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Temporal Airy Pulses for Precision Processing of High-Bandgap Dielectric Materials

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High bandgap materials like fused silica and soda-lime glass are widely utilized in optics, optoelectronics, and microfluidics due to their advantageous properties, such as transparency, thermal stability, and chemical resistance. However, conventional methods of processing these materials pose significant challenges. Ultrashort pulse lasers are now essential for precise micromachining of these materials, due to their ability to induce nonlinear absorption with minimal thermal damage. Bandwidth-limited pulses with Gaussian temporal and spatial profiles predominantly result in surface ablation craters when interacting with dielectric materials. Our previous study demonstrated that Temporal Airy Pulses (TAP), generated by imposing cubic spectral phase on 30 fs pulses from a Ti:Sapphire laser at 790 nm, enabled sub-diffraction-limited processing of fused silica [2]. A theoretical model was also developed to explain how positive and negative TAP modulate the balance between multiphoton and avalanche ionization during laser-induced breakdown [1]. This model was experimentally validated by time-resolved measurements of transient electron plasma density [3].
In this study, we expand TAP to address the precision dicing of ultrathin soda-lime glass plates. We conducted a comparative analysis of three distinct pulse types: bandwidth-limited (BWL) of 30 fs pulses and TAP with positive and negative cubic phase of 600,000fs (TAP+ and TAP-). These pulses were evaluated at various fluences and two focusing conditions, 50× and 20× microscope objectives. The performance of the cutting process was evaluated by measuring the breaking force using a custom four-point bending setup. We also assessed the surface and cross-sectional quality through visual analysis using optical microscopy.
Our findings show that TAP+ provides clean, flat-cut edges with superior breaking strength, significantly outperforming BWL and TAP- pulses [4]. A close examination of these results suggests that TAP laser processing has the potential to serve as a promising non-contact alternative to mechanical cutting methods, particularly in the context of thin dielectric and semiconductor substrates.

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