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Microstructural analysis of the modifications in substrate-bound silicon-rich silicon oxide induced by continuous wave laser irradiation

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Abstract

Laser-irradiation of silicon-rich silicon oxides (SRSO) is a promising technique for spatially well-defined production of silicon nanocrystals (nc-Si) showing room temperature photoluminescence. In this work, we use continuous-wave (CW) laser processing to generate nc-Si in SRSO films on fused silica substrates. One main problem is damage introduced by laser processing which results in a porous layer beneath the original film surface as is consistently shown by electron tomography and energy-dispersive X-ray spectrometry. Processing conditions for damage-free nc-Si formation are identified by systematic variation of laser intensity and measuring the depth of the damaged region by transmission electron microscopy (TEM). By combining TEM imaging and analysis it is shown that the damaged region has a composition close to SiO_2 which is due to a predominant loss of silicon rather than an a result of surface oxidation during laser processing.

1. Introduction

Low-dimensional silicon system show room-temperature photoluminescence due to quantum confinement [1]. One possible route to Si nanostructures with potential applications for light-emitting devices are silicon nanocrystals (nc-Si) embedded in SiO_2. Such structures can be generated from substoichiometric SiO_x with $x<2$ which is subsequently referred to as silicon-rich silicon oxide (SRSO). Such oxides exhibit a phase transformation into nanocrystalline silicon (nc-Si) and stable SiO_2 upon high-temperature thermal annealing [2,3]. Laser irradiation instead of thermal annealing potentially allows for spatially well-controlled nc-Si formation [4]. However, local energy deposition by laser irradiation inevitably suffers from heat loss due to substantial temperature gradients especially in the case of substrate-bound SRSO films necessary for technical applications [5]. This will require high laser intensities and allow only a narrow process window for efficient generation of nc-Si without damage or ablation of the film. Phase separation using pulsed excimer lasers seems to be possible, but crystalline Si is only obtained at fluences exceeding the damage threshold [6-8]. For the case of substrate bound films and cw laser annealing it has been thought, that the local temperature is not sufficiently high in order to induce the phase separation of SRSO into nc-Si and SiO_2. Hence, focus has been on laser irradiation of free-standing SRSO films in previous studies mainly performed by *Khriachtchev* and co-workers [5,9,10]. In a recent study [4], we have demonstrated for substrate-bound SRSO films that conditions of CW laser irradiation can be adjusted such that Si structures showing strong photoluminescence (PL) can be formed while avoiding surface damage due to laser irradiation. At higher laser intensity, however, laser-treated SRSO shows pronounced damage reducing the PL yield.

In this paper, we report microstructural investigations of CW laser irradiated SRSO thin films on SiO_2 substrates.