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Fabrication of anti-reflective moth-eye structures using ultrashort-pulse laser processing and their application to radio astronomy observations.

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In radio astronomy, suppressing surface reflection from optical components such as lenses, windows, and filters is a fundamental yet crucial issue for improving signal detection sensitivity. This is especially important in the sub-terahertz to terahertz frequency range, where typical transparent materials have high refractive indices and suffer from substantial Fresnel reflection. Moth-eye surface structures are promising because they provide a gradual effective refractive-index transition between air and the substrate, enabling broadband anti-reflection without multilayer coatings. However, moth-eye structures for these wavelengths require submillimeter-scale heights and periods, which are difficult to fabricate by conventional lithography or mechanical machining, especially over large areas and on various materials. In this talk, I report the fabrication of such structures using ultrashort-pulse laser processing, a maskless direct-writing technique that enables three-dimensional surface structuring over macroscopic areas.

By controlling the laser irradiation and scanning conditions, we formed moth-eye structures with suitable height, pitch, and arrangement for sub-terahertz and terahertz optics (Fig. 1) [1-3]. The fabricated structures effectively reduced reflection and enhanced transmission over broad frequency ranges relevant to astronomical observations. Importantly, these laser-fabricated moth-eye structures have already been implemented in optical components used at a radio astronomy observatory, demonstrating their practical applicability beyond laboratory-scale experiments [4-5]. We also found that, when combined with a thin absorbing film, the structures can function as ultrabroadband absorbers [6]. Because the anti-reflective function is integrated directly into the substrate surface, moth-eye structures offer high robustness under vacuum and cryogenic environments, avoiding failures associated with multilayer coatings. These results demonstrate that ultrashort-pulse laser processing can overcome a key fabrication bottleneck and provide a promising platform for broadband and durable optical components for next-generation high-sensitivity radio astronomy instruments.

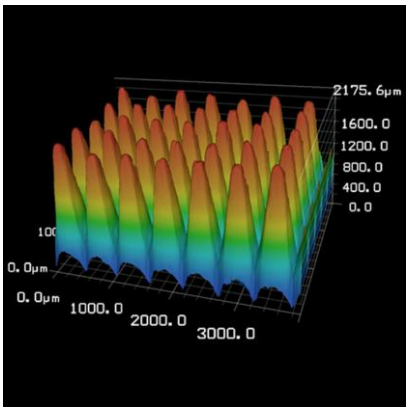

Fig. 1. Laser microscope image of a moth-eye structure fabricated by ultrashort-pulse laser processing.

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