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Etching Rate Enhancement of Porous Silicon Produced by Lasers

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ABSTRACT

Two laser systems work with different operational modes have been used to produce silicon nanostructure surfaces. Pulsed Nd:YAG laser has been employed to produce silicon textured surface which containing nano/microstructures. Effects of laser energies (80 – 200) mj were examined to produce surface of different structures. While Diode laser (532 nm) of fixed power (50 mW) was used in the second stage to modify the porous structure over the textured surface. The effect of different surface morphology on the laser induced etching process was studied using atomic force microscope (AFM) and an image processing program to sketch the surface plot to the samples depending on the optical microscope photos. The photoluminescence spectra have been utilized to study the nanocrystallite size distribution in porous silicon, it shows high peak position lies in (2 - 2.1) eV.

Keywords: Laser induced etching, Nanostructured silicon, Porous silicon

تحسين معدل القشط للسليكون المسامي المنتج بالليزر

الخلاصة تم في بحثنا هذا استخدام ليزرات تعمل بانماط تشغيل مختلفة في تحضير تراكيب نانوية ومايكروية على سطح مادة السليكون. عملية تحضير العينات تمت بمرحلتين، الاولى باستخدام ليزر النيديميوم–ياك النبضي لتكوين اسطح ذات تراكيب مختلفة الاحجام بالاعتماد على اختلاف طاقات الليزر)08-002(ملي جول. المرحلة الثانية تم فيها استخدام ليزر الدايود بطول موجي235 نانومتر وقدرة)05 ملي واط(ذات نمط التشغيل المستمر لحث التفاعل الكيمياوي واحداث عملية التنميش على اسطح مادة السليكون المشععة بالمرحلة الاولى. تمت دراسة تاثير طبوغرافية السطح على كفائة عملية التنميش بالاعتماد على صور المجهر الضوئي وصور MFA. كذلك تمت دراسة خاصية الاستضائة لعينات السليكون المسامي والتي دلت على وجود علاقة لعملية التنميش بطبيعة السطح. حيث وجد بان معدل قيمة فجوة الطاقة لتراكيب السليكون النانوية تراوحت بين 2-1.2 الكتـــــرون–فولـــــت.

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INTRODUCTION

Crystalline silicon (c-Si) is the heart of electronic industries but its role is very limited in many other applications [1]. Reducing dimensionality in c-Si to the nanometer scale leads to major consequences in the material properties such as optical, electrical, vibrational, electronical and structural properties compared with those in the bulk c-Si. Nanostructures based on silicon semiconductor have attracted attention as potential nanoscale building blocks for enhanced performance for optoelectronics and photovoltaic applications [2, 3].

Semiconductors with structures down to few nanometers are an important, basic on which, many potential properties strongly dependent [4]. Silicon nanostructures have been widely studied, primarily due to potential for intential engineering of properties not readily obtained in the corresponding crystalline bulk solids. Formation of nano/microstructured surface using laser ablation in liquids has been extensively explored by using various parameters like laser energy. When a semiconductor surface is irradiated by intense laser light, local heat free carriers are generated which eventually lead to surface vaporization [5, 6].

Porous silicon could be described as a fine complex network of morphology separated by very thin walls consisting silicon nanocrystillites at different sizes. Its structure can be produced by various techniques under different conditions. A continuous wave (CW) laser of suitable wavelength could be used to induce chemical reaction between the hydrofluoric acid and the silicon wafer in process called laser induced etching. This process strongly dependent on the silicon resistance. Laser nanostructured silicon surfaces exhibited strong photoluminescence due to their porous structure which suffering quantum confinement to its charge carriers [7, 8].

We propose this method to enhance the etching rate of porous silicon by using two stages of preparation. This method represented by intense conditions created at the focus of Q-switched pulse laser to create a new form of silicon with unique optical properties. Irradiation of silicon surface with pulse laser of appropriate energy in ethanol liquid solution results in micro-nanometer sized structures [9, 10]. Thereafter, a CW laser applied over the irradiated area to induce porous silicon.

Aims of our study are focused on utilizing lasers to produce silicon nanostructures in two different stages; silicon surface textured by laser ablation in liquid and laser induced etching. We have also studied the morphological evolution as well as the optical properties as a function of surface structure.

EXPERIMENTAL WORK

The experimental procedures followed in our project are very simple. We have used (n-type) polished silicon wafer (1.5- 4) Ω.cm as a target of the orientation (100). The sample preparation process contained two stages; the first concern on create micro/nano structure surface on the silicon using Q-switched Nd:YAG laser operating at a pulse repetition rate of 1 Hz, at the fundamental wavelength 1064 nm with a pulse duration of 15 ns . The second has been done by using CW diode laser (wavelength of 532 nm and 50 mW power) to produce porous silicon on the textured surface for 15 min etching time.

The silicon wafer was cut to many regular pieces (1x1 cm^2) and cleans it very well using the ethanol in order to remove the unwanted layer. The silicon pieces were fixed tidily in Teflon holder localized inside HF resist container. The silicon surface textured with Nd:YAG laser for 10 pulses in ethanol at different laser energies, then we etched the textured area with CW laser inside HF acid has 49% concentration in fixed etching time. The silicon surface reconstructed after irradiation with pulsed laser was examined using an optical microscope; while nanostructural changes caused by CW laser were investigated by an atomic force microscope (AFM).The PL spectra were studied with laser excitation source of 514 nm.

RESULTS AND DISCUSSIONS

Surface modifications of the silicon flat surface using various laser energies and its effect on the porous silicon structure has been studied. Experiments were performed to illustrate the effect of surface roughness on the laser induced etching process. Atomic Force Microscope (AFM) and high resolution optical microscope has been used to investigate the nanostructured layer. In order to demonstrate the surface uniformity, we employed an image processing program to sketch the surface plot to the irradiated area depending on the optical micrographs. Photoluminescence emissions of porous silicon prepared by CW laser were studied with 514 nm wavelength as an excitation source.

We have employed two stages in our work to investigate the effect of surface morphology on the laser induced etching process. Stage one starts by using pulsed Nd:YAG laser work with different laser energy to prepare fine structures on the silicon target immersed in the ethanol liquid media. Subsequently, the textured surface was irradiated by CW diode laser with fixed etching time.

To investigate how the surface morphology evolves with increasing the laser energy, the other parameters are kept at standard conditions. It is found that the laser energy has a significant effect on the surface structure. Increasing the laser energy leads to increasing the evaporating materials from the surface which leads to produce very fine structures has dimensions in the micro and nano-scale. The morphology of the silicon surface has very important effect on the porous silicon formations and its etching time. Figure (2) (A, B, C and D) shows the surface evolution of the porous silicon irradiated with 532 nm diode laser of fixed power (50 mW) over the silicon surface textured by various laser energy from (80 – 200) mJ. Following the irradiation with 80 mj, small peaks of different sizes represents the evolution of porous silicon across the irradiated area. With the sample irradiated with 120 mj, a distinct regular conical pattern appears on the surface which means increasing in the etching rate with increasing the fine surface structure as shown in Fig. (2B). During the laser energy of 200 mj, the appeared conical pattern increases and distributed over the irradiated surface. After etching the textured surface with continuous wave (CW) laser at fixed etching time, the chemical reactions take place and leads to create porous silicon structure depend on the conical sizes. Since the charge carriers are settled in the peaks of the structures [2], this will increase the etching rate speed. Furthermore, the resulting porous silicon seems to be controllable when we manage the surface morphology.

We have also studied the photoluminescence spectra of the porous silicon samples over textured and non-textured surfaces at fixed conditions to identify the effect of textured surface on the particle size and size distribution. Fig. (3) (A,a and B,b) shows the AFM images and the PL spectra to the porous silicon structure. One can clearly see as distinct in figure (3, A) that the PL irradiation from sample etched without textured surface has energy peak position of approximately 2 eV and broad peak which indicates wide particles have different particle sizes. Figure (3,B) shows the PL of the sample etched over textured surface area. This sample shows higher energy peak position as compared with figure above could reach to 2.1 eV and the PL peak intensity becomes higher which indicates the high number of the small nanostructures contributing in this emission.

CONCLUSIONS

Silicon nanostructures could be synthesized by lasers works with different operational mods. The beads of different laser energy serve our purpose which is produce surface of various morphologies distributed over the silicon surface. It is obvious that the etching process is being efficient when the surface have small conical structure. Increasing the laser energy applied on the silicon surface leads to create surface damage in fine shapes has smaller sizes when laser energy increased. These shapes have significant effects on the etching rate as well as the porous silicon formation.

REFERENCES

[1] Heneley.H., G. Fuge., J. of Appl. Phys, Vol.97 (2005).
[2] Kukreja.L.M., B. N. Singh and P. Misra, P.O.CAT, Indore, INDIA (2006).
[3] Riabinina.D., C. Durand, M. Chaker and F. Rosei, Applied Physics Letters, 88 (2006).
[4] Henley.S.J., G. M. Fuge and M. N. R. Ashfold, J. Appl. Phy., 97, 023304 (2005).
[5] Nederson.J., T. M. Cotton, Applied Spectroscopy, 47, 1959 (1993).
[6] Grigoriu.C., I. Nicolae, V. Ciupina, G. Prodan, H. Suematsu, K. Yatsui, Journal of Optoelectronic and Advanced Materials, Vol.6, No.3, p. 825-830 (2004).
[7] Patrone.I., D. Nelson, V. I. Safarov, M. Sentis, W. Marine, S. George, Appl. Phy. Lett., 87, 3829 (2000).
[8] Chrisey.D.B., G. K. Hubler, Wiley, New York (1994).
[9] Preuss.S., A. Demchuk and M. Stuke, Appl. Phys.A, 61, 1, 33-37 (1995).
[10] Acquaviva.S., A. Perrone, A. Zocco, A. Kline and C. Fotakis, Superficies Vacio9, 169-173 (1999).

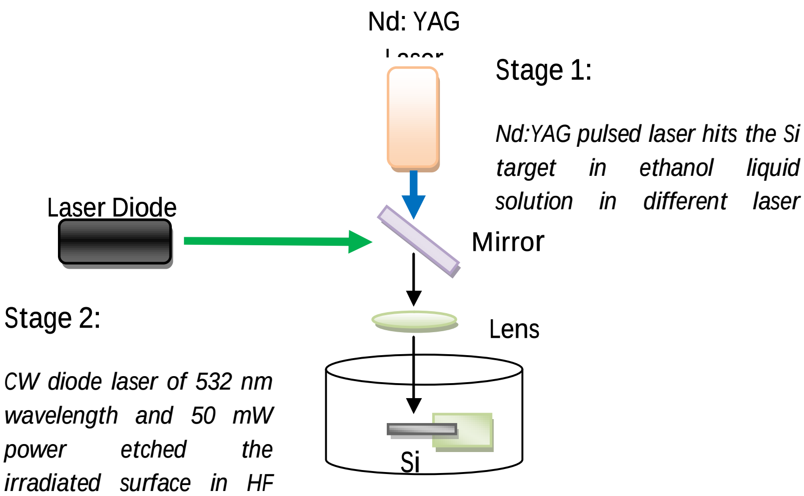

Figure (1) shows the experimental setup of the sample preparation Stages employed in our work

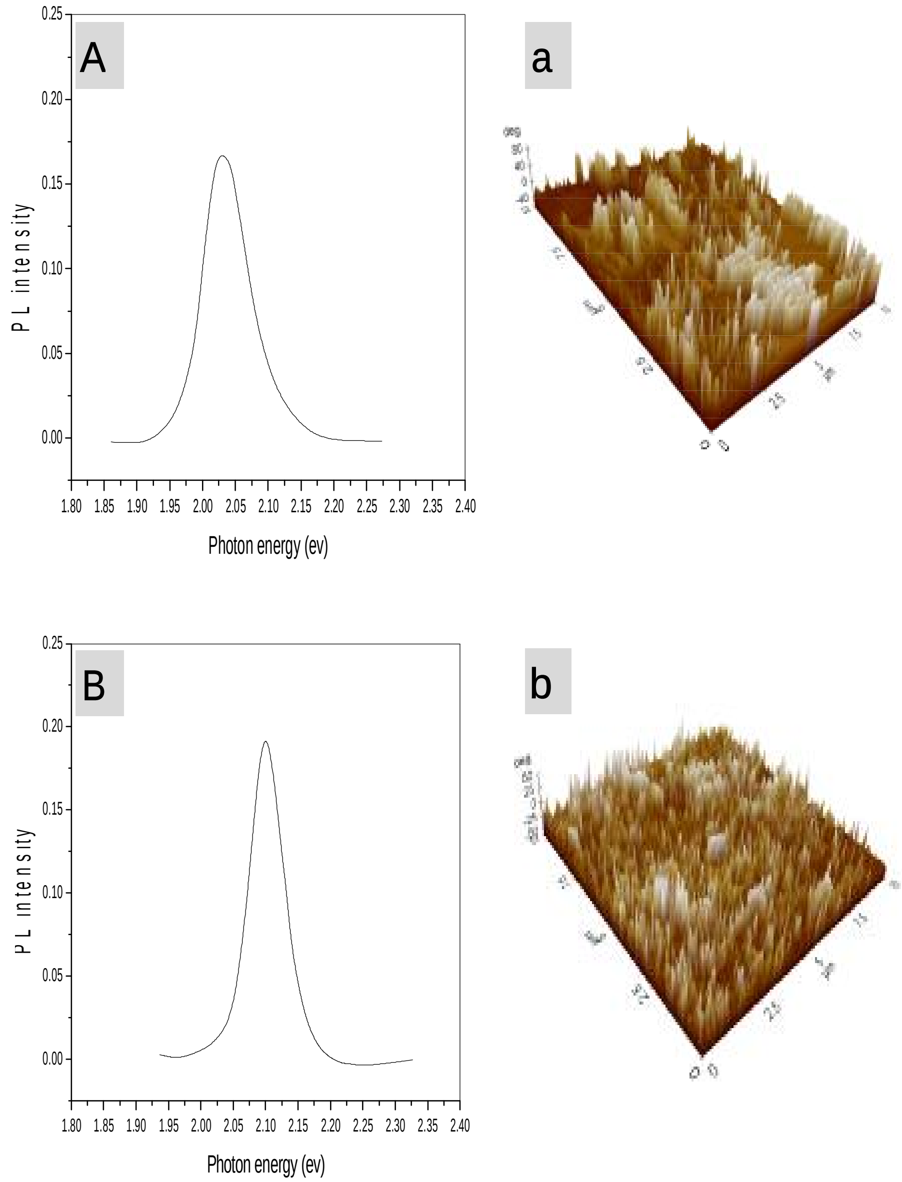

Figure (2) the surface evolution of the porous silicon prepared On various surface structures synthesized at different Laser energies (A) 80 mj, (B) 120 mj, (C) 160 mj and (D) 200 mj.

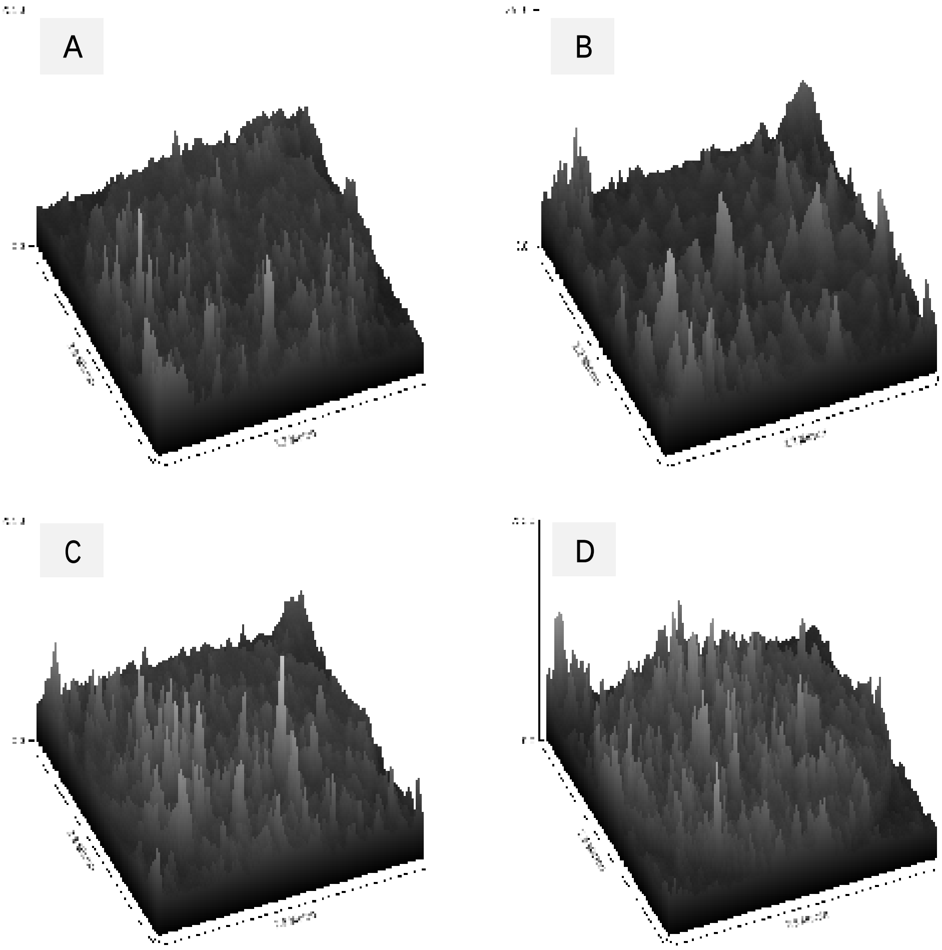

Figure (3) the AFM image and photoluminescence emitted from porous Silicon prepared (A, a) without textured surface and (B, b) with textured surface.