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Visible Enhanced Photodetector Made by Spray Pyrolysis

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Abstract: Barium–doped TiO_2 / n-Si photodetector was fabricated by spray pyrolysis exhibited visible enhancement responsivity profile with peak response at 600 nm flat response between 650 and 900 nm. The quantum efficiency was 30% and specific detectivity was $5x10^{12}$ $W^{-1}Hz^{1/2}cm$ at peak response. The GaAlAs laser diode was used to estimate the rise time of the detector.

Introduction

Titanium dioxide is an n-type semiconducting material with energy band gap of about 3.5 eV [1]. The electron concentration in the conduction band arises primarily from the lack of stoichiometry produced by oxygen deficiency. The high electrical resistivity (about 10^7 Ω.cm [2]) of the undoped TiO_2 films prompted extensive studies on TiO_2 as a dielectric. Foremost in this regard is the effort reported on TiO_2 as antireflection coating material in solar cells [3] and as insulating material in capacitor [4]. A high electrical conductivity is not a great challenge and easily can be obtained by doping, for instance with fluorine or barium.

Simultaneously high conductivity and high transparency (i.e., figure of merit parameter is high) put forward TiO_2 in the list of transparent conductive oxides (TCO). Wide investigation had been focused on TCO semiconductor as photovoltaic devices such as SnO_2 /Si [5]. ITO/Si [6], In_2O_3 /Si [7], and ITO /InP [8], while mild investigations are found on TiO_2 /semiconductor photovoltaic devices [9, 10].

In the case of Ba-doped $T`O_2$/n-Si heterojunction, the deposited TCO semiconductor acts as a window for wavelengths more than 350 nm, while the substrate semiconductor acts as an absorber for the transmitted photons up to 1100 nm (i.e., the cut-off of silicon). When the resistivity of TiO_2 film is lowered by doping, the series resistance will be low and hence, PV parameters may be reinforced.

This paper is the first reported study on n-TiO_2:Ba/n-Si isotype heterojunction photo-detector fabricated by the low cost spray pyrolysis technique.

Experiment

Spray–Pyrolysis Epitaxy

TiO_2:Ba films were sprayed onto 111 single crystal n-type silicon of 3-5 Ω.cm resistivity. The solution of the spraying was prepared by dissolving 0.479 g metallic titanium and 0.197 g barium carbonate in 100 ml of concentrated HCl acid. After the dissolving, the solution was diluted by adding 100 ml of distilled water. The total solution will contain 0.1 M of $TiCl_3$ and 0.01 M of $BaCl_2$. The chemical reaction is:

$$Ti + BaCO_3 + 5\,HCl \longrightarrow TiCl_3 + BaCl_2 + \uparrow CO_2 + H_2O + \uparrow 3/2H_2$$

$$TiCl_3 + BaCl_2 + 3H_2O \xrightarrow{\Delta} TiO_2 + BaO + 5HCl\uparrow + 1/2H_2\uparrow$$

The silicon substrates were maintained at 400°C during spraying. Thickness obtained was between 20 and 40 nm.

Photoresponse Measurements

After Al ohmic contact, the Al-nTiO_2:Ba /nSi-Al photodetectors were illuminated by monochromatic light in the range of 400-1100 nm with the help of monochromator. The rise time was determined by using 200 ns-pulsed GaAlAs laser diode of 10 kHz frequency.

Results and Discussion

Figure 1 shows typical spectral responsivity plot of n-TiO_2:Ba /n-Si isotype heterojunction. It is obvious from the figure that there are two distinct regions. The first one is situated at around 600 nm. This peak is probably belonging to titanium oxide. The second region which starts from 650 nm shows flat response (i.e., responsivity is independent on wavelength) up to 900 nm. This distribution is dissimilar to that of diffused silicon p-n junction. This effect is due to the wide-bandgap of TiO_2 semiconducting material which resulted in high responsivity at shorter wavelengths (visible enhanced photodetector) i.e., the absorption of high-energy photons occurs in diffusion length of TiO_2. It is evident that this photodetector can be used to detect many lasers e.g. He-Ne laser, Ar laser, and GaAlAs laser. The quantum efficiency curve is shown in Fig. 2. At peak response, the quantum efficiency is 30%. This high value of quantum efficiency as compared with other heterojunctions [11] is ascribed to more photon absorption at short wavelengths. Furthermore, the low value of refractive index for TiO_2 is a reason for increasing internal quantum efficiency. Room temperature specific detectivity is illustrated in Fig. 3. Maximum value (5×10^{12} $cm.Hz^{1/2}.W^{-1}$) was obtained at peak response that indicates high value of shunt resistance and hence, the leakage current will be low.

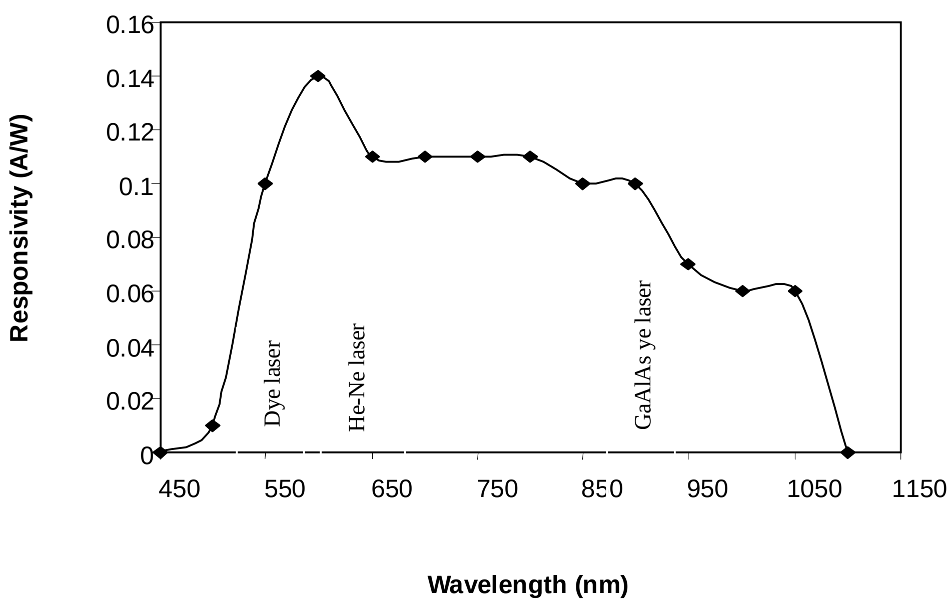

Fig. 1 Spectral Responsivity Plot of n-TiO_2:Ba/n-Si Heterojunction Detector.

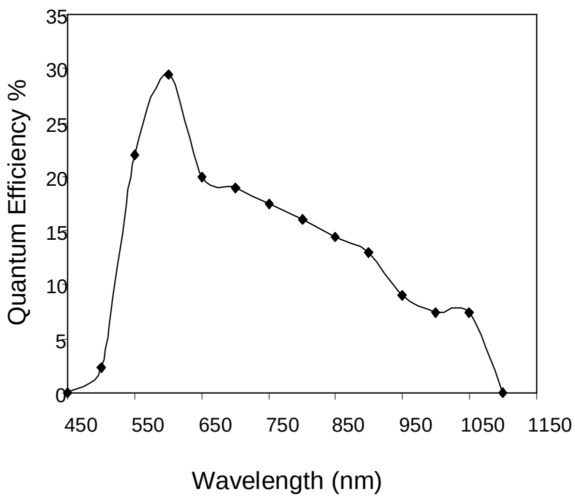

Fig. 2 Quantum efficiency curve.

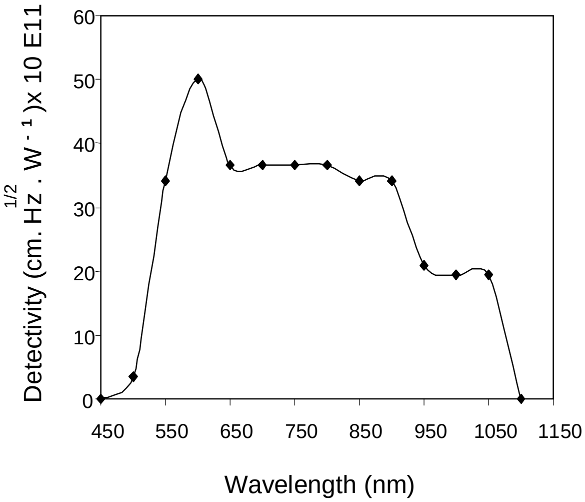

Fig. 3 Room temperature detectivity vs wavelength.

The photographic portrait shown in Fig. 4 demonstrates the profile of the output photovoltage respect to time when the detector is irradiated by laser pulses (904 nm). The rise time of photodetector measured from 10% to 90% of the signal was 50ns (taken at V_L=10 V, R_L=50Ω). The fall time shows plain delay, which can be attributed to the large lattice mismatch, which produces high density of interface states, so the recombination centers will be high.

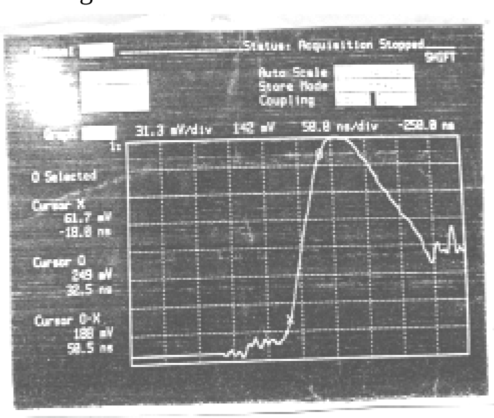

Fig. 4 A Photograph of pulse waveform of photodetector.

Conclusions

Isotype n-TiO_2:Ba /Si photodetector introduces more absorption at high energy photons and responsivity profile gives its peak at 600 nm. Interface states greatly affect the fall time of the detector.

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تصنيع كاشف يمتلك استجابية عالية في المنطقة المرئية بطريقة الرش الكيميائي الحراري

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الخلاصة

يتضمن البحث ، تصنيع كاشف TiO_2/n-Si وذلك برش غشاء TiO_2 المشوب بالباريوم على شرائح سليكونية مانحة . أظهرت نتائج الاستجابية الطيفية للكاشف أنه يمتلك استجابية عالية في المنطقة المرئية من الطيف وأن قمة الاستجابة كانت عند الطول الموجي 600 نانومتر ، وقد لوحظ أن المنطقة الطيفية المحصورة بين660 و900 نانومتر ذات استجابية ثابتة . كانت أعلى قيمة للكفاءة الكمية 30 % . بينما بلغت قيمة الكشفية النوعية 5×10^{12} سم هيرتز $^{1/2}$ واط $^{-1}$ عند الطول الموجي 600 نانومتر . جرى حساب زمن النهوض للكاشف بأستخدام ليزر GaAlAs .