Study the Effect of CO_2 Laser Annealing on Silicon Nanostructures

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Abstract

The recent discovery of strong room-temperature photoluminescence from silicon nanocrystals fabricated by different methods is an extremely important scientific breakthrough with enormous technological implications because of possibility of integration of silicon based electronic and optoelectronic devices. This paper the effect of Laser annealing technique used to produce nanoparticales by CW laser was proposed. The laser spot was focused within 0.6 mm beam radius to synthesize silicon rich oxide SiO_x nanostructures in silicon nanostructures thin films by laser ablation of silicon target on glass. The CO_2 laser beam λ (10.6μm) with power Plaser ranging from 1 to 10 Watt. Two lasers were employed; the first, Q-switched Nd:YAG laser to prepare an amorphous silicon film on glass substrate and the second, CW CO_2 laser beam to produce local heating and synthesize a silicon oxide nanostructures. A sufficient absorbing CO_2 laser beam was used to induce local heating at optimizing surface temperature. The optical and surface morphological properties of SiO_x films annealed by CO_2 laser are primarily investigated the effect of parameters such as power density and elimination time.

Keywords: Silicon nanostructures, Laser ablation, Laser annealing

1. Introduction

In recent years, there has been increased interest in the synthesis and characterization of nanosized particles. Research in this direction is strongly motivated by the possibility of designing nanostructured materials that possess novel electronic, optical, magnetic, chemical, and mechanical properties.

Ever since visible photoluminescence (PL) was observed in Si nanostructures(Yan Wang, Ruifeng Yue,Guohua Li, 2000)(Shinji Takeoka, Minoru Fujii, and Shinji Hayashi, 2000)(L. T. Canham, 1990). Si nanostructures have attracted great interest in microelectronics and optoelectronics due to opportunities to incorporate optoelectronic functions into Si integrated circuits. Significant effort has been focused in recent years on the formation and the characterization of silicon nanostructures films may be produced by different techniques, i.e., plasma enhanced chemical vapor deposition (PECVD), ion implantation, sputtering, pulse laser deposition etc(N. Daldosso, G. Das, S. Larcheri, and L. Pavesi, 2007). Among the fabrication methods, Pulsed laser deposition (PLD) is a versatile technique for the growth of thin films and nanostructure materials. The variation of deposition parameters yields significant changes in film properties (E. Irissou, B. Le Drogoff, M. Chaker, and D. Guay, 2003). In the PLD method, the size distribution of Si nanostructures can be flexibly controlled by a raying background gas species and pressure, laser flounce, target-to-substrate distance. On the other hand, annealing and oxidation greatly determine the surface condition and crystal structures of Si nanostructures that play significant roles in the properties of the prepared films.

Laser annealing of Si has been demonstrated to offer advantages over furnace annealing such as exceeding the Solid solubility limit of doping in Si, lattice damages and having less defects after annealing. One of the important parameters in laser processing is the laser illuminating time and laser power density as function of annealing temperature(J. D. Hoyland and D. Sands, 2006). The widely used quantum confinement effect (QCE) theory explains the high efficiency light emission as a result of the band-to-band radiative recombination of electron–hole pairs confined in Si NSs whose surfaces are very well passivated by Si–H or Si–O bond(B. Delley and E. F. Steigmeier, 1993). There is also experimental evidence that amorphous species amorphous-Si (a-Si) or(a-SiO_x) used to confine Si NS can be responsibl for the light emission (T. V. Torchinskaya, N. E. Korsunskaya, L. Yu. Khomenkova, 2001). Dai et.al (X. Y. Chen, Y. F. Lu, Y. H. Wu, B. J. Cho, M. H. Liu, D. Y. Dai, and W.D. Song, 2003), have investigated the effects of thermal treatment conditions on the structures.

This paper investigate the annealing effects on the optical, morohological PL properties of Si nanostructures formed by PLD. The thickness of the deposited films was ≈200 nm.

2. Experimental setup

The crystalline silicon wafer of conductivity (n-type) and resistivelyof 2×10-4 Ω.cm, (111) orientation was used as a target. The substrate used for deposition was borosilicate glass slides Laser ablation experiments were carried out. by using Q-swiched Nd:YAG laser (λ=1064 nm) with a pulse duration of 10ns and a repetition rate of 1 Hz. The laser energy was set at 600mJ for 10 pulses and the substrate-target distance maintained at 30 mm, at an incident angle of 45◦, The target was mounted on a rotating holder to minimize pit formation. Films were produced by collecting the ablated material onto substrates under low oxygen pressure(0.01–1.5mTorr). and held at room temperature, A silicon nanostructured films thikness has been measured by an optical interferometric method.

After deposition The CO_2 laser annealingwas performed in atmosphere using a continuous-wave CW CO_2 laser with ranging from 1 to 10W. The laser spot was focused within 600μm using a odehemispherical lens.fordurations ranging from1 to 15mins.

According to the thermal model described by Wei et al., we can estimate the steady state temperatures(in Kelvin) in the center of the irradiation spot to be:

$$\mathrm{Tc} = \frac{\mathrm{fIa}\sqrt{\pi}}{2\mathrm{k}} \tag{1}$$

Where f is the fraction of the absorbed power density, I, of the laser beam, a is the beam radius, and K is the thermal conductivity of the irradiated material. Afterwards, The morphology of the deposited films was analyzed at various stages of the deposition process and treatment by atomic force microscopy (AFM), Photoluminescence (PL) spectra taken from irradiated areas of the samples were measured at room temperature.

3. Results and discussion

Results reported in Fig.2 show that a PL spectra which observed on the as-deposited sample and also after annealing and its intensity increases as a function of the annealing temperature. The intensity reaches its maximum after 1000 °C annealing. For increasing annealing time at 1000 °C, The increase in intensity as a function of the annealing temperature, the observation of the same band after 1200 °C annealing, and the fast decay time seem to exclude the possibility that this band originates from the point defects mentioned above. The present results could be consistently explained assuming that after deposited of SiO_x corresponding to the extended defects like clusters or chain of silicon are formed. These structures can act as radiative sites. The PL intensity increase as a function of the annealing temperature could be explained in terms of annealing of defects that can give rise to non-radiative recombination, while no significant Si rearrangement takes place below 1000 °C due to the low silicon diffusivity.

The surface roughness was examined by AFM. Fig.3 shows the three-dimensional image of SiO_x thin films that were annealed by CW CO_2 laser. The laser annealing of SiO_x thin film yields small structues, which are more uniformly distributed than those in the as deposited SiOx thin film. The laser-annealed SiO_x thin film had a smoother surface. The uniformity of the SiO_x thin film was improved with laser annealing because with shorter sintering cycles and reduced thermal gradients, finer particles were obtained and the particles were more uniformly sized.

4. Conclusion

The result observed stronger blue PL at room temperature with the sample annealed in than that with the sample as deposited. As annealing temperature increased from 800 to 1200°C, the intensity of PL peak became stronger. The results indicate that the origin of the peak around the (560-nm) region is related to a quantum size effect of Si nanostructures.

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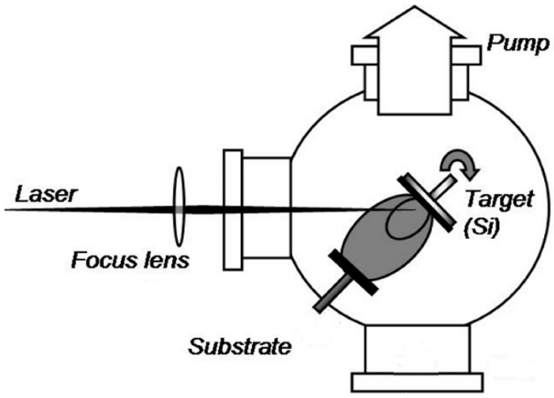

Figure 1. schematic diagram of the Pulsed laser deposition (PLD) set-up.

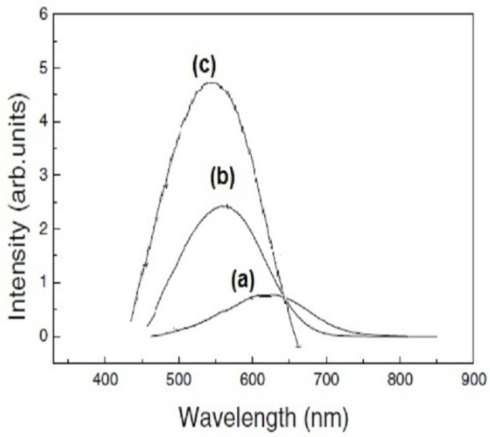

Figure 2. PL spectra from SiO_x films which were annealed at (a) as deposited, (b) 800 ◦C and (c) 1200 ◦C.

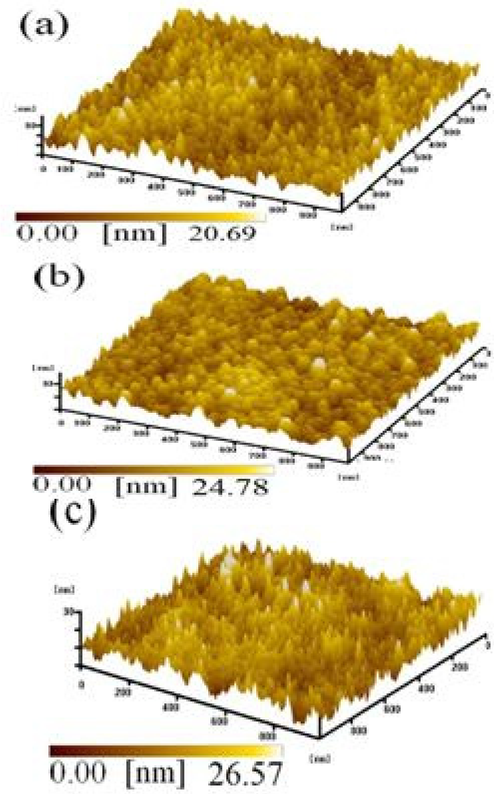

Figure 3. AFM three-dimensional images of SiO_x thin films, which were annealed at (a) as deposited, (b) 800 ◦C and (c) 1200 ◦C.