Time resolved ablation mechanisms during fs-laser structuring of dielectric thin films with differing band gaps

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Abstract

In the production process of silicon microelectronic devices and high efficiency silicon solar cells, local openings in thin dielectric layers are required. In the latter case, silicon nitride (SiN_x) thin films are used as anti-reflection layers and silicon oxide (SiO_2) films as passivation layers. The openings can be selectively structured with ultra-short laser pulses by confined laser ablation processes in a fast and efficient single-pulse production step.

The aim of this work is to obtain a deeper understanding of the physical laser-material interaction during the laser ablation processes. For this purpose, two dielectric thin films with different band gap energies, SiO_2 (E_{gap} = 8 eV) and SiN_x (E_{gap} = 2.5 eV), on planar silicon (Si) wafers are structured with infrared fs-laser pulses (E = 1.2 eV). Pure Si is laser processed in comparison to study the role of bare substrate. The results show, that SiO_2 layers are selectively structured by confined laser ablation. SiN_x layers, however, are ablated by a combination of direct laser ablation and confined laser ablation at fluences well above the ablation threshold (factor 2.5). Then, SiN_x islands remain in the spot center. The applied Gaussian shaped laser pulses cause a nonlinear multi-photon absorption in the spot center leading to a local direct laser ablation process of the SiN_x film. Due to the larger band gap of SiO_2 films direct ablation is not observed here.

Pump-probe investigations are performed to investigate and to compare the temporal course of the different ablation types. The direct ablation process is observed on the Si sample, the pure confined ablation on the SiO_2 sample. The combination of both ablation types is observed during the SiN_x structuring.

By comparing the temporal ablation process of a substrate and two thin film systems with different band gaps the corresponding physical ablation mechanisms can clearly be identified. Absorption leads to direct laser ablation in the bare Si as well as in the center of the irradiated SiN_xwhereas low absorption in the rim of the irradiated SiN_x and in the SiO_2 film leads to absorption in the underlying Si substrate leads to confined ablation.