replace the eye’s natural lens through minimally invasive procedures, they eliminate the ability to accommodate, forcing patients to choose between corrected distance or near vision, often requiring additional eyewear [2]. This limitation underscores the need for personalized IOLs. In this study, we explored femtosecond laser ablation (513 nm, 200 fs) on PMMA IOL surfaces to create micron-scale apodized patterns. This marks the first use of this specific wavelength for IOL surface modification. We also introduced a novel combination of Scanning Electron Microscopy (SEM) and Optical Coherence Tomography (OCT) to assess ablation depth. The resulting smooth microstructures show promising potential for advancing customized refractive and cataract surgery solutions.

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Materials and Methods

A simplified schematic of the experimental setup is depicted in Figure 1. We utilized the PHAROS Laser System from Laser Conversion emitting 200 fs pulses and operating at a wavelength of 513 nm (second harmonic). The maximum power of the laser was 528 mW and the maximum repetition rate was 6 kHz. Laser beam diameter before the lens was 4.5 mm (at the 1/e2 of the maximum). The intraocular lenses used as samples were made from PMMA and had powers of +24.5 and +25.5 diopters (Hanita lenses, model BAL-15). During the experiments the energy and the intensity of the beam was changed in order to achieve different ablation spots.

The ablation spots obtained on the IOL were characterized by two methods. The resulting structural and optical changes of the ablation process were analyzed by SEM and OCT was used to measure the depth of the ablation spot [3].

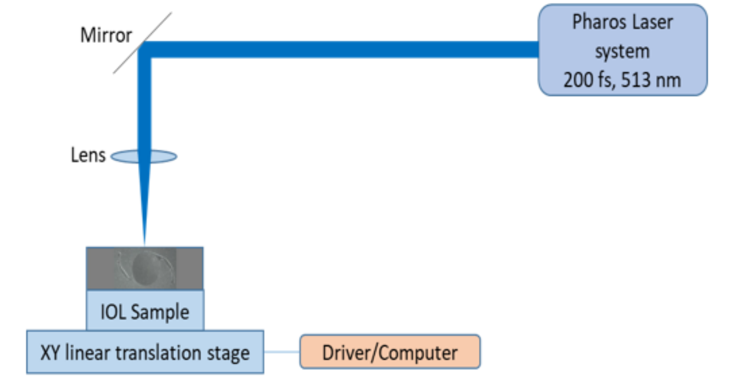

Figure 1. Simplified schematic of the experimental setup. The laser beam is focused on the sample by a 15 mm focal-length lens.

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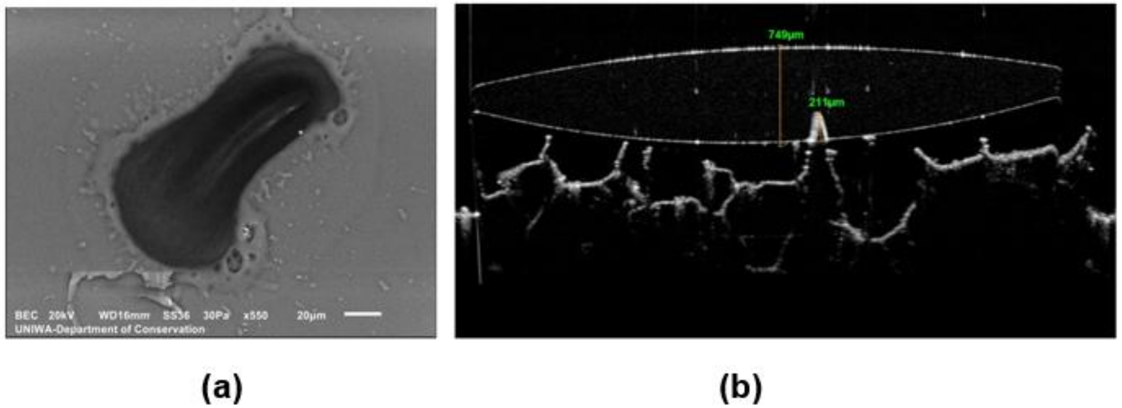
Results

Following the final experimental series, indicatively we present an image of one of the ablated samples. We utilized 200 femtosecond laser pulses at 513 nm (second harmonic) and we observed, for the first time to our knowledge, the formation of well-defined craters on the surface of PMMA intraocular lenses (IOLs). These craters exhibit smooth edges and are notably free of internal cracks or debris, which is crucial for maintaining the optical integrity of the lens [Figure 2].



(a) (b)

Figure 2. maximum power 528 mW , maximum repetition rate 6 kHz, 200 pulses (a) SEM image of laser ablated spot; (b) OCT images of the measurements of both IOL thickness and the ablation depth.

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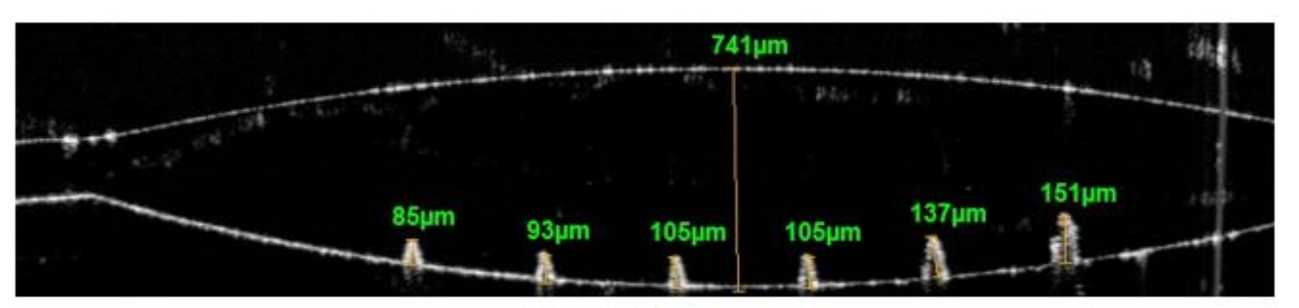
Results

These findings confirm that femtosecond laser pulses can induce controlled and repeatable structural changes in PMMA IOLs. The correlation between laser parameters—such as pulse energy, repetition rate, and focusing conditions—and the resulting morphological features provides a foundation for predictive modeling of laser-material interactions.

Moreover, the smoothness and precision of the ablated structures suggest that such modifications could be harnessed for custom refractive tuning. By adjusting laser parameters, it may be possible to engineer localized changes in refractive index or introduce diffractive patterns that alter light propagation through the lens. This opens the door to post-manufacturing customization, allowing for patient-specific corrections in diopter strength or chromatic filtering.



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Conclusions

The interaction of femtosecond laser pulses with PMMA intraocular lenses reveals significant implications for ophthalmic applications, particularly in the areas of lens modification, precision micromachining, and potential enhancement of surgical out-comes. This study demonstrates that femtosecond lasers can induce controlled structural changes on the surface of PMMA with minimal thermal effects, owing to their ultrashort pulse duration and high peak intensity. These findings support the feasibility of using femtosecond laser technology in the visible and in the blue-UV range with specific intensities for precise intraocular lens adjustments, such as correcting refractive errors for the construction of customized optical properties either before cataract surgery, either post-implantation or engraving identification marks. However, further investigation is warranted especially in the area of UV, focusing the laser on both the surface and the interior of the IOL to assess long-term material stability, biocompatibility, and the effects of repeated or high-energy exposure. The insights gained from this work contribute to the development of more advanced and personalized ocular treatments, pushing the boundaries of what is possible in laser-assisted ophthalmology. Femtosecond laser processing presents a promising route toward the next generation of customized, high-precision IOLs [3].

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