Submicron structures created on metal thin films by submicron focusing of femtosecond EUV light pulses

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Recent advances in manufacturing focusing mirrors for extreme ultraviolet (EUV) light have enabled us to achieve submicron-size focusing of high-order harmonics (HHs) of ultrashort near-infrared (NIR) laser pulses [1]. Indeed, it has been demonstrated that submicron-size processing of solid surfaces such as polymethyl methacrylate [2] and Ni [3] can be achieved using a EUV focusing mirror system by which HHs in the EUV wavelength region are focused on a submicron surface area at the fluence of about 100 mJ/cm^2. However, it has also been realized that materials having a high damage threshold such as Si cannot be processed at the fluence level of 100 mJ/cm^2. In the present study, we have revealed that submicron-size processing of Si using HHs of ultrashort near-IR laser pulses can be achieved below the damage threshold of Si as long as Si is coated by a thin film made of Au or Ag and explore the mechanism of the processing of Au-coated Si and Ag-coated Si by changing systematically metal species coated on a Si substrate.

NIR femtosecond laser pulses (790 nm, ~40 fs, 4 mJ, 1 kHz) are focused using a plano-convex lens into a semi-infinite gas cell filled with an Ar gas to generate HHs in the EUV wavelength range (27–41 nm). The HHs are focused onto the surface of a solid sample using a Wolter mirror. As the solid samples, a Si wafer and Si wafers coated with a thin film of metal species of Au, Ag, Cr, Pd, and Pt are chosen. The coating of the thin metal films whose thickness is ~100 nm is performed by a DC magnetron sputtering process. Different positions of the samples are irradiated with the focused HHs pulses at three different numbers of shots (N = 10, 100, and 1000). The images of the processed spots on the sample surfaces are recorded using an atomic force microscope.

For Cr and Pt, only the coated metal layer is processed at N = 1000, so that the Si substrate is kept intact. For Pd, the depth of the cone-shaped submicron-size hole is slightly deeper than the layer thickness (~100 nm), showing that the Si substrate is processed to a small extent by the EUV light. For Ag and Au, the depth of the cone-shaped submicron-size holes is much deeper than the layer thickness (~100 nm), and the processed depths below the Si surface are 180 and 200 nm, respectively. The characteristic phenomena of the metal-layer assisted EUV laser processing identified in the present measurements can be interpreted based on the penetration depth and the thermal conductivity. The penetration depths of Pd, Ag, and Au at λ ~ 30 nm are 7, 7, and 8 nm, respectively, which are much shorter than the penetration depth of Si, 269 nm. This means that the metal thin layer can absorb the energy of incident EUV laser pulses efficiently, and the surface temperature can be higher than the melting point of Si (1687 K), so that Si atoms are evaporated to be removed. The efficient EUV processing identified for Ag and Au compared with Pd can be interpreted by the higher thermal conductivity of Ag and Au compared with Pd.

References

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