Demonstration of femtosecond laser micro-stressing in correction of thin silicon optics for X-ray telescopes

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Abstract:
Fast development of ultrafast laser technologies over the last two decades has triggered wide applications in the processing of both transparent and opaque materials, from micromachining to laser surgery. Future space X-ray telescopes, for example the Lynx X-ray Observatory under study for the 2020 Astrophysics Decadal Survey, requires high resolution, large field of view and large effective area X-ray mirrors. Various scientific, engineering and economic considerations make the manufacturing and correcting of the telescope optics challenging. In spite of many major improvements in current methods, such as glass slumping, silicon pore optics, and monocrystalline silicon polishing, the resolution limitations and stability problems have not been fully addressed.

We are developing a novel X-ray mirror correction method using femtosecond lasers, by focusing the laser beams into small volumes (~ a few cubic microns) beneath the surface of the substrate, and creating local stresses inside the focusing region. We pattern these laser shots densely to further create macro structural change of the whole mirror substrate, to compensate the undesired substrate stresses introduced from other mirror manufacturing processes. This novel process provides a rapid and precise way of inducing controllable deformations within the interior of thin optics, which is crucial to fulfil the stringent resolution requirements for telescope mirrors. In this paper, I will present our latest design of the femtosecond laser micromachining system at MIT SNL/RLE using an IR laser at 200 fs pulse duration. We demonstrate this process on both thin flat fused silica optics and silicon substrates. I will report on the experimental results of structural deformation and local changes of material properties in the mirror substrates, by measuring surface wavefront with interferometers and analyzing images with optical microscopes. I will also discuss the influence of machining properties, such as laser pulse energy and machining density, to the induced stress inside the silicon substrates.