Sensitivity of gold nanoparticles doped in porous silicon

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Abstract

In this work gold nanoparticles (AuNPs), were prepared. Chemical method (Seed-Growth) was used to prepare it, then doping AuNPs with porous silicon (PS), used silicon wafer p-type to produce (PS) the processes doping achieved by electrochemical etching, the solution etching consist of HF, ethanol and AuNPs suspension, the result UV-visible absorption for AuNPs suspension showed the single peak located at ~(530 – 521) nm that related to SPR, the single peak is confirmed that the NPs present in the suspension is spherical shape and non-aggregated. X-ray diffraction analysis indicated growth AuNPs with PS. compare the PS layer without AuNPs and with AuNPs doped for electrical properties and sensitivity properties we found AuNPs:PS is more better than PS layer alone that refer to the AuNPs is improve properties PS.

Key words

Gold nanoparticle, Seed-Growth, PS, electrical properties and gas sensor.

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تحسسية الذهب النانوي المطعم بالسليكون المسامي

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الخلاصة

في هذا العمل حضرنا دقائق الذهب النانوية، استخدمت الطريقة الكيميائية للتحضير ثم طعمت مع السليكون المسامي، استخدم سليكون نوع P لتحضير السليكون المسامي حيث تم تحضيره بالتنميش الكهرو كيميائي تضمن محلول التنميش كل من حامض الهيدروفلوريك والايثانول وعالق دقائق الذهب النانوية. من نتائج امتصاص الاشعة الفوق البنفسجية والمرئية للدقائق النانوية للذهب اظهرت قمة منفردة تقع بين (530-521) نانومتروهذا يعود الى وجود SPR أن وجود القمه المنفرده اكد ان الدقائق النانوية الموجدوة بالعالق كروية الشكل وغير متجمعة. وتحليل حيود الأشعة السينية وأشار نمو دقائق الذهب النانوية مع السليكون المسامي. ومقارنة طبقة السليكون المسامي بدون الدقائق النانوية و مع الدقائق النانوية المطمة بالسليكون المسامي ان الخصائص الكهربائية وخصائص التحسسية وجدنا ان الدقائق النانوية المطعمة بالسليكون المسامي هو أفضل بكثير من طبقة السليكون المسامي وحدها هذا يشير أن دقائق الذهب النانوية حسنت خصائص السليكون المسامي.

Introduction

Coupling system includes metal nanoparticles (MNPs) with semiconductor nanocrystals (SiNCs) has been subject of big interest for scientific community [1]. Due to their unique physical and chemical properties of MNPs, this material have at least one of the feature, the presence surface Plasmon resonance (SPR), the functionalization of surface with organic molecules is easy and the physical and chemical stability [2].

AuNPs are the subject much attract attention because the unique physical and chemical qualities which have this material, where this properties depend on size and shape particle. AuNPs have special important because tunable shape and size, high absorption

coefficient, high stability in different environment, and environmental friendly because it non toxicity so we can use in medicine, biotechnology and catalysis sensing [3-5]. AuNPs is prepare by Top-down method or Bottom-up method, both methods have great attention because nanostructure material prepare by this method been with less defect and greater homogeneous chemical [6].

Chemical reduction is a bottom-up method. This is the reduction of ionic metal salt in a suitable medium in presence of surfactant applying reducing agent such as sodium borohydrid, sodium citrate, ascorbic acid. [7, 8]. Seed growth is popular and convenient process to obtain particle with desired size and shape. The advantage of this method is, the time of reaction is shorter, cheaper, and simple and the product can be scaled up [3]. This method includes two step first, synthesis of seed particle by reducing metal salt ion with strong reducing agent in presence capping or stabilizing agent. Then added to growth solution which consider the second step of this process contain metal salt ion with CTAB and weak reducing agent ascorbic acid AA [9]. AuNPs used to improve sensor that based on PS when doped with it, PS is most attractive host platform to produce sensor due to has unique properties where it has large surface area to volume ratio, simple to fabricate and can control the pore size by controlling the parameter of fabrication [10, 11], PS can be formed by electrochemical etching of c-Si with fluoride solution [12].

In this paper prepare AuNPs by Seed-Growth method then the solution used as one element of solution etching to produce PS layer to use gas sensor our study prove the AuNPs improve sensitivity PS layer for gas.

Experimental

AuNPs is synthesized using Seed-Growth method. (1) seed solution: use double distill deionized water to dissolve amount of the powder from sodium citrate, $HAuCl_4$ and $NaBH_4$. The final solution contain the 20 ml of 0.1 M from sodium citrate, 50 ml of 0.015 mM) from $HAuCl_4$ and 0.6 ml of ice-cold 0.01M $NaBH_4$. The solution was kept at room temperature for 1hour, before add to Growth solution. (2) Growth solution: involve 200 ml of 0.05mM from $HAuCl_4$, 40 ml of 0.1mM-CTAB and 0.5 ml of 0.1 M-Ascorbic Acid. Also dissolved this powder from this material in double distill deionized water. The final solution is divided into five samples; all contain (40ml of growth), with different seed 1 ml, 2 ml, 3 ml seed, 4 ml and 10 ml.

The AuNPs solution adds to solution etching the solution become contain Hydrofluoric acid (HF), Ethanol (C_2H_5OH) and AuNPs solution the amount of HF acid is 20%. Use the electrochemical etching to prepare the PS layer where put p-type silicon in solution etching with current density 15mA/cm² and 15min that etching time. Also we prepare PS layer from p-type silicon by electrochemical etching at solution etching contain (HF and Ethanol) the concentration of HF in the solution is 20% with current density 15mA/cm² and etching time is 15min.

Results and discussion

Fig.1 shows the UV-Visible absorbance spectra of the AuNPs suspension prepared at different amounts of seed 1 (S_1), 2 (S_2), 3 (S_3), 4 (S_4) and 10 ml (S_5) with growth 40ml for all samples. When increasing the amount of seed from 1ml to 10 ml the absorption peak is shifted to lower wavelength from 530 nm for 1 ml seed to 521 nm for 10 ml seed that

attributed to the AuNPs decreased size when the amount of the seed increased while the intensity of absorption peak increased due to the intensity depends on the concentration of AuNPs. When the amount of seed increased, the amount of AuNPs formation increased [13]. The single peak is confirmed that the NPs present in the suspension is spherical in shape and non-aggregated [14, 15].

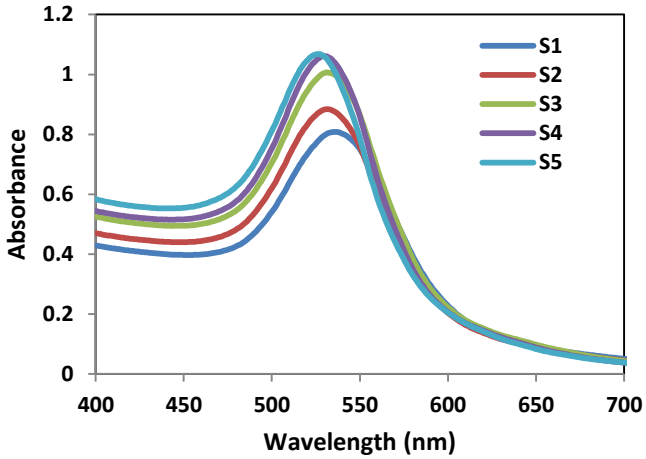

Fig.1: Absorbance spectra of AuNPs suspension with different amount of seed.

From absorption spectra, it can calculate the value of energy band gap. We found the value of energy gap increased with increasing the amount of seed at 1ml seed the energy gap is 2.11 eV while at 10 ml seed the value is 2.16 eV that attributed to the decrease in the particle size.

Fig. 2 shows AFM, 3D image for AuNPs doped with PS. The AFM image is confirmed finding AuNPs, the average size of pore be made of on c-Si wafer 31.41 nm for 1 ml of seed and average size 32.38 nm for 10 ml of growth.

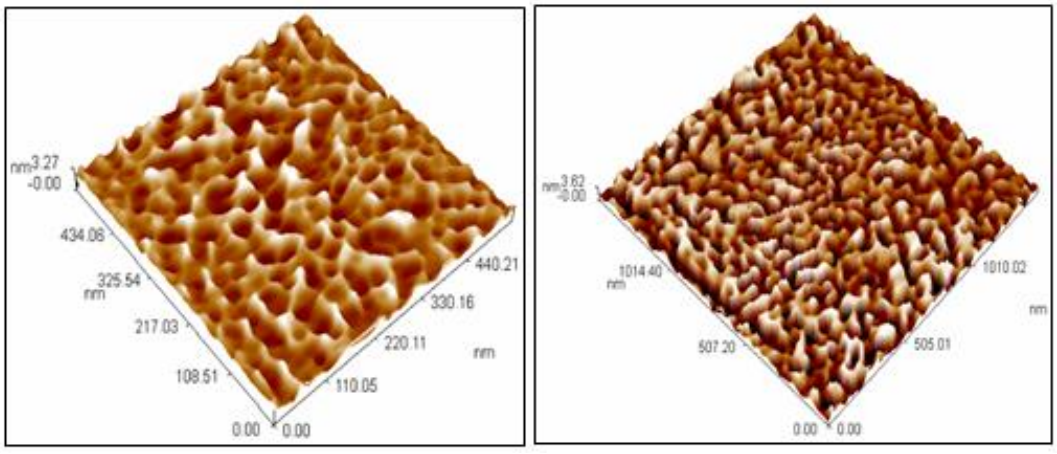

Fig. 2: AFM 3D image for AuNPs doped with PS left with 1ml of seed right with 10ml of seed.

Fig. 3 shows FTIR spectra in the wavelength range 400 to 4000 cm^{-1}, to the sample contained 1ml of seed. The predominance of element is Oxygen, Hydrogen, carbon and gold in the structure due to the doping of AuNPs at PS. The peaks present in the spectra corresponded to Si-H, bending mode

located at 468 cm^{-1}, Si-O bend in O-Si-O at 698 cm^{-1}, the peak near 939 cm^{-1} can be attributed to Si-H_2 scissors mode, the band CO_3Au^- located at 1087 cm^{-1}, the band at 2071 cm^{-1} attributed to Si-H stretch Si_3-SiH, band of Si-Au located at 3086 cm^{-1} and the band located at 3635 cm^{-1} assigned to $AuOH^-$ [16, 17]. This chemical group in this samples due to chemical reaction between Au (atoms and ions) with the element chemical composite this parameter. Present carbonet complex attributed to the atmospheric CO_2 and also presences the different reducing agent [14].

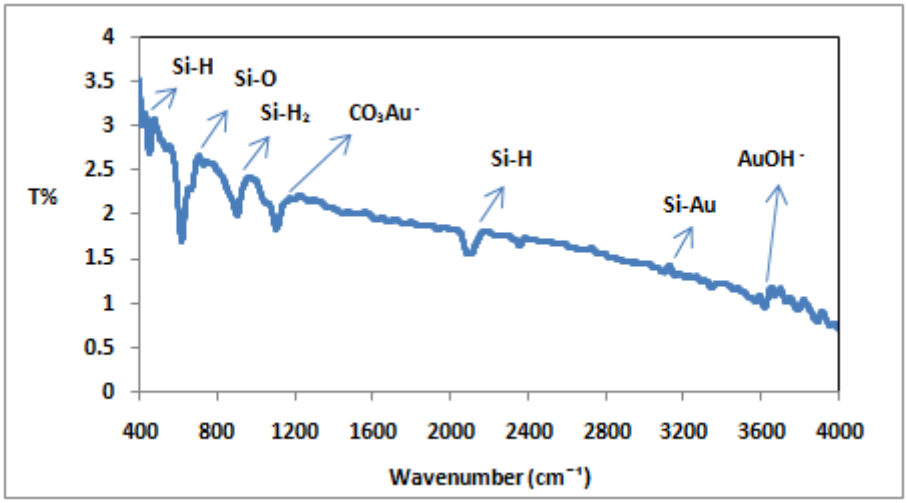

Fig. 3: FTIR spectra of AuNPs doped with porous silicon.

XRD spectrum of AuNPs doped with PS is shown in Fig. 4 observed the formation of crystalline AuNPs during the chemical reduction, the diffraction peaks for gold oxide at $2\Theta=32.68^o$ (311), 61.38^o (220) while the peaks for PS at 2Θ~67 (100).

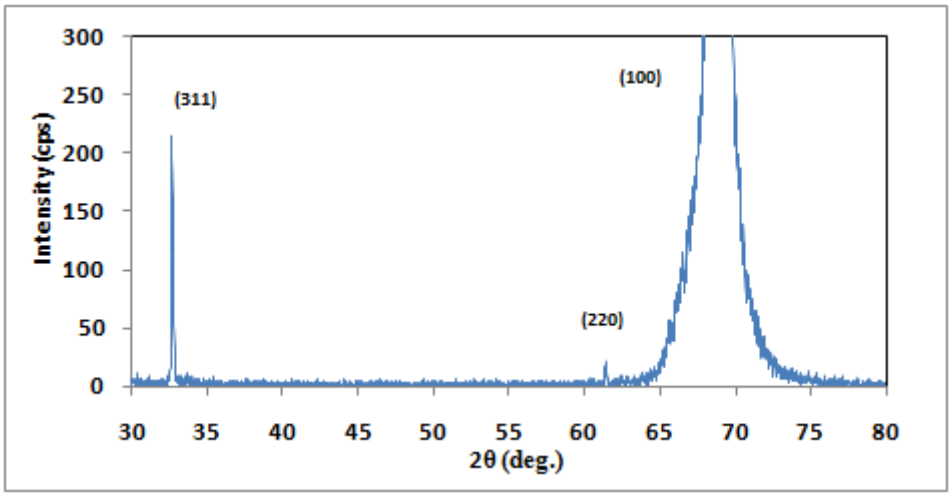

Fig.4: XRD of AuNPs doped with PS.

Fig.5, shows the dark *I-V* characteristics in forward and reverse direction of AuNPs doped in PS. From the figure, found the forward current increases after embedding AuNPs. Current increases by increasing

voltages due to double Schottky junction between AuNPs and PS layer. It's increasing the voltage the resistance junction decrease thus the current increase. As the concentration of AuNPs increase the resistivity of PS layer decrease because the nanopores become filled with AuNPs that lead to increase the current [18].

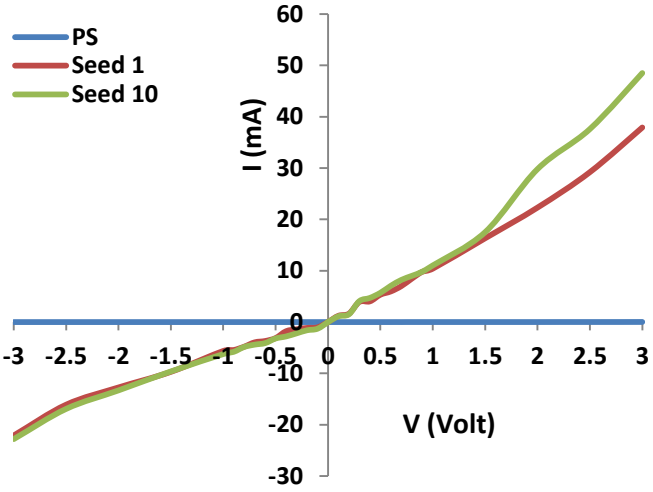

Fig. 5: The I-V characteristics of AuNPs doped with PS.

Fig. 6 shows *I-V* under white light illumination of AuNPs doped with PS. The Figure confirm the photocurrent increase when power increase because the generation electron-hole pair, this mean reduces the resistance with increasing photon energy of the illuminating light [19].

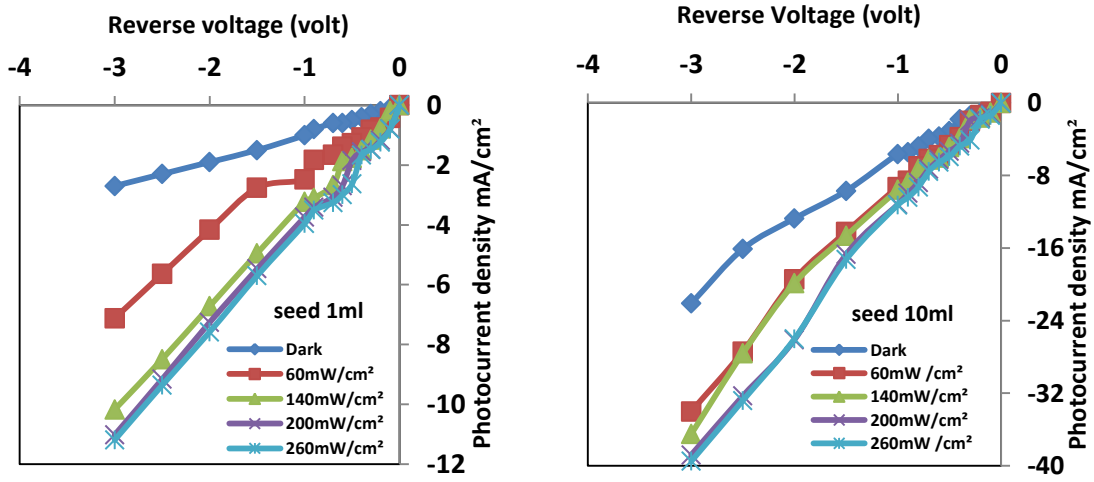

Fig. 6: I-V characteristics of AuNPs doped with PS under whit light illumination.

The sensor sensitivity (*S*) is defined as the change in the resistance of sample during the exposure gas where $S = [(R_g - R_a)/R_a] \times 100\%$, where R_g is the resistance in gas and R_a is the resistance in air [20]. From Fig. 7, it observed the sensitivity of PS doped with AuNPs increases when exposed to CO_2, when the sample adsorbed CO_2 the Schottky structure between PS and AuNPs is more sensitive to CO_2 the Schottky structure is influenced by the change in barrier height where the barrier height depend on the AuNPs

work function which reduce when exposed CO_2 gestate lead to reduce the resistance. Also we can see the sensitivity of PS doped with AuNPs is higher than PS layer [21].

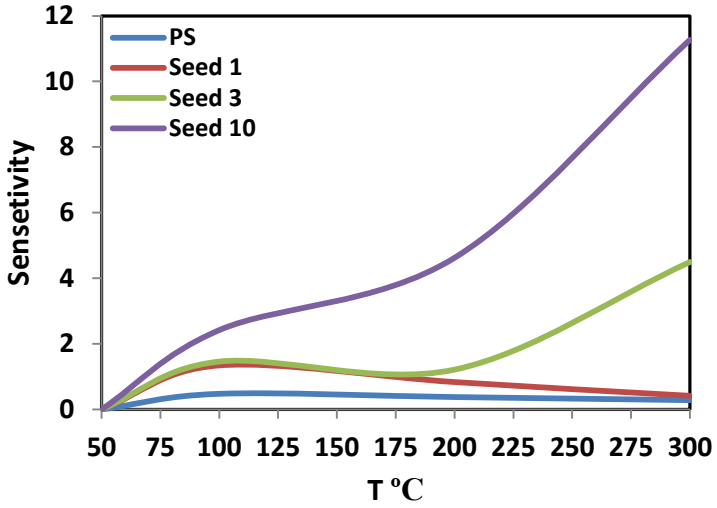

Fig.7: The sensitivity of AuNPs doped with PS at different amount of seed.

Conclusions

From the results previous, Uv-Vis we can conclude the shape of particle is spherical shape and the peak absorption located at ~ 520 nm that indicated the SPR, and from I-V curve and sensitivity curve observed the AuNPs is crucial role to enhance the properties of PS where the electrical properties and sensitivity is improved higher than the PS layer alone.

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