Analysis and prediction of surface topography evolution in laser recovery monocrystalline silicon

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Surface defects generated during the machining of monocrystalline silicon optical components can weaken the performance of optical systems. Recovery of the damage introduced by mechanical machining to optical components is a crucial approach to enhancing the overall performance of optical systems. In this study, pulsed laser was employed to recover monocrystalline silicon mirrors post single-point diamond ultra-precision cutting. The surface topography evolution of monocrystalline silicon with varying laser fluence was investigated using white-light interferometry, and a predictive model for laser-recovered surface topography was established. The findings indicate that the recovery process can be divided into six regimes according to the evolution of surface topographical characteristics with varying laser fluence: bulge, coalescence, smoothness, groove, ripple, and ablation. When the laser fluence ranged between 16 and 23 J/cm², surface cutting texture were effectively eliminated, reducing surface roughness from 6 nm to 0.7 nm. The predictive model accurately calculates the post-laser-recovered surface topography, exhibiting a Root Mean Square Error of less than 1 nm in alignment with experimental results. Thermal stress, melting, and vaporization are the primary driving forces influencing surface shaping. The plastic deformation induced by thermal stress can lead to amorphous transformation in the substrate material, as well as the plastic protrusions on the surface. Melting facilitates the material's self-driven movement towards a state of minimal surface energy, which is typically a flattened condition. However, an excessively high laser fluence can exacerbate Marangoni convection and vaporization on the material's surface, thereby degrading both surface and subsurface quality. By employing the predictive model to effectively coordinate these factors and optimize laser parameters, the recovery of monocrystalline silicon from machining damage can be achieved.