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Substrate and coating defect planarization strategies for high-laser-fluence multilayer mirrors

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ABSTRACT

Planarizing or smoothing over nodular defects in multilayer mirrors can be accomplished by a discrete deposit-and-etch process that exploits the angle-dependent etching rate of optical materials. Typically, nodular defects limit the fluence on mirrors irradiated at 1064 nm with 10 ns pulse lengths due to geometrically- and interference-induced light intensification. Planarized hafina/silica multilayer mirrors have demonstrated >125 J/cm^2 laser resistance for single-shot testing and 50 J/cm^2 for multi-shot testing for nodular defects originating on the substrate surface. Two planarization methods were explored: thick planarization layers on the substrate surface and planarized silica layers throughout the multilayer in which only the silica layers that are below one half of the incoming electric field value are etched. This paper also describes the impact of planarized defects that are buried within the multilayer structure compared to planarized substrate particulate defects.

1. Introduction

High-quality multilayer laser mirrors for 1064 nm wavelength laser systems operated in the nanosecond pulse length regime tend to be fluence-limited by micron-scale nodular defects [1–6]. These defects originate as inclusions that are then over coated with multilayer thin films. Electric-field modeling has clearly shown light intensification due to the geometric and interference nature of these defects [7–16]. The inclusions are caused by contaminates on the surface or from particulates generated during the coating process that become imbedded inclusions within the multilayer stack. Previous work has explored planarization of substrate surface inclusions and an associated improvement in laser resistance [17,18]. Planarization technologies were originally developed for extreme ultraviolet lithography mirrors [19,20] and then extended to optical materials and scaled from nanometer to micron-size defects.

Nodular defects can occur throughout the multilayer structure and not just on the substrate surface as shown in Fig. 1. Previous attempts to planarize silica layers throughout the multilayer structure resulted in flat-bottom-pit laser damage at the interfaces with the highest electric-field peaks [17]. A proposed solution has been to not planarize the outer silica layers, in order to reduce the electric-field value within the etched layers to one half of the electric-field value of the incoming laser beam [18]. Specifically, the multilayer mirrors were manufactured with no etching of the half-wave overcoat and the outer three quarter-wave silica layers. Fig. 2 shows the effectiveness of both types of planarization methods on 1 μm tall cylindrical pillar defects. This work describes a study of planarization in multilayers of hafnia and silica in which micron-size defects are simulated to occur within a depth where the electric field value of the incoming beam is reduced to one half. Different designs and planarization protocols were considered. Planarization was found to be particularly effective in doubling the laser resistance of typical non-engineered coating defects.

2. Experiments And Results

The planarization process is described in detail elsewhere [17,18]. The coating design used in this study was Air: L(LH)^{15}: Substrate where L = silica and H = hafnia, the same coating design used in previous studies. The layers are quarter-wave optical thicknesses that are angle-matched at 45 degrees incidence angle for a high reflector centered at 1064 nm. The physical thicknesses are approximately 210 nm for silica and 152 nm for hafnia and there are a total of 30 layers with the final layer being a half-wave silica overcoat.

The deposition process used for planarization is dual ion beam sputtering (IBS) [21]. The secondary ion source is pointed normal to the substrate and used for etching the deposited silica layers. The etch rate increases with increased incidence angle to a maximum near 50 degrees. Nodular defects have a range of incident angles that increase radially due to their domed geometry. Normally nodular defects tend to increase in diameter as the multilayer structure is deposited over the

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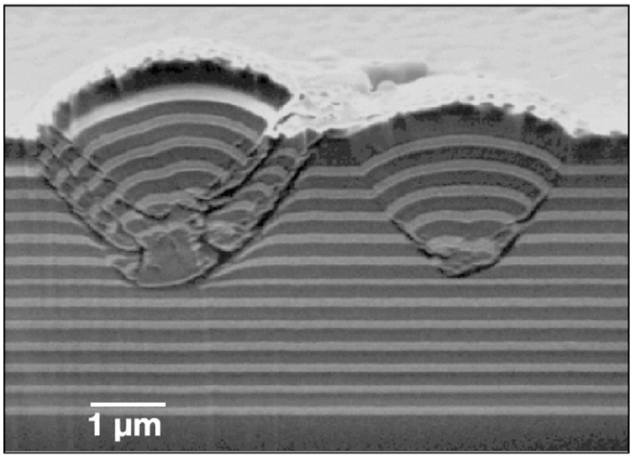

Fig. 1. SEM image of a Focused Ion Beam (FIB) cross section of nodular defects imbedded within an e-beam deposited hafnia/silica multilayer interference coating for laser mirrors. Hafnia layers are shown as bright while silica layers are dark.

defect [3]. The etching process, however, is most efficient at the nodule edges resulting in shrinking (or smoothing) of the nodule diameter as more material is added.

Substrate defects were manufactured via contact lithography and dry etching of the substrate. 1 μm tall cylindrical pillars were fabricated with diameters of 1, 2, and 5 μm. Additionally, 1 μm deep pits with a diameter of 5 μm were also etched into the substrate. The spacing between defects was ten times the defect diameter. A 1 mm diameter laser beam was used for laser damage testing allowing sampling of a significant number of defects at each testing site.

2.1. Thick Planarization Layer On The Substrate Vs. Planarization Throughout The Multilayer – Engineered Substrate Defects

To validate the effectiveness of planarization via either a thick planarization layer on the substrate or planarization of silica layers throughout the multilayer, four sets of samples were created and then laser damage tested.

- Sample 1: No planarization
- Sample 2: 3 μm thick silica planarization layer deposited on the substrate

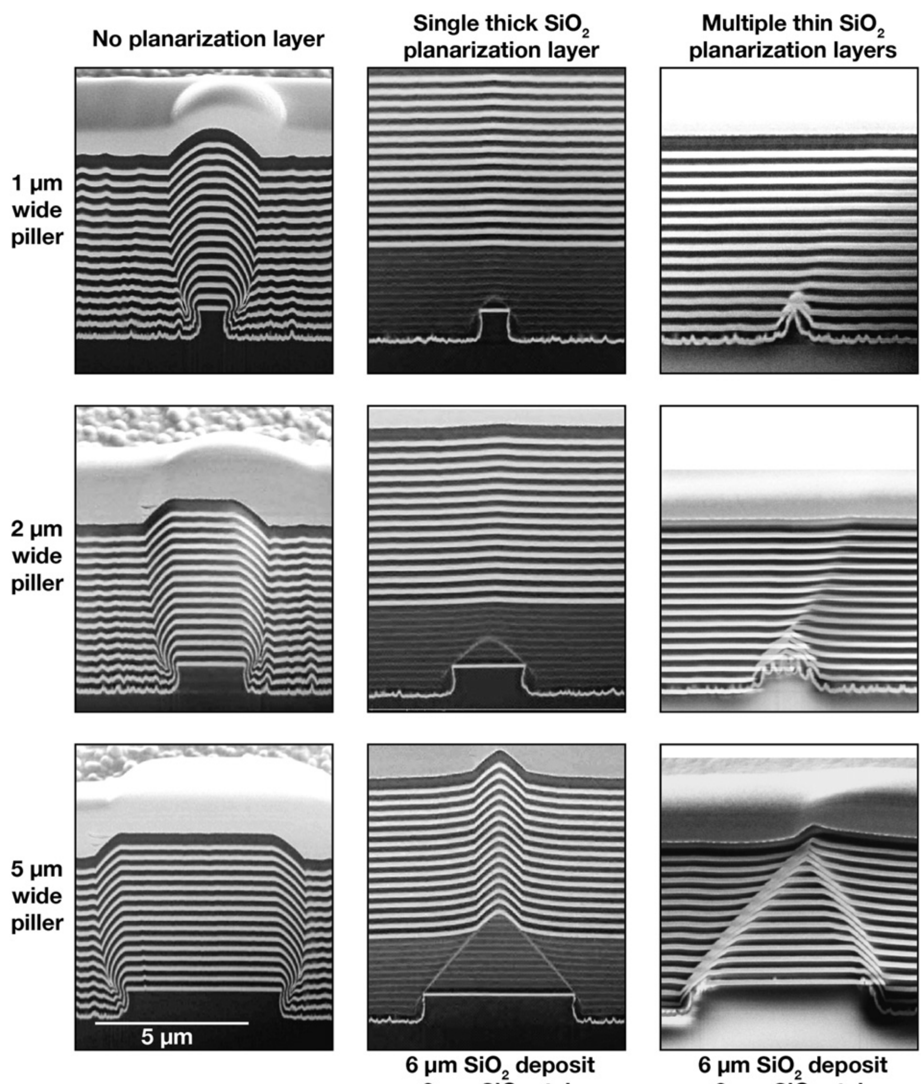

Fig. 2. Visual comparison (SEM imaging) of no planarization (left images), thick planarization layer on substrate only (central images), and planarization throughout the hafnia/silica multilayer coating (right images) for a range of different cylindrical pillar widths**.** Hafnia layers are shown as bright while silica layers are shown as dark in these images.