Visible Photoluminescence Enhancement Of Silicon Oxide

Kifah Q. Salih

Abstract: We have been proposed a treatment method for the visible photoluminescence enhancement of SiO_2 layer thermally grown on Si<100> wafer by surface texture modification. We have used liquid nitrogen (LN2) as treatment method. That method applied at different exposure time from 10min to 30sec.Room temperature photoluminescence (PL) of treated SiO_2/Si samples was studied using the 514.5 nm line of an Ar+ Laser.PL signal in the wavelength rang 530-880 nm was observed .AFM and SEM have used to study the surface texture change. Samples of an exposure time (1 min, ±30sec) show emission at 580-880 nm with a maximum PL intensity .We have observed the PL intensity and spectra shape of treated samples are dependent on the surface texture modification. The visible PL is enhanced 2-fold by the surface treatment. The origin of the visible PL emission of SiO_2 has been investigated on QCLC model.

Key words: Visible photoluminescence, SiO_2, surface texture and surface defects

1 INTRODUCTION

Efficient radiative recombination in silicon-based Light-emitting semiconductor devices is complicated by its indirect-band-gap structure, which makes Si a poor light emitter [1]. Surface improvement of Si-based materials such as SiO_2/Si has been a continuing goal of Silicon-based materials manufacturers. In many cases, particale size and defect detection on surfaces is hampered by the presence of surface roughness because of its significant effects on the physical properties of the structures. There are contradictory experimental results concerning the shift of the PL peak due to oxidation.PL red shift is caused by defect states [2].The intensity of PL peak related to defects increases with the increase of annealing temperature up to the critical temperature [3].The origin of visible PL emission of Si in Silicon oxide still remains to be clarified [4]. In the present work, we use liquid nitrogen (LN2) as thermal treatment method for modification the surface texture of SiO2 samples. That method was performed at different exposure time (10min-30sec). The study of that method effect on the visible emission characterization and surface texture characterization of treated samples was carried out by using CW PL technique and AFM, SEM techniques respectively. According to the visible emission of treated and untreated samples, we try to investigate that emission on QCLC model because the mechanism of visible photoluminescence of SiO2/Si is not clear up to now.

2 EXPERIMENTAL TECHNIQUES

Silicon oxide films were prepared by thermal oxidation of Si<100> wafers. A thick oxide layer (~1µm) was grown on samples by flowing O_2 over the sample. We have designed a setup of thermal treatment method as shown in Fig. (1), to modify the surface texture of samples.

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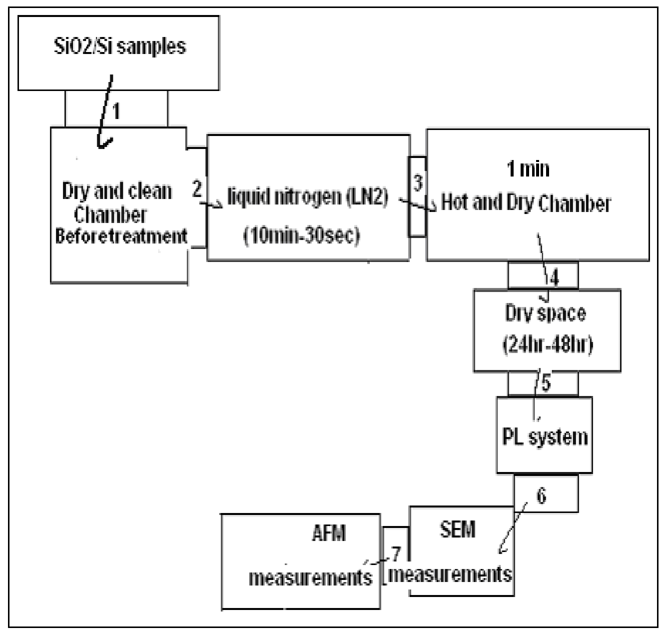

Fig.1. Schematic illustration of the setup of treatment method

Another preparation of the samples was to dip each sample in liquid nitrogen for different exposure time (10min-30sec) by using the setup as shown in Fig. (1) .The exposure time (t_x) of each sample is equal to:

$$t_x \text{ (sec)} = 30*X \qquad (1)$$

X is the number of the sample (X=1, 2, 3…20) for $t_{min.}$ =30 sec and t_{max}=10 min.

Treated samples were removed from the treatment chamber and transferred to PL system, scanning electron microscopy(SEM) and atomic force microscopy (AFM) measurements.PL emission was recorded using a Ar+ laser (photon energy 2.4 eV,hv>Eg of sample).All measurements were carried out at the room temperature under the same conditions. The spectrum of a SiO_2 film was obtained under relatively high excitation level. In this paper; we present the optimum results.

3 RESULTS AND DISCUSSION

Figs. (2-3) show the SEM and AFM of the treated and untreated samples. All SEM and AFM images show the change in surface texture after treatment. The effect of thermal treatment on the surface defects and grains is shown in Figs. (2-3).The change of grain size can alter the optical properties of surface such as the visible PL emission of SiO_2/Si.It suggests that the surface with smaller grain size and low defects density exhibits as a good surface for incident light by reducing the scattered light and increasing the absorbed light. So, Surface defects and big grain size cause the quenching of the surface emission. In this work, we have obtained an increasing in PL emission intensity after treatment.

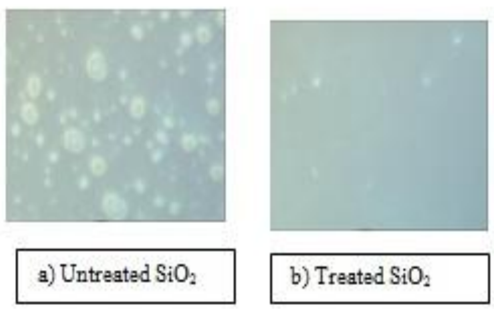

Fig.2. SEM images of the treated and untreated SiO_2 samples

Abroad PL peak in the range of 530-880 nm was recorded as shown in Fig.4.We have found that the PL spectral distribution is very sensitive to excitation conditions. The intensity of the recorded PL emission varies from exposure time to exposure time, which is probably due to different surface conditions. Samples of exposure time (1min, ±30sec) show emission at (530 - 880 nm) with a maximum PL intensity (2-fold) as shown in Fig.4.This result is indicating that the new surface texture is able to increase the radiative channels because these radiative channels are unavoidably quenched by defects or contaminants or grain boundaries.

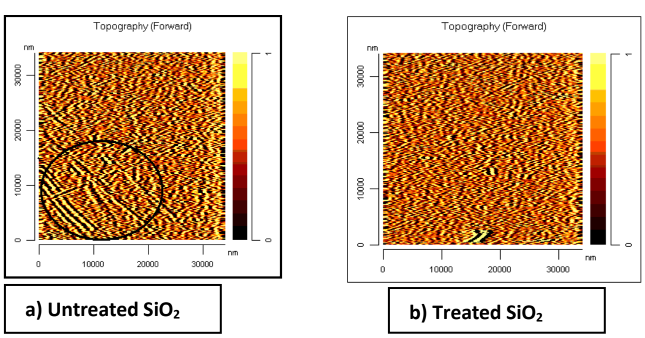

Fig. (3): AFM images of treated and untreated SiO_2 samples

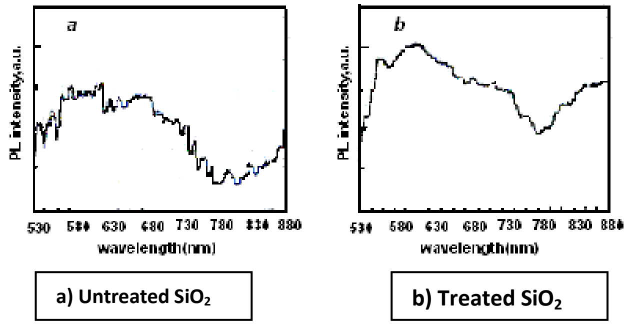

Fig.4. PL spectra obtained at room temperature a) untreated SiO2 b) treated SiO2

Before treatment, a weak emission band has reported from 530 nm up to 880 nm (Fig.4a) because of low surface quality. We suggest that radiatively relaxation of excited oxygen atoms causes the orange PL and stagnant air causes radiative transitions at ~ 530 nm [5] .The interface between Si<100> and thin film of SiO_2 can play as active medium and crucial rule in the radiative recombination mechanism [6]. The visible PL is enhanced 2 -fold after treatment. That enhancement is occurred due to the enhancement in radiant flux Φ_λ , which is proportional to the PL intensity [7].Φ_λ is given by [7]:

$$B(\lambda)d\lambda = k_\lambda \Phi_\lambda(\lambda)d\lambda \quad (2)$$

B (λ) and K_λ are the brightness of the luminescence in a wavelength-width d (luminous flux) and the spectral luminous efficiency respectively.So, Φ_λ is improved in term of the surface texture modification (low defects density and smaller grain size). Also, it is possible that diffuse scattering from the surface of SiO_2 is reduced after treatment as we mentioned above. This study leads to the conclusion that the defects are on the surface and not in the bulk as clear in our results. we have made the discussion of the visible emission origin of the treated/untreated sample on QCLC model of the Quantum Confinement / Luminescence Center [8-10], in which the recombination process occurs at luminescent centers is in good agreement with our study .So, we have designed model for our study according to QCLC model with some correction as shown in Fig.5.

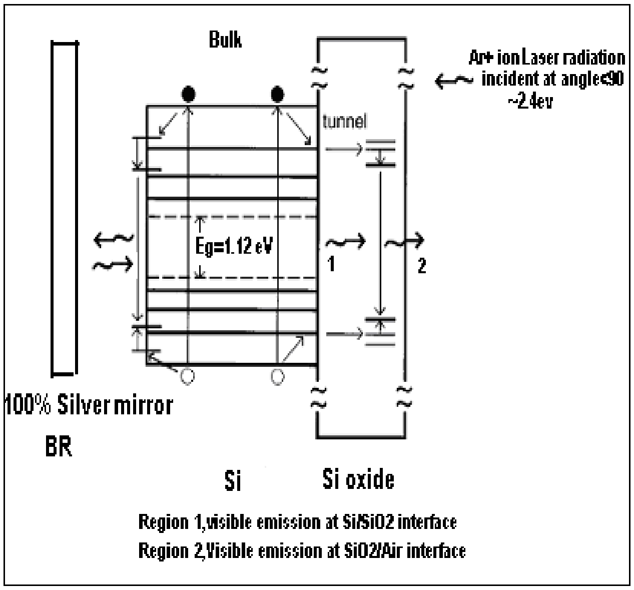

Fig. (5): Schematic illustration of the visible luminescence process as in our study

From Fig. (5), the main point of this model is that the photo-excitation of the carriers does not take place in the bulk (band to band transition) to cause the excitation in an energy range much bigger than the Eg_{Si}. The radiative recombination center of electron–hole pairs inside the bulk is smaller than that outside (region 1 and region 2) ,so that most carriers produced inside may tunnel into the surrounding SiO_2 layer and then recombine to emit visible light through SiO_2/ Air interface by energy much bigger than the energy of band to band transition which enhanced by the new surface after treatment(see Figs.(2-3)) not by surface defects as mentioned in the Quantum Confinement / Luminescence Center (QCLC) model.So,the visible emission of Si-based materials is the surface emission which depends on surface texture and surface temperature in addition to the effects of laser interaction zone at the surface such as photo- thermal effects (resonant condition)or maybe it is thermo luminescence related to the black body radiation at certain temperature.

4 CONCLUSION

We have studied the effect of LN_2 thermal treatment on PL emission and surface texture of SiO_2.PL intensity and PL emission shape were changed due to the surface texture modification and surface quality. In addition to surface smoothing, smaller grain size and reducing the surface deffects, the mean aim of this study is to enhance the visible emission. Our results reveal that the emission enhancement was occurred after applying that thermal treatment. Furthermore this method not only provides new surface texture, but also enhances the optical emissions from 530 nm up to 880 nm .This increasing can explain by the grain size change and material quality. As shown in our results that the visible emission of SiO_2/Si is the surface emission which depends on surface texture and surface temperature.

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