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Study the Effect of Different Silicon Substrate Resistivities on the Photoluminescence Results

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ABSTRACT:

The silicon-based electroluminescent devices are most commonly used in recent years, especially in optical equipment. The physical properties of the photoluminescence are investigated experimentally in this paper. The silicon substrate resistivity is tested dependence of the photoluminescence of porous. The formation current density of p-type and highly doped p-type silicon are studied. It is found that using 40 mA/cm^2 as a formation current density produced a large number of contributing nano crystals. The applied low current caused a weak photoluminescence intensity, and the increasing of the formation current density led to increase the contributing Nano crystallizes. For the optimum case with smaller nanocrystallite sizes, the photoluminescence intensity decreased by the fast etching process, and the high current density produced a small number of nanocrystallite sizes and very weak photoluminescence. The higher resistivity doesn't give a higher intensity and better results in photoluminescence of used porous silicon.

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دراسة تأثير المقاومة النوعية المختلفة للسيليكون على نتائج التلولؤ الضوئي

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الكلمات المفتاحية:

سيليكون مسامي
تلؤلؤ ضوئي
مقاومة نوعية

الـــخُـــلاصـــة:

الاجهزة الكهروضوئية والتي تعتمد على السيليكون هي الاكثر انتشارا في السنوات الأخيرة وخصوصا في المعدات البصرية. في هذا البحث تمت دراسة الخصائص الفيزيائية للتلؤلؤ الضوئي عمليا و بشكل خاص اختبار تأثير المقاومة النوعية المختلفة للسيلكون المسامي على تلك الخصائص. حيث تم دراسة كثافة تيارالتشكيل للسليكون لنوعين الاول من النوع p والثاني من النوع p عالي التطعيم. وقد وجد أن استخدام 40 مللي أمبير/ سم٢ كشدة تيار تشكيل سوف يؤدي الى أنتاج عدد كبير من بلورات النانو المساهمة. ووجد ان التيار المنخفض يتسبب في ضعف كثافة التلؤلؤ الضوئي بينما ان زيادة كثافة تيار التشكيل سوف يؤدي إلى زيادة اعداد ذرات النانو المساهمة. الحالة المثالية مع الأحجام الأصغر من البلورات النانوية، شدة التلؤلؤ الضوئي سوف تنخفض بعملية التنميش السريع ، بينما أنتجت كثافة التيار العالية أحجام صغيرة من البلورات النانوية وتلؤلؤ ضوئي ضعيف جدًا. لا تعطي المقاومة النوعية الأعلى شدة أعلى ونتائج أفضل في خصائص التلؤلؤ الضوئي للسيليكون المسامي المستخدم.

1. INTRODUCTION

Because of the important fundamentals physical properties of the Silicon, the investigation of silicon quantum dots is a very effective branch of research, of different subjects and of promising applications in a new electronic equipment. Steiner and Lang [1] studied the electro-optical properties and some features of porous silicon for micromechanical applications. Because of the formation of porous silicon doping sensitivity, they found that a large range of pores and crystallite sizes can be formed simply. Wolkin et al. [2] investigated the size effects on the photoluminescence of silicon quantum dots current in porous silicon tuned in a wide range from ultraviolet to the infrared. Foll et al. [3] reviewed all manifestations of pores in silicon with respect to possible applications. They emphasis on putting macropores, detailed and explained the cases of pore formation models. They discussed separately applications of meso, macro, and micropores simultaneously with several status of particular experimental subjects.

Hessel et al. [4] reported the bulk preparation of nanocrystalline via straight forward reductive thermal annealing. They showed that this method gives quantitative yields of installed powders in huge quantities that will have facilitating the solution process ability, handling easy, and the production of patterned optoelectronic films. Kim et al. [5] demonstrated that three dimensions, particles of porous silicon that contain of bulk sizes larger than 20 mm can be prepared by simple thermal annealing. They proved there is no need for a sealed ampoule when using that method and the reduction is simple to scale up. Park et al. [6] investigated nanoparticles of luminescent porous silicon that can transport a payload of drug and of which the radical near-infrared photoluminescence can observe of both degradation and accumulation in vivo. Their results demonstrated a new kind of low-toxicity degradation pathway with a multifunctional nanostructure for in vivo applications.

Warren et al. [7] studied highly structured silicon micro wire arrays as absorbers for solar energy-conversion systems. They showed that the silicon microwave array geometry allowing for effective combination of photo produced carriers from unclean materials that have short minority-carrier propagation lengths when together allowing for high external quantum and high optical absorption yields for charge-carrier combination. Huang et al. [8] demonstrated a silver catalyzed hetero epitaxial growth of gallium phosphide nanowires on silicon. They inferred from the crystallographic analysis that silver from catalyst is inserted into the GaP during the chemical beam tuned operation. They modified, by using the time-resolved emission spectroscopy and PL spectrum, the optical properties of Ag-catalyzed GaP NWs, with bandgap transitions in the blue range.

Canham [9] lately are accounted for the preparation of silicon materials that indicate greater effective in room-temperature photoluminescence. Silicon is the first material that has been used in the electronics and optical equipment industry, but its indirect band gap and weak photoluminescence features have impeded implementations in the optical equipment. Recently, researchers started to improve the silicon-based electro luminescent equipment from the material usually mentioned to as porous silicon, and they have investigated the physical properties of the photoluminescence.

Many preparation techniques have been adopted in synthesizing porous silicon; among them is the electro-chemical etching technique. The formation of porous silicon is used to electrochemical etching of silicon in hydrofluoric acid (HF). Different pore morphologies can be gained by the doping of the anodized silicon substrate, the nano-metric pores from p-type substrates are made, and from illumination of n-type substrates, the micrometric pores are obtained.

The aim of this work is to investigate and study the physical properties of the photoluminescence, and test the substrate resistivity's dependence on the photoluminescence of porous silicon.

2. EXPERIMENTAL WORK

A wire-cut machine was used to prepare the square-shaped samples of a p-type silicon at different resistivities, the area of each sample is 1x2 cm^2. In order to remove the oxides, all samples were etched with CP4 solution consisting of (HNO_3, CH_3COOH, and HF) of ratios (3:3:5) for 15 minutes. Alcohol and ultrasonic waves produced by Cerry PUL 125 device was used to clean the samples. In next stage, the water and ultrasonic waves for 15 minutes is used again to clean them.

Edwards coating system was used to fabricate Ohmic contacts by evaporating 99.999 purity aluminum wires. The technique of Four-Point Probe (FPP) was used to measure the physical properties of the silicon substrates, such as the type of conductivity and resistivity.

The electrochemical etching process was used to produce the porous silicon samples. The cell consists of two electrodes, the first of silicon wafer is the anode, while the cathode is represented by a non- corrosive HF acid material like platinum. These electrodes were immersed in the HF acid inside a Teflon container. Current density (J_{ps}) plays an important role in the electrochemical etching process. The current density is given by [9]:

$$J_{ps} = BC^{\frac{3}{2}} \exp\left(-\frac{E_a}{KT}\right) \qquad (1)$$

Where:
E_a is the activation energy,
C is the acid concentration wt% of HF
B = constant equal to 3300 mA/wt%$^{-3/2}$.

A photoluminescence of silicon nanocrystallite constituting the porous silicon was carried out. 514 nm CW diode laser was used to probe the p-Si layer as an excitation source, with photon energy 2.41 eV which could excite a wide range of nanocrystallite sizes. A laser power density of approximately equal to 5 mW/cm^2 was focused on the samples. This low power density can rule out any significant sample heating during spectroscopic measurements.

3. RESULTS AND DISCUSSION

Effect of the formation current density of p-type silicon of 2.179 Ohm.cm resistivity, at HF concentration of 30% and 30 min was studied and give in figure (1-a, b, c).

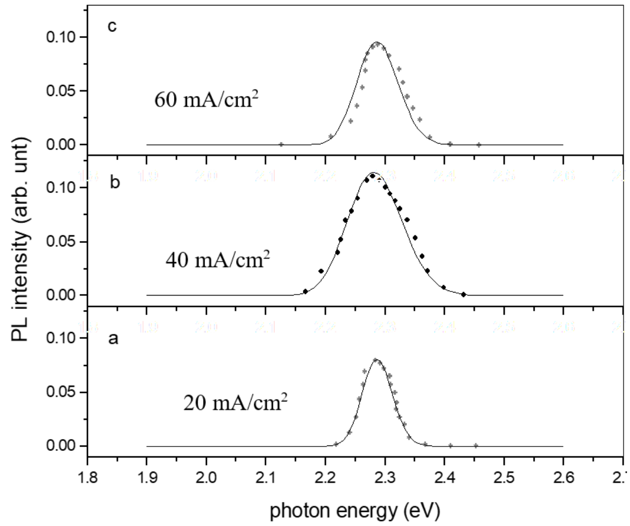

Figure 1: Current density effect on the photoluminescence at 2.179 Obm.cm resistivity.

Figure (1-a, b) and table (1) revel that increasing the current density from 20 to 40 mA/cm^2 leads to shift the photo luminescence peak position from 2.28 to 2.29 meV due to the size reduction of silicon Nano crystals as shown in figure (1-b) .

Increasing the current density to 60 mA/cm^2 causes removal of smaller nano crystallites abundant at the top of the porous layer due to excessive etching shown in figure (1-c).

Moreover, one can note that using 40 mA/cm^2 as a formation current density produced a large number of contributing nano crystals. This is reflected in the FWHM, the value of FWHM for such a current density was 120 meV which is the optimum compared to other cases, therefore, one can conclude that the proper selection of the formation current density is 40 mA/cm^2.

Table 1: Photolumincense fitting parameters for p-type silicon of 2.179 Ohm.cm resistivity

Current density	L_0[1] (Å)	Δ[2] (Å)	FWHM[3] (meV)	PL (eV) peak position
20	20.2	0.11	70	2.28
40	19.6	0.195	120	2.29
60	20.22	0.15	90	2.285

[1]L_0: Lattice constant; [2]Δ: Mo-sadegh constant; [3]FWHM: full-width half maximum

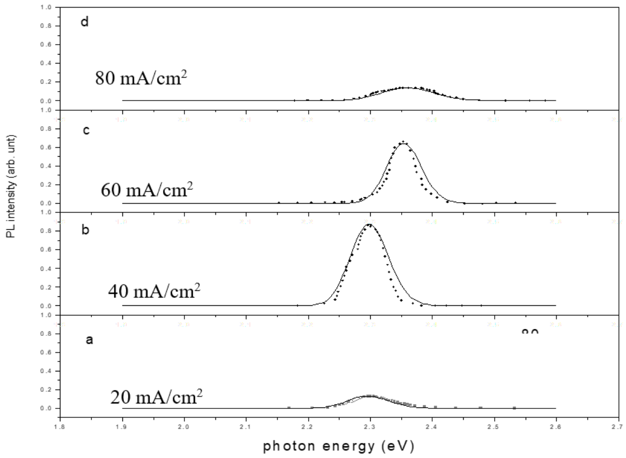

Figure 2: Current density effect on the photolumincense at 0.00375 Ohm.cm resistivity.

Effect of the formation current density was studied for a highly doped p-type silicon of 0.00375 Ohm.cm resistivity, the photoluminescence spectra in this case confirm that the porous layers have smaller nanocrystillite size. Those photolumincenses got blue shifted to the word higher energy, figure (2-a, b, c, d) and table (2) show the effects of using various formation current densities of highly doped p-type silicon. When low current density of about 20 mA/cm^2 is used, a weak photolumincense intensity was observed due to low number of luminescent size. Further increasing of the formation current density to 40 mA /cm^2 leads to increase the contributing nano crystallizes that add an increase consequently, figure (2-b).

The optimum case was achieved when smaller nanocrystillite sizes was obtained (figure (2-c)), but one should mention here that the photolumincense intensity decreased due to the fast etching process. While, the high current density of 80 mA/cm^2 produced a small number of nanocrystillite sizes, and a very weak photolumincense was observed, but a wide range of luminesce silicon nanocrystillites was contributed the photolumincense emission. Therefore, a FWHM of 100meV was appeared.

Table 2: Photolumincense fitting parameters for p-type silicon of 0.00375 Ohm.cm resistivity

Current density	L_0 [1] (Å)	Δ [2] (Å)	FWHM [3] (meV)	PL (eV) peak position
20	19.6	0.165	70	2.29
40	19.64	0.111	70	2.3
60	20.1	0.13	50	2.32
80	20.12	0.14	100	2.3

[1]L_0: Lattice constant; [2]Δ: Mo-sadegh constant; [3]FWHM: full-width half maximum.

4. CONCLUSIONS

In this work, the formation current density of p-type silicon is studied, and it can concluded that using 40 mA/cm^2 as a formation current density produced a large number of contributing nano crystals and the current density was 120 meV, which is the optimum value. The same parameters are investigated for heavy doped p-type silicon, the low current applied caused a weak photolumincense intensity, and the increasing of the formation current density led to increase the contributing nano crystallizes. The results show a good agreement with Canham [9]. Finally, the optimum case was achieved with smaller nanocrystillite sizes, the photolumincense intensity decreased by the fast etching process, and the high current density produced a small number of nanocrystillite sizes and a very weak photolumincense

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