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Study of Silicon Solar Cells with Nanoporous Silicon Layer

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ABSTRACT

Today over 90 % of all photovoltaic solar cells produced worldwide are composed of the silicon (single crystal, multicrystalline, amorphous, etc.). Notwithstanding this, the moderately significant expense of silicon solar cells stays the fundamental impediment for their considerably more extensive applications. Actual standards of working of photovoltaic solar cell and activity of antireflecting covering have been momentarily introduced. This part audits examinations completed in the course of the last 10–15 years concerning the utilization of permeable silicon layers in silicon solar cells. Information on photovoltaic boundaries of silicon solar cells with slender permeable silicon layer as antireflecting covering and furthermore reflectance information of PS layers have been summed up. Benefits of nanostructured PS use in silicon solar cells, concerning increment of the cell powerful surface territory, bringing down of the reflectance, widening of the compelling band hole of close surface area of cell, and so forth, which at long last advance improved silicon cell effectiveness and work on the innovation, have been introduced.

1. Introduction

Today's photovoltaic solar panels are widely used to supply the power and buildings. The record of total solar cell item in 2010 was around 20 GW. More than 95% of all solar cells created overall are made out of the silicon (single gem, polycrystalline, undefined, lace and so forth) and mastery of silicon-based solar cell market most likely will be do as such in the short term. The primary purpose behind prevailing part of silicon solar cells in word market is top notch silicon that created in enormous amounts for microelectronic industry. Also silicon solar cell preparing doesn't trouble the climate.

The primary necessities for ideal solar cell material are (a) immediate band structure, (b) band hole somewhere in the range of 1.1 and 1.7 eV, (c) comprising of promptly accessible and non-poisonous materials, (d) great photovoltaic change proficiency, (e) long haul solidness [1]. Silicon is the second most bountiful component in the world's covering (35 %) after oxygen. It is the base material for photovoltaic change of solar range radiation going from bright to the close to infrared, anyway it can ingest the little segment of solar radiation, for example can change over photons with energy of the silicon band hole. The hypothetical bend for transformation proficiency of solar cell materials versus band hole for single intersection cell (Figure 1) shows that silicon (1.1 eV) isn't at the limit of the bend (about 1.4-1.5 eV) however moderately near it [2]. The proficiency for ideal silicon solar cell can reach about 30% (for AM1.5 at 300K).

Photoelectron properties related with aberrant band construction and high reflectance of translucent silicon (about of 30-35%) are as yet a challenger for creation solar cells with high transformation effectiveness. High refractive file of glasslike silicon (about 3.5) in solar range district of 300-1100 nm makes enormous optical misfortunes which can be decreased by utilizing antireflection covering (ARC). Albeit exceptionally effective twofold and triple antireflection coatings are accessible, most fabricated translucent silicon solar cells utilize basic and modest single-layer ARC with generally helpless antireflection properties [2].

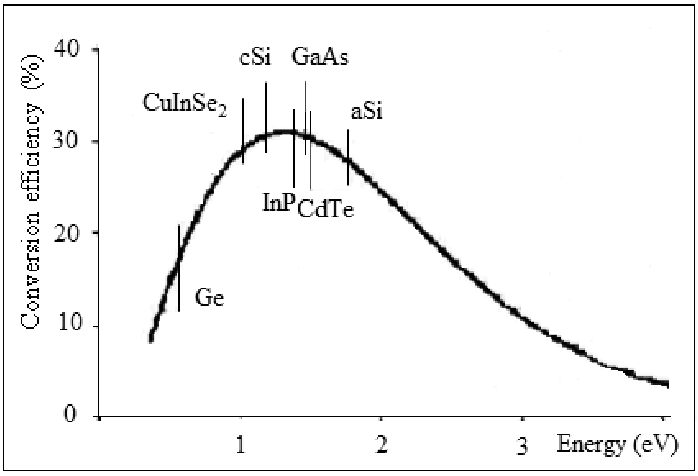

Figure 1: Conversion efficiency depending on semiconductor band gap (AM1.5, 300K).

The first observation of a visible photoluminescence at room temperature in nanostructured porous silicon opened the potential outcomes of wide reach photonic and biologic applications because of tunable refractive list, enormous surface/volume proportion a biocompatibility of porous silicon [3]. Today the porous silicon is rapidly turning out to be very import and flexible material for solar cell innovation.

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The translucent design, substance, electrical, photoluminescence and optical properties of porous silicon have been broadly concentrated by different test procedures [4]. Porous silicon can be framed by synthetic scratching, electrochemical drawing and photograph electrochemical carving of silicon in HF-based arrangements at room temperature. Consequently the substance innovation can be more adjusted to mechanical creation of solar cells because of its effortlessness and lower cost. Porosity, thickness, refractive file of layer, pore size and so forth rely upon development boundaries (electrolytes substance, current thickness, temperature, precious stone direction, doping type and focus, time carving and so on) Sizes of pore and pores dividers can be changed from 5-10 nm to hundreds micrometers subject to manufacture boundaries. Conceivable outcomes of minimization of reflectance (because of light catching in pores), increment of band hole of porous silicon layer (because of quantum constrainment of charges in the PS microcrystallites) by changing of porosity permit to utilize PS layer as both ARC and wide-band hole photosensitive layer. A years ago the porous silicon layers are generally utilized in silicon solar cell applications [4].

2. Photovoltaic characteristics of solar cells

For the solar cell with the series resistance Rs and shunt (or parallel) resistance Rs_h current voltage characteristic is determined as [5]

$$I = I_0\left\{\exp\frac{qV - IR_s}{AkT} - 1\right\} + \frac{V - IR_s}{R_{sh}} - I_l \qquad (1)$$

Here Io is the reverse saturation current, A is diode ideality factor, q is elementary charge, k is Boltzmann's constant, T is absolute temperature, I_l is photo-generated current. Figure 2 shows the representation of the dark and the illuminated characteristics of the p-n junction [7].

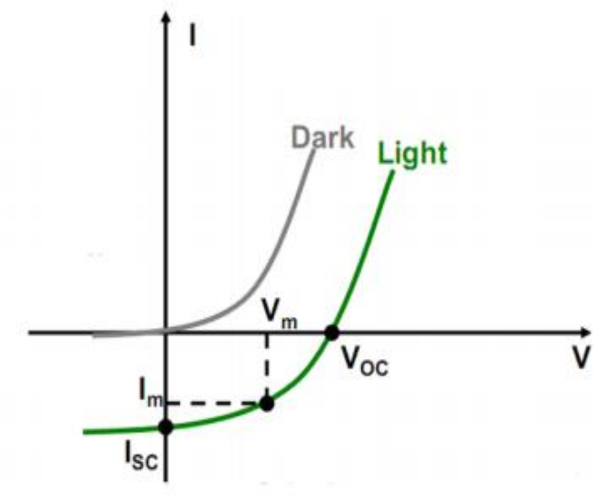

Figure 2: The dark and light current-voltage characteristics of the p-n junction.

The reverse saturation current is given:

$$I_0 = \frac{qD_n n_i^2}{L_n N_A} + \frac{qD_p n_i^2}{L_p N_D} \qquad (2)$$

Here Ln and Lp are diffusion length, Dn and Dp are diffusion coefficient of minority carriers (electrons and holes, respectively), ni is intrinsic carrier concentration, NA and Nd are concentration of acceptor and donor impurities, respectively. When the solar cell is operated at open circuit (I=0, i.e. the shunt resistance is high) then the open-circuit voltage is given [8]:

$$V_{OC} = \frac{AkT}{q}\ln\left(\frac{I_l}{I_0} + 1\right) \approx \frac{AkT}{q}\ln\frac{I_l}{I_0} \qquad (3)$$

Very low values of R_{sh} produces a significant reduction of V_{oc}. An increase in reverse saturation current Io produces a reduction in Voc. The reverse saturation current is determined by the leakage current of carriers across the p-n junction under reverse bias [9]. The leakage cur- rent is a result of recombination of carriers on either side of the junction. For the solar cell working at short circuit (V=0, i.e. low R_s and I_o , and high R_{sh}) the short-circuit current is equal to photocurrent Isc≈ Il

3. Losses in solar cells

The losses in silicon solar cells can be related with [10]: (a) recombination losses, (b) series resistance losses, (c) thermal losses, (d) metal/semiconductor contact losses,(e) reflection losses

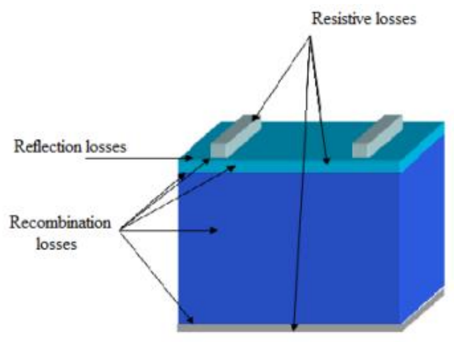

Figure 3. Schematic representation of energy losses in solar cell.

(a) Recombination losses can be caused as result of surface and bulk recombination, recombination in depletion region and recombination at metal/semiconductor contact (Figure 3). Re- combination losses mainly influence on the open-circuit voltage. The incomplete chemical bonds presenting on the surface of semiconductor play role of traps for photo-excited carriers and therefore recombination on traps can result in reduction on photocurrent. The surface recombination velocity S is expressed as [11]:

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$$S = \sigma v N_t \quad \textbf{(4)}$$

Where σ and v are capture cross section for carriers and thermal velocity of carriers, respectively, N_t is the number of surface traps. The reduction of surface recombination speed is generally reached by testimony of dainty passivation films on top surface of cell (for instance SiO2 or Si3N4 films) by substance fume statement (CVD), plasma upgrade synthetic fume affidavit (PECVD) or warm oxidation method). The standard procedure for the decrease of the surface state thickness of Si is warm oxidation at 800oC for 15 min in dry oxygen [7]. Passivation of silicon surface outcomes in critical decrease of surface recombination speed (from 8x104 to 1.6x102 cm/s). Pollutions and translucent deformities, introducing in mass area of semiconductor can assume part of snares for transporters. Decrease of grouping of rest pollutants in greater part of semiconductor, as per Schockey and Read model, will diminish the snare helped recombination speed. Utilizing the mass semiconductor material having lower focus pollutions and deformities can build the dissemination length of minority transporters and along these lines can diminish the recombination misfortunes in main part of solar cells [11].

4. Fabrication and properties of porous silicon

Porous silicon layer on monocrystalline Si substrate and its production by the procedure of electrochemical carving of silicon substrate in HF arrangement or by compound scratching in HFHNO3 combination are referred to as right on time as from 1956 [3,8]. Electrochemical scratching of silicon is appealing a consequence of the probability to tune the pore size several nanometers to a few numerous micrometers, just by picking wafer doping level and cutting conditions. Moreover, a wide extent of porous layer thickness, porosities, surface zones and morphologies can be molded depending upon the cutting conditions. The mass silicon was shown modifies during the cutting to wipe like plan with silicon segments and hydrogen covered pores. The most un-troublesome electrochemical cell is showed up in Figure 4. The Si wafer goes probably as the anode and the platinum is the cathode. The thickness of porous silicon layer on Si substrate is deter- mined by term of drawing. The porosity, for instance the void part in the porous layer is deter- mined by the current thickness (around 10 - 100 mA/cm2), plan electrolyte, resistance and the doping thickness of Si substrate [12].

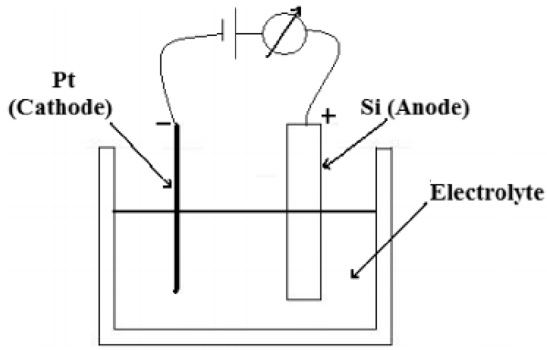

Figure 4: Cross-sectional view of lateral anodization cell.

The structure and size of pores in porous silicon layer formed on n-Si substrate differ from those for layer on p-Si. In the event that electrochemical drawing was done at moderately low current thickness (10-80 mA/cm2), at that point the nearby disintegration of silicon surface happens. Herewith, pore arrangement starts on surface deformities of Si and further development of pores into silicon substrate continues because of the openings dispersion to Si-electrolyte interface. On account of enormous curlease thickness (0.5 - 0.8 A/cm2) when the measure of openings moving to Si-electrolyte interface is high, the scratching of top locales of Si substrate is liked. It guarantees the uniform etching of silicon surface and arrangement a smooth surface of substrate (the supposed the electropolishing cycle). The raising the current thickness over the basic incentive toward the finish of anodization measure brings about a unit of the porous silicon film from Si substrates [12]. The conduct at high current densities ends up being helpful to create porous silicon unsupported layers.

The inhomogeneity in porosity and thickness of porous of the porous layers is frequently ob- served on creation with electrochemical anodization cell. They are most likely because of the air pockets that structure and stick on silicon surface. The inhomogeneity in porous and thickness should be taken out and the convergence of the HF must be locally steady on the surface of the silicon substrate. Evacuation of the air pockets on the outside of the silicon and accordingly planning of homogeneous porous silicon layers is acknowledged with utilizing a stirrer. The distance between the silicon wafer and the platinum cathode additionally effects on the homogeneity, while the state of platinum cathode nearly doesn't impact on homogeneity. There is a sure distance for given cell when the porous silicon layers are homogeneous. The thickness of the porous silicon layers predominantly relies upon term of anodization process, while the porosity relies upon the current thickness. It is be noticed that the personality of the thickness-carving time and porosity-current thickness relations rely upon direction, type and focus level in silicon and conditions anodization measure (the electrolyte structure, distance between silicon wafer and platinum terminal, enlightenment and so on) [13].

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5. Porous silicon layers in silicon solar cells

As stated above the features of porous silicon (a quantum system, a sponge or columnar structure and an extremely large pore surfaces) provide many possible applications, such as light emitting diode, chemical and biological sensor, hydrogen fuel cell, photovoltaic cell, antireflection coating in solar cells etc. Diminishing of reflectance (somewhere in the range of 30 and 3%) and increment of band hole of porous silicon layer (somewhere in the range of 1.1 and 1.9eV) with increment of porosity makes nanoporous silicon as a promising material for use in the solar cell innovation. In this way arrangement of nanoporous layer on frontal surface of PS/Si solar cell with lower reflectance and bigger band hole, extending the unearthly scope of photosensitivity, will add to expanding of transformation productivity. Moreover, formation of Si-H and Si-O bonds on silicon surfaces followed by electrochemical drawing in HF-based arrangement will give passivation the pore surfaces. Hence, the room temperature manufacture just nanoporous silicon layer on frontal surface of prepared silicon solar cell, rather than three-venture measure (texturization, antireflection layer depo- sition and passivation), performed at high temperatures on standard innovation can essentially improve the photovoltaic boundaries and diminishing the expense of silicon solar cells [14].

Antireflection properties of nanoporous silicon layer on p-type silicon were examined in [36]. PS layers were set up by electrochemical drawing of silicon in 1HF: 1C2H5OH solution. The normal reflectance between frequencies 300-1000 nm was 10.3 % for the ideal PS layer. The examination of the interior quantum productivity of (n+ - p) silicon solar cell with porous silicon layer as antireflection covering showed that quantum effectiveness was practically identical to that of a solar cell with a SiNx antireflection covering arranged utilizing plasma-improved substance fume testimony. There are two innovation of development of porous silicon layer on silicon solar cells: (1) the flimsy porous silicon is shaped on definite advance on surface of prepared Si solar cell with metal contacts and (2) the relative- ly thick porous silicon layer is framed before producer dispersion and metal contact testimony. In the principal case the thickness of porous layer (70-150 nm) should be not as much as profundity of n + - p (or p + - n)- intersection (300-800 nm), dPS < dpn and term of electrochemical carving is short (around 5-15 s). In the second case the thickness of the porous layer (5-15μm) is altogether huge than the profundity of area of n + - p (or p + - n) intersection (dPS>dpn) and length arrangement of porous lay- er is essentially bigger (around 10-30 min). It very well may be normal that the profile of n + - p intersection should be a level in the principal case and non-level (it is like profile of porous layer surface) in the subsequent case. From the outset howl will be viewed as results on photovoltaic properties of silicon solar cells with slight po- rous layer shaped on definite advance manufacture of cells.

The surface change of silicon solar cells was utilized for development of photovoltaic characteristics of silicon solar cells in [37]. p-type boron-doped monocrystalline silicon wafers with direction of (100), resistivity about of 3 Ω cm and thickness of 250-380 μm were utilized for manufacture of solar cells by screen-printed measure [8, 38]. n + - producer layer with 0.5-1.0 μm thickness and 15-20 Ω/□ sheet opposition was framed because of phosphorus dispersion. Formation of porous silicon layer on n + - surface of the gadget was performed on the last advance of the solar cell manufacture grouping. Manufacture of PS layer on n + - p intersection was done at galvanostatic condition (consistent current) in an electrolyte arrangement HF:C2H5OH:H2O (1:1:1 in volume) under brightening. Decision of ideal thickness of porous silicon layer as ARC on surface of (n + - p) silicon solar cell and decision of the refractive list, which unequivocally relies upon porosity were characterized from conditions introduced previously [15].

6. Conclusion

The review of investigations of the use of the nanoporous silicon in silicon solar cell showed that an increase in the conversion efficiency (about of 25-30%) is achieved for PS/Si solar cell compared to a cell without a PS layer. Simultaneously, the presentation of silicon solar cells with PS layer is more than that of silicon solar cells with ordinary ARC. The lower estimation of successful reflectance (up to 3%) for nanoporous silicon layer that altogether decreases the optical misfortunes is one of fundamental reasons of progress of execution of PS/Si solar cell. A wide-band hole nanoporous silicon (up to 1.9 eV) bringing about enlarging of the otherworldly district of photosensitivity of the cell to the bright piece of solar range may advance the expansion the productivity of silicon solar cells with PS layer. Note ought to be taken that properties of PS layer and consequently photovoltaic qualities of solar cell can change on running under brightening, warming and so forth As of now, to the extent our insight goes, distributions on transient soundness of PS-based solar cells are practically missing in writing. Works related with corruption wonders in PS/Si solar cells is the matter of effective interest for additional explores. In light of the outcomes introduced in this audit and considering the effortlessness of manufacture of porous silicon layer on silicon we can securely make to the determination that the nanoporous silicon is a decent contender for use on readiness of ease silicon solar cells with high effectiveness. It gives expect the modern creation of PS-based silicon solar cells.

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