The Opto-Electronic Characteristics of Multi-Porosity Silicon System

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ABSTRACT

Photo-electrochemical etching with step- gradient illumination intensity was used to generate multi – porosity silicon quantum wire system (Q.W.Si) on n-type silicon wafer. A nano size photonic device of AL/Q.W.Si /si/AL was fabricated to investigate the electrical properties and the surface morphology with the aid of scanning electron microscopy. The J-V characteristics of (AL/Q.W.Si /AL) show a rectifying behavior with high ideality factor compared for single layer (Q.W.Si) devices with (AL/Q.W.Si /AL). The high value of ideality factor was explained based on the high density of the dangling bonds are found on the internal surface of the multi porosity layer, leading to poor electrical properties.

المميزات الالكترونية الضوئية للاسلاك السيليكونية الكيمة المتعددة المسامية

الخلاصة

في هذا البحث تم استخدام التنميش الضوئي الكهروكيميائي و بشدات ليزرية متدرجة لانتاج الاسلاك السيليكونية الكمية ذات المسامية المتعددة على شريحة سيليكون نوع n-type . تم تصنيع نبيطة نانوية الاحجام ذي التركيب (AL/Q.W.Si /AL) لاجل دراسة الخصائص الكهربائية للاسلاك النانوية الكمية. اظهرت القياسات الكهربائية وجود سلوك تقويمي و بمعامل تقويم عالي ومما فسرذلك الى الكثافة العالية للاواصر المتدلية و التي تؤدي الى اضعاف الخصائص الكهربائية.

INTRODUCTION

Porous silicon (PS) has recently been shown to have potential inhighly efficient solar cells as a reflector due to large light-trapping. Therole of the PS reflector is to boost the photon absorption in the activeepitaxial layer for low energy photons and therefore to increase thecarrier generation and resulting short-circuit current of the cell.Previously, various morphologies and porosities of PS were employed to enhance the light trapping in solar cell. These included conventional

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single-layer PS [2–4], multi-porosity PS [5], multilayer Bragg [6] and chirped PS reflectors [7, 8]. Among these studies, the multi porosityhas a controllable multi in the index of refraction and demonstratesa broadband antireflection property in silicon wafer. However, very few reports were studied on this multi-porosity PS [5].The optoelectronic properties of multi porosity Q.W.Si system was investigated under step-gradient etching current density [9]. In this work, a multi-porosity Q.W.Silayer was formed on n-type silicon using photo-electrochemical etching with a step-gradient illumination intensity ranging from 10mW to 40mW of CW laser diode of wavelength of 655nm as a function ofetching time. Electrical properties of the multi-porosity Q.W.Silayerwere extracted using J-V characteristics and scanning electron microscopy (SEM).

EXPERIMENTAL WORK

The porous silicon samples were prepared using silicon wafers (111), with n-doping, and resistivity of (10-13 Ω.cm), 508 μm thickness. After cutting into (1x1.5) cm2 specimens and standard cleaning steps, we prepared porous silicon structure of multi-porosity by photo-chemical etching process. In this technique the samples are dipped into mixture of HF:Ethanol, (1:2). A step gradient illumination power on 1cm^2 area exposed on the Psi surface, from (10,20,30,40)mW/cm^2 was applied with time interval (2,4,6and8)min respectively, to form a multi porosity Q.W.Si with thickness of 20μm. For comparison, some Q.W.Si samples were etched with a fixed illumination intensity to form a conventional single-layer Q.W.Si. Typical photo-electrochemical etching apparatus are schematically shown in Figure (1). After wards,aluminimum electrode was evaporated onto the surface of multi- porosity Q.W.Si and single porosity Q.W.Si. Two sandwich structures of Al/multi-porosity Q.W.Si /n-Si/AL and AL/single Q.W.Si /n-si/AL were fabricated to extract the electrical properties of porous silicon.

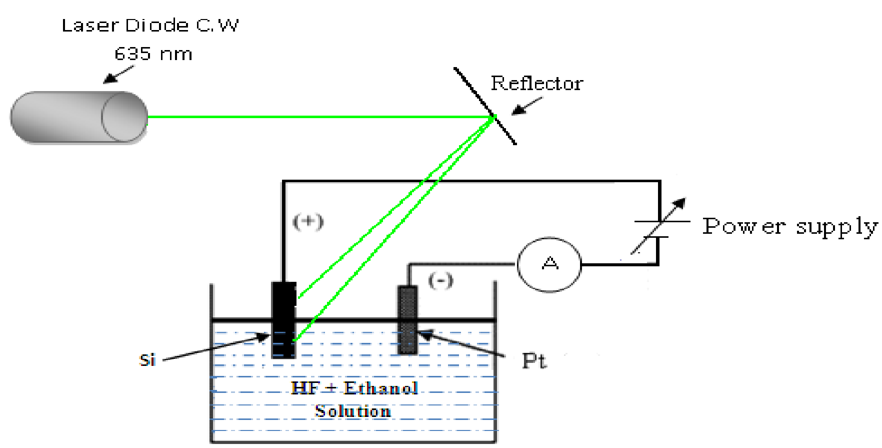
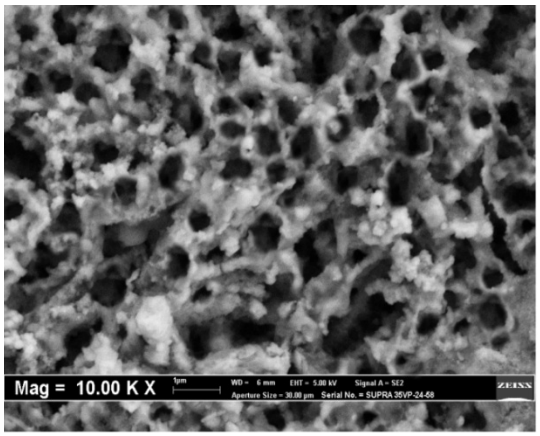
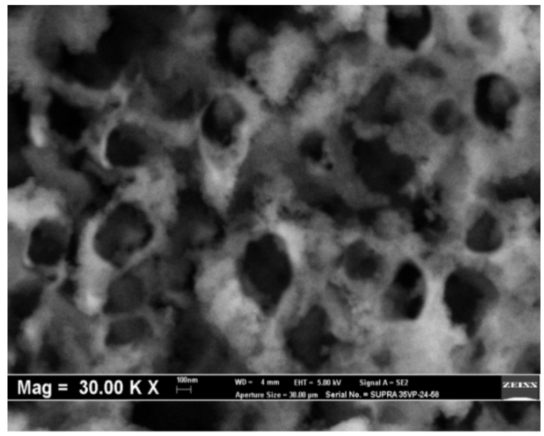


Figure (1) The Schematic diagram of the Photo-electrochemical etching apparatus.

RESULTS AND DISCUSSION

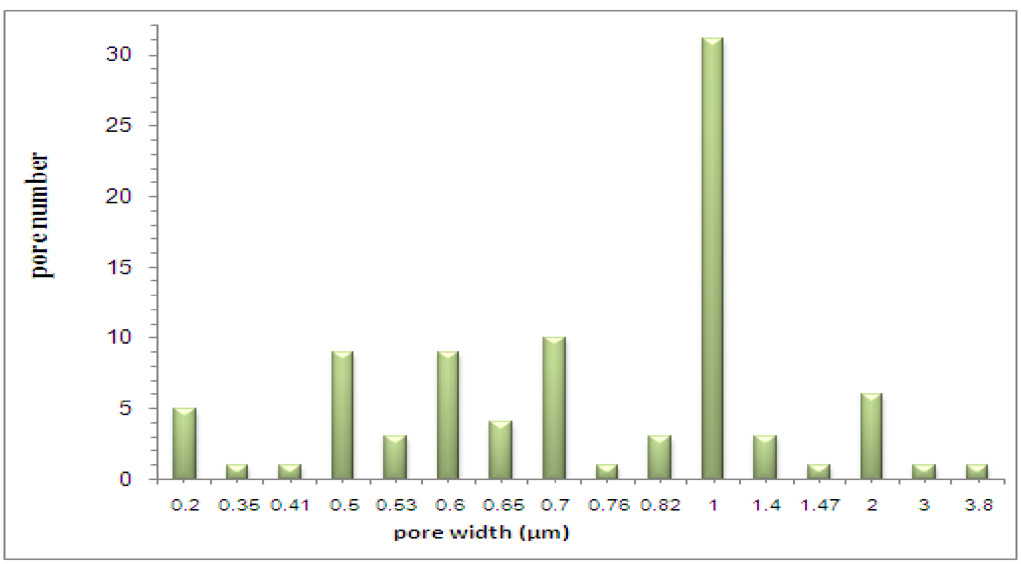
The SEM images for single and multi Q.W.Silayers etched with fixed illumination rise intensity of 10 mW/cm^2 and step gradient illumination are shown in Figure (2a and 2b), respectively. Compared to the sample with constant - illumination intensity etching, as in Figure (2a), the SEM image Figure (2b) of step-gradient etching sample demonstrates a gradient pore-size from large to small pore.



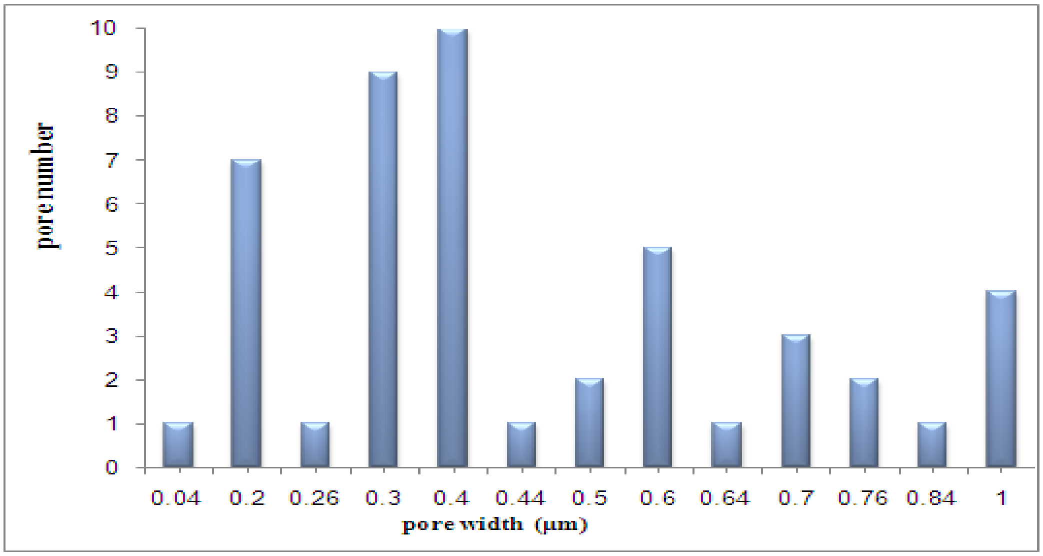


(a) (b)

Figure (2) SEM images for the (a) single layer (Q.W.Si) with fixed-illumination intensity of 10mW/cm2 and (b) multi – porosity (Q.W.Si).



(a)



(b)

Figure (3) Statical distribution of pore size at (a) single layer (Q.W.Si) with fixed-illumination intensity of 10mW/cm2 and (b) multi – porosity (Q.W.Si).

The increasing of laser illumination intensity step (lram 10 to 40 mW/cm^2) will lead to increase the number of pores per unit area from 2*10^8 Pore/cm^2 to 25 *10^8 pore/cm^{2}respectively.

Also the pore shape change from nearly circular cross-section to star full cross-section due to the excessive etching at the pore wall and increase the process of silicon dissolution in HF solution[10].The largeness in pore width may be attributed to increase in holes number on surface silicon electrode with increasing illumination intensity which leads to preferential dissolution between nearest neighbor pores, thereby promoting the pore-pore overlap [10].The statistical distributions of pore diameter size at two illumination level (a) single layer Q.W.Si fixed illumination intensity of 10mW/cm^2 and (b) multi-porosity Q.W.Si are shown in Figure (3). It is clear from this Figure that the distribution was nonsymmetrical for both samples. The pores sizes varied from (0.2 to 2) μm. The increasing in the illumination intensity, lead to increase the number of pores with size in the range (0.2-0.4) μm for Figure (3b) compared with the pore size in the size of 1μm for Figure (3a).

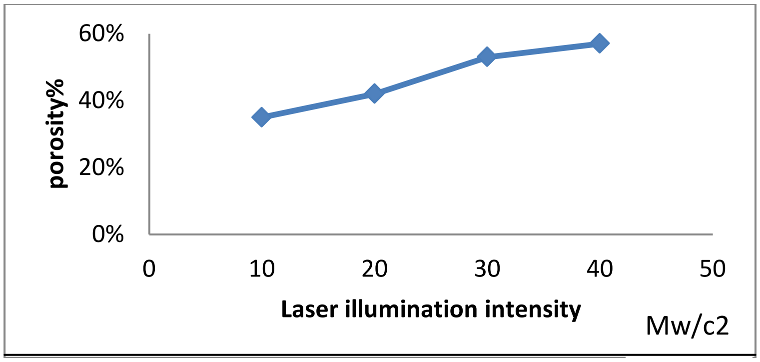


Figure (4) porosity as a function of different etching Illumination intensity.

The porosity as a function of different etching illumination intensity are shown in Figure (3), Figure (4) for the Q.W.Si with fixed power density and variable power density. The porosity is defined as the fraction ofvoid within the Q.W.Si layer and can be easily measured by the weightmeasurements. The origin sample before etching has a weight of m_1,just after etching the weight is m_2, and m_3 is the weight of the sample after removing the Q.W.Silayer.Thus the porosity is estimated by:

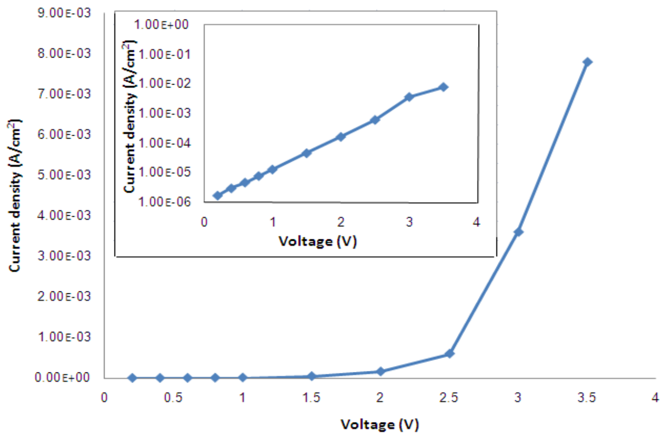
$$\gamma(\%) = \frac{m_1 - m_2}{m_1 - m_3} \qquad \ldots (1)$$

The thickness of the Q.W.Si layer (d) is determined by using gravimetric measurements.

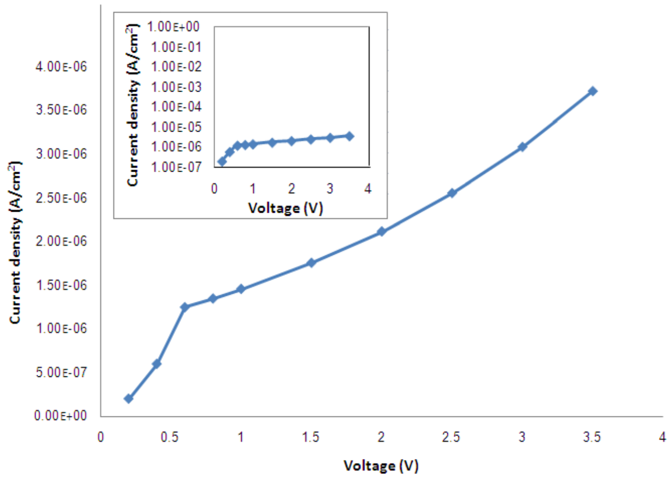
$$d = \frac{m_1 - m_2}{A \times \rho} \qquad \ldots (2)$$

Where (A) corresponds to the illumination area (cm^2) and (ρ) to the density of bulk silicon ($\rho = 2.33$ g/cm^3).

It is found that the average pore-size increases with increasing in illumination intensity due to larger etching ability. Such a phenomenonconfirms the stare full-shape in SEM image in our experiment with that illumination intensity increases from 10to 40mW/cm^2. However, the porosity increases with increasing in laser intenstiy, from 35% for the sample etched with 10mW/cm^2 to 56% for 40 mW/cm^2. The largerporosity obtained at higher illumination intensity is attributed to the extrachemical dissolution of the layer, which leads to a difference in themicrostructure [11]. The J-V characteristics of Al/multi-porosity Q.W.Si/n-Si and Al/single-layerQ.W.Si/n-Si structures measured under dark and with voltage ranging from (0-5V) is shown in Figure (5).



(a)



(b)

Figure (5) J-V characteristic for (a) single layer (Q.W.Si) with fixed-illumination intensity of 10mW/cm2 and multi porosity Q.W.Si.

We found that the dark current decrease with the increase in etching laser intensity, due to the multi porosity system which is obtained in higher etching illuminationthe value of ideality factor which accounts for any deviation on the measured foreword current-voltage characteristics from ideal behavior at room temperature was extracted from the semi-log plots which are depicted in Figure (5) is about (12) for single porosity layer while for multi porosity layer is increased to about (85). This increasing in ideality factor is related to increase of the density of the inter face state at the porous silicon boundary [9].

CONCLUSIONS

Multi- porosity silicon quantum wire system has been fabricated on crystalline silicon wafer using photo-electrochemical etching with step-gradient illumination intensity. A nano size photonic devices of (AL/Q.W.Si /AL) were prepared to extract the opto-electronic properties. It was found the measured J-V characteristics of (AL/Q.W.Si /AL) shown a rectifying behavior with high ideality factor compared with single layer (Q.W.Si) devices (AL/Q.W.Si /AL) the high value of ideality factor was explained based on the high density of the dangling bonds are found on the internal surface of the multi porosity layer, leading to poor electrical properties.

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