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Enhanced photo luminescence from porous silicon on texturized surface

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Abstract. Porous silicon (PS) was formed on both polished and texturized single crystal silicon (1 0 0) by anodic etching. Photoluminescences (PL) from both of these silicon surfaces were measured and compared. A two-fold enhancement of PL from textured silicon surface was obtained. This enhancement could be ascribed to the geometry of the textured surface.

Keywords. Silicon; porous silicon; photoluminescence.

1. Introduction

Ever since the discovery of the visible light emission from porous silicon in 1990, an extensive research on both theoretical and experimental aspects of porous silicon has been started all over the world (Canham 1990; Chen *et al* 1993; Li *et al* 1993; Nakajima *et al* 1993; Teschke *et al* 1993; Wang *et al* 1993; Kontikiewicz *et al* 1994; Pavesi *et al* 1994; Takasuka and Kamei 1994). But little work has been reported so far about the role of the surface morphology of silicon wafer on the photoluminescence of the porous silicon. Recently, Jain *et al* (1994) reported an increase in PL intensity from PS layer on textured surface. The present paper reports the study about the effect of surface texture on the intensity and spectral response of the photoluminescence from porous silicon (PS).

2. Fabrication and measurement

Porous silicon was formed on both polished and textured single crystal *p*-type silicon (1 0 0) of 4 ohm-cm resistivity in a special cell containing HF (48%) methanol (1:1) and by sending constant current 10 mA/cm^2 for 15 min using Pt as cathode and sample as anode. Back surfaces of both samples were coated with Al-paste and sintered for better current conduction. The Al-layer was coated with wax before placing the sample in the cell.

A typical SEM picture of porous silicon on textured surface is shown in figure 1. It is seen that the surface consists of micro-particles with the diameters in the range 5–20 nm (Nobuaki and Suemune 1993; Jain *et al* 1994).

To measure photoluminescence (PL), light from a xenon arc lamp was passed through a narrow band interference filter (350 nm) and then incident on the sample. The photoluminescent ray from the sample was then passed through a visible band pass filter so that reflected UV rays were cut off. The spectrum of the transmitted PL rays

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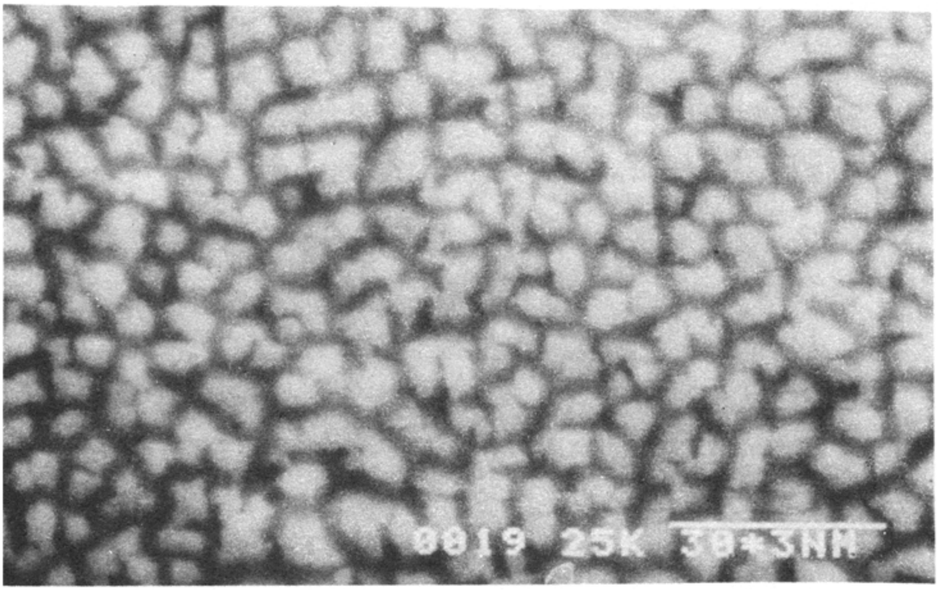

Figure 1. SEM picture of surface morphology of PS.

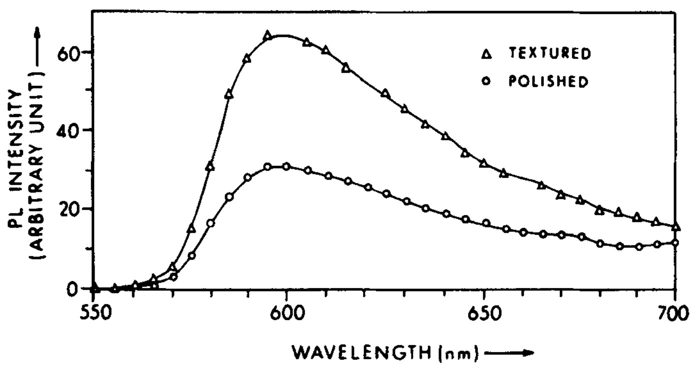

Figure 2. PL spectra of PS layers on textured and on polished surfaces.

from the filter were then analyzed by Monochromater (Oriel Model No. 77250), photo multiplier tube (Model No. 77341) and Oriel detection system (Model No. 7070).

3. Results and discussion

Figure 2 shows PL spectra of PS layers on texturized and on polished surfaces.

It is interesting to note that the PL intensity increased by about two times by the simple surface treatment (texturization) on the (1 0 0) polished silicon. The enhancement in PL may be due to (a) better absorption by the texturized surface i.e. reduced reflection from the surface (absorption factor) and (b) increased area due to texturization (area factor).

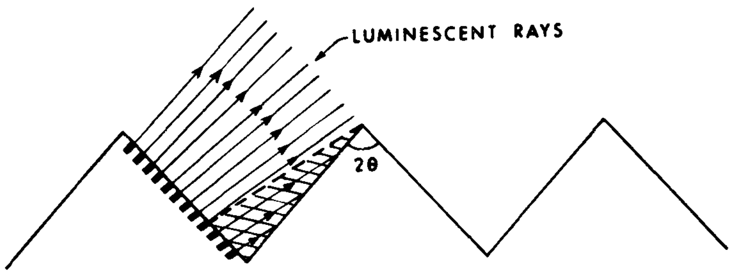

Figure 3. Geometry of the structure of the pyramid and possible pores and PL emission.

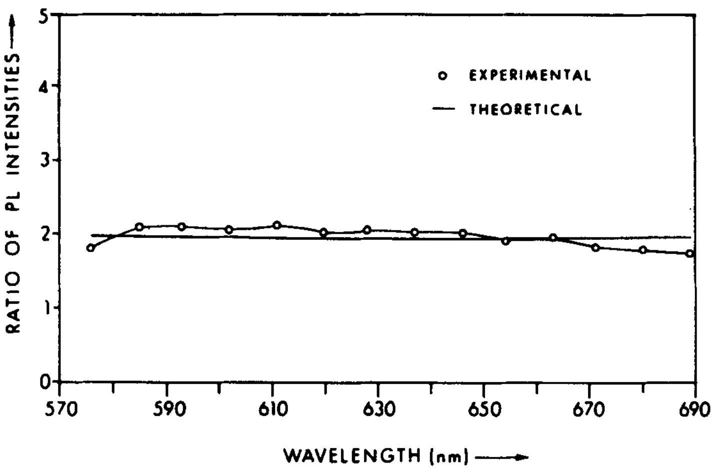

Figure 4. Ratio of the PL spectrum from PS layer on textured and on polished surface.

The enhancement due to the above two factors is partly attenuated by the geometry of the structure of the pyramid (figure 3). The intensity of PL from texturized silicon is approximately given by

$$I_T = K(1 - R_T)[1/\sin\theta][(1 - \cos 2\theta) + (R\cos 2\theta)]I_0, \qquad (1)$$

where R_T is reflection coefficient of the texturized surface at the incident wavelength, 2θ the angle at the apex of the pyramid, K, a constant depending on the luminescent efficiency per unit planar area, I_0, the incident light intensity and R the reflection coefficient of the photoluminescent ray.

This expression has been derived on the basis of the fact that a fraction $[(1 - \cos 2\theta)]$ of the area of the texturized silicon surface gives rise to unobstructed PL rays and the remaining fraction of PL is incident on the adjacent pyramids. The above expression is valid for all microgrooved surface for which $\theta \leqslant 45°$. For $\theta \geqslant 45°$, PL from the microgrooved surface will be totally unobstructed and therefore the intensity from the texturized surface will be given by

$$I_T = I_0 K(1 - R_T)/\sin\theta. \qquad (2)$$

From the porous silicon on polished (non texturized) surface, the PL intensity is

Table 1. Values of the reflection coefficients of the textured silicon surface at the incident wavelength ($\lambda = 350$ nm) for different apex angles. $R_N = 0{\cdot}557$ at $\lambda = 350$ nm.

Apex angle (in degrees)	R_T
125	0·55
105	0·43
90	0·32
70·5	0·29
55	0·17
45	0·13
30	0·06
20	0·025

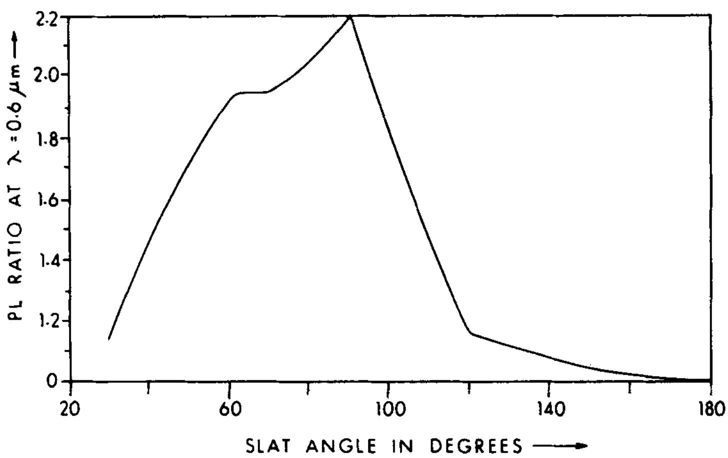

Figure 5. A theoretically calculated plot of the ratio as a function of the apex angle of the microgrooved surface.

given by

$$I_N = K(1 - R_N)I_0,$$

where R_N is the reflection coefficient of planar surface at the incident wavelength.

Therefore, the ratio of the PL intensity from the PS on textured surface and from PS on polished surface is given by

$$I_T/I_N = \frac{(1 - R_T)}{(1 - R_N)\sin\theta}[(1 - \cos 2\theta) + R\cos 2\theta], \tag{3}$$

for $\theta \leqslant 45°$ and

$$I_T/I_N = \frac{(1 - R_T)}{(1 - R_N)\sin\theta}, \tag{4}$$

for $\theta \geqslant 45°$.

Figure 4 shows the experimentally observed ratio of the PL spectrum from PS layer on textured and on polished surface and also the ratio calculated theoretically. The apex angle of the pyramidal textured surface is 70·5°. The values of R_T and R_N at the incident wavelength $\lambda = 350$ nm for different apex angles are shown in table 1. An excellent agreement between the experimental and theoretical results is found.

Figure 5 shows a theoretically calculated plot of the ratio of PL spectrum as a function of the apex angle of the microgrooved surface. It can be seen from the figure that the maximum ratio is of the order of 2·2 at an apex angle 90° and is decreased on both higher and lower apex angles.

Therefore, PL intensity can be increased approximately two times by simple texturization on polished (1 0 0) Si surface and the increase can be primarily ascribed to the geometry of the textured surface.

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