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Fabrication of luminescent a-Si:SiO_2 structures by direct irradiation of high power laser on silicon surface

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ABSTRACT

In this paper, the structural and compositional modification of polished silicon (Si) wafers by irradiation of second harmonic of Q switched high power Nd: YAG laser in air is reported. The surface morphology, recorded by scanning electron microscope (SEM), shows micro cluster formation. Raman spectra reveal the presence of amorphous silicon embedded in silicon dioxide (SiO_2) matrix in these structures which is further confirmed by energy dispersive X-ray (EDX) and Fourier transform infrared (FTIR) spectroscopic studies. These nanostructures of amorphous Si embedded in SiO_2 matrix (a-Si:SiO_2) showed luminescence in far red region. The effect of laser fluence on the photoluminescence properties and its possible origin were discussed.

Introduction

The nanostructured silicon, viz.; nano-crystalline (nc) Si, nanostructured amorphous Si (a-Si), nc Si or a-Si embedded in amorphous SiO_2 matrix, porous silicon (po-Si) etc. shows intense visible and near infrared photoluminescence [1–3]. Radiative recombination rate for amorphous Si nano particles is two to three orders of magnitude higher than that for crystalline Si nano particles. Visible photoluminescence (PL) from nanostructured a-Si, as well as its oxides and nitrides grown by various deposition techniques were reported in the literature [4–6]. Photoluminescence properties make nanostructured Si potential candidate as emitters for field-emission based devices such as high-definition displays as well as other vacuum microelectronics devices and systems [7], MEMS-based memory devices [8] and light emitting devices [9]. The thin nanostructured film can be grown onto a substrate by magnetron sputtering [10], chemical vapor deposition [11], pulsed laser ablation [4,12] etc. In some cases, it is important to produce local nanostructured area directly on a silicon-based device or on assembled integrated chip. The local etching of a Si based film can be performed by nano second pulsed radiation from a laser with a high precision. In the present paper, the generation of a-Si:SiO_2 nanostructures via laser ablation and its room temperature PL properties are discussed.

Experimental setup

The polished silicon (1 0 0) wafers were irradiated by loosely focusing a second harmonic (532 nm) of a Q switched high power Nd: YAG laser (pulse duration of 8 ns and repetition rate of 10 Hz) in air at room temperature as shown in Fig. 1. The laser beam was steered by a prism and irradiated on the target at an incident angle $\sim 30^\circ$ to avoid back reflection. The focal spot of laser beam onto the Si target was elliptical with major and minor axes of ~1.9 mm and 1.6 mm, respectively. The focusing of high power laser onto Si target in air results in the breakdown of the material and the atmospheric air in the neighborhood of focal region. This produces Si and oxygen ions which reacts and get deposited onto the target around the periphery of the focal spot to yield a-Si:SiO_2. The laser fluence was varied approximately from 0.35 to 2.67 J cm^{-2}. The Raman spectra of a-Si:SiO_2 were recorded at room temperature (*RT*) using micro-Raman setup (Lab-Ram HR 800) in back scattering geometry. The 488 nm line of Ar ion laser was used as excitation source. The same laser was used for PL studies of the samples at RT. The surface morphology was recorded by SEM and the compositional analysis was performed by EDX. FTIR transmission spectra of all the samples were recorded to get the confirmation of the presence of SiO_2. Transmission electron microscopy (TEM) images

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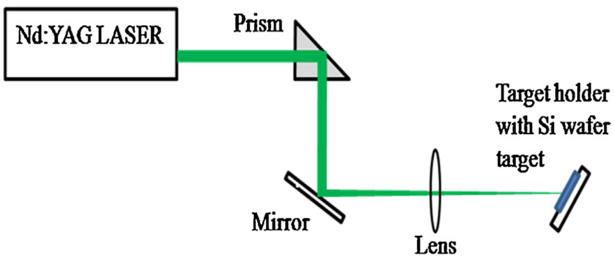

Fig. 1. Schematic diagram of experimental setup for laser irradiation of silicon.

were recorded for analyzing particle size distribution of the whitish clusters. Selected area electron diffraction (SAED) pattern was also recorded for all the samples.

Result and discussion

Fig. 2 shows SEM image of the laser irradiated spot onto Si target at a laser fluence of 1.46 J cm^{-2} after 6000 shots of laser. A central dark crater-like region surrounded by white clusters is clearly visible in the SEM image. The magnified view of white region is shown in Fig. 3(a). It shows the formation of cauliflower like structure with non-uniform size distribution varying from 10 to 20 μm. The Raman spectrum (200–700 cm^{-1}) of these structures is shown in Fig. 3(b). It displays a prominent band (400–550 cm^{-1}) and a shoulder toward the low energy tail (350–400 cm^{-1}) of this band. The 400–550 cm^{-1} band with broad peak at around 483 cm^{-1} (FWHM ~ 105.6 cm^{-1}) is attributed to first-order scattering of vibrational TO phonon modes of amorphous silicon [13,14]. The inset in Fig. 3(b) shows the Raman spectrum of unexposed Si target displaying a sharp intense peak at 521 cm^{-1}, a characteristics of bulk crystalline Si. It arises from the first-order Raman scattering of the longitudinal optical (LO) and the transverse optical (TO) phonon modes which are degenerate at the Brillouin zone center in crystalline Si [13,14]. Fig. 3(c) shows the RT PL spectrum of above sample. It displays a broad asymmetric PL ranging from 1.6 to 2.2 eV, having a band tail in blue region, with a peak around 1.82 eV [3,13]. Fig. 4(a)–(c) shows magnified SEM image, Raman spectrum and PL spectrum of central dark region of the above sample, respectively. The SEM image displays formation of

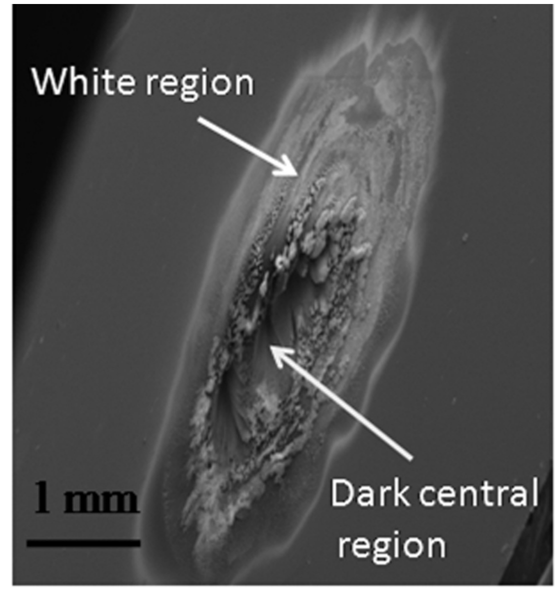

Fig. 2. SEM image of focal spot of laser irradiated Si target at laser fluence ~1.46 J cm^{-2} after 6000 shots.

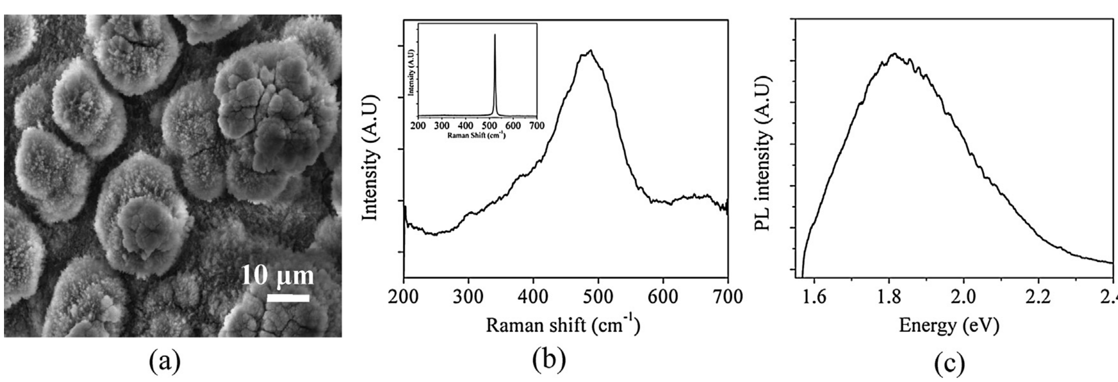

Fig. 3. (a) SEM image, (b) Raman spectrum and (c) RT Photoluminescence spectrum of whitish clusters formed at laser fluence of 1.46 J cm^{-2} (6000 laser shots).

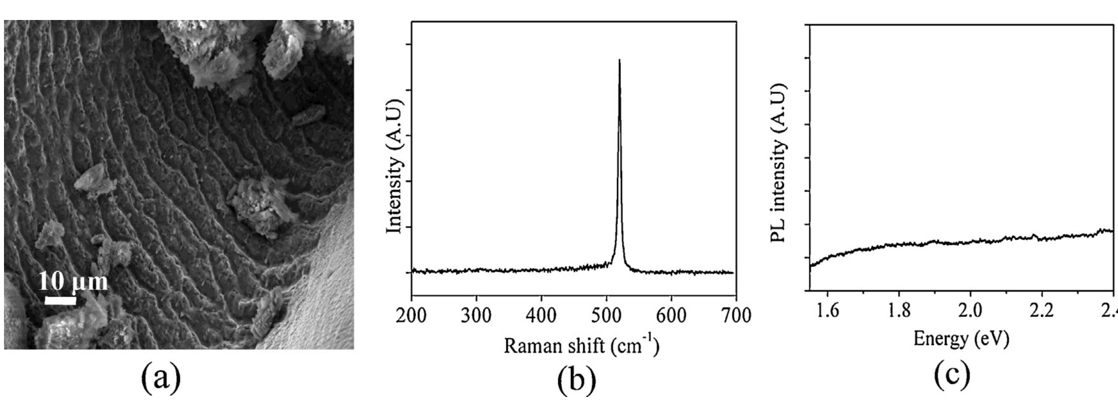

Fig. 4. (a) SEM image, (b) Raman spectrum and (c) RT Photoluminescence spectrum of dark central region formed at laser fluence of 1.46 J cm^{-2} (6000 laser shots).

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