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Removal of Lattice Imperfections that Impact the Optical Quality of Ti:Sapphire using Advanced Magnetorheological Finishing Techniques

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Abstract

Ti:sapphire has become the premier lasing medium material for use in solid-state femtosecond high-peak power laser systems because of its wide wavelength tuning range. With a tuneable range from 680 to 1100 nm, peaking at 800 nm, Ti:sapphire lasing crystals can easily be tuned to the required pump wavelength and provide very high pump brightness due to their good beam quality and high output power of typically several watts. Femtosecond lasers are used for precision cutting and machining of materials ranging from steel to tooth enamel to delicate heart tissue and high explosives. These ultra-short pulses are too brief to transfer heat or shock to the material being cut, which means that cutting, drilling, and machining occur with virtually no damage to surrounding material. Furthermore, these lasers can cut with high precision, making hairline cuts of less than 100 microns in thick materials along a computer-generated path. Extension of laser output to higher energies is limited by the size of the amplification medium. Yields of high quality large diameter crystals have been constrained by lattice distortions that may appear in the boule limiting the usable area from which high quality optics can be harvested. Lattice distortions affect the transmitted wavefront of these optics which ultimately limits the high-end power output and efficiency of the laser system, particularly when operated in multi-pass mode. To make matters even more complicated, Ti:sapphire is extremely hard (Mohs hardness of 9 with diamond being 10) which makes it extremely difficult to accurately polish using conventional methods without subsurface damage or significant wavefront error. In this presentation, we demonstrate for the first time that Magnetorheological finishing (MRF) can be used to compensate for the lattice distortions in Ti:sapphire by perturbing the transmitted wavefront. The advanced MRF techniques developed allow for precise polishing of the optical inverse of lattice distortions with magnitudes of about 70 nm in optical path difference onto one or both of the optical surfaces to produce high quality optics from otherwise unusable Ti:sapphire crystals. The techniques include interferometric, software, and machine modifications to precisely locate and polish sub-millimeter sites onto the optical surfaces that can not be polished into the optics conventionally. This work may allow extension of Ti:sapphire based systems to peak powers well beyond one petawatt.

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