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Amorphous Al/n^+ a-SiC/i a-SiC/p^+ a-SiC/i a-Si/n^+ a-SiC Hetero-Junction Photo-Transistor with High Gain and High Speed

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This is a first report on the heterojunction amorphous SiC/Si phototransistor with the structure of Al/n^+a-SiC/i a-SiC/p^+a-SiC/i a-Si /n^+a-SiC. This new device has a very thin a-SiC base (100Å) and a-SiC emitter, which provides an effective barrier to accumulate more photo generated holes at the base and therefore improved the gain significantly. An optical gain of 40 was obtained at an incident power of 5μW.

§1. Introduction

It has been demonstrated that hydrogenated amorphous semiconductors become very useful in making various kinds of photo-sensing devices. Recently, we have successfully fabricated the amorphous silicon homojunction bulk barrier phototransistor[1-4], with high gain (~12) and high speed (~30μs). In order to improve the gain performances, a heterojunction a-SiC/a-Si bulk barrier transistor was successfully made and will be reported.

A heterojunction phototransistor with large bandgap at the emitter potentially possesses higher gain than homojunction device, due to carrier accumulation effect at the emitter-base junction[5], in which we have adopted a-SiC:H as a wide bandgap materials.

In this report, a new type of amorphous heterojunction phototransistor with the structure of glass/ITO/n^+ a-SiC/i a-Si /P^+a-SiC/i a-SiC/n^+ a-SiC/Al was successfully fabricated by the plasma decomposition of an $((1-x)SiH_4+xCH_4)$ gas mixture. This new structure of phototransistor has a very thin a-SiC base (100Å), and a-SiC emitter which provide an effective barrier to accumulate more photo-generated holes at the base and therefore improved the gain significantly.

§2. Device Fabrication

The cross-section view of the new device is shown in Fig.1.

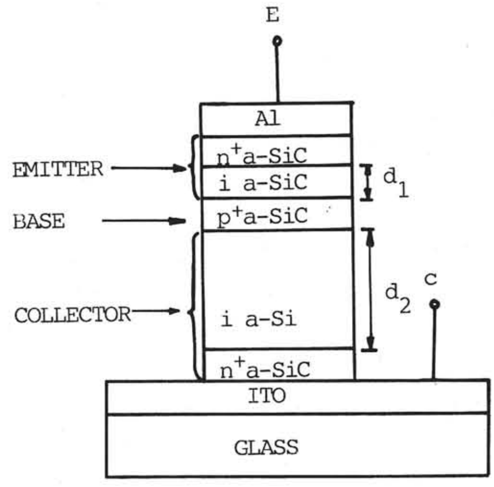


Fig.1 The schematic cross-section view of the new device.

An ITO coated glass plate with sheet resistance of 50Ω/□ was used as the substrate. After substrate cleaning process, the sample was put into the plasma enhanced CVD reactor. Before the deposition of amorphous film, the substrate temperature was kept at 250°C for 60 min. Full details concerning the condition required for deposition have been given elsewhere[1,2,4].

First, a thin n-type a-SiC:H of 100Å was deposited as collector, followed by a undoped a-Si:H layer of 2000~7000Å thick. Next, a 100Å thick p-type a-SiC:H as base was grown. Then, a 160Å thick undoped layer and a 300Å thick n-type a-SiC:H were grown as emitter. In order to grow a-SiC:H film, a $SiH_4(0.45)+CH_4(0.55)$ gas mixture was employed with PH_3 or B_2H_6 as doping gas, and the R.F. power is 30W. While for a-Si:H film deposition, diluted silane gas (75-percent H_2+25-percent SiH_4) was used, and the R.F. power is 40W. And during the deposiiton period, the chamber pressure is 1 torr.

The amorphous heterojunction phototransistor is similar to the a-Si homojunction bulk barrier phototransistor, which is a kind of majority carrier devices. In order to get high current gain, the device is designed in such a way that both sides of the undoped i-layer and the base region are completely depleted from free carrier at any bias condition[4). Thus a triangular barrier is formed between emitter and collector. Normally, the device is operated with the collector electrode biased positively with respect to the emitter electrode, defined as normal operation, and it is irradiated through the collector side by light beam. The energy band diagram of the heterojunction transistor is given in Fig.2(a) and (b) for equilibrium and nonequilibrium condition, respectively.

§3. Result of Measurement

The typical current-voltage curve under illumination for a phototransistor with collector-base undoped i-layer of 7000Å is given in Fig.3.

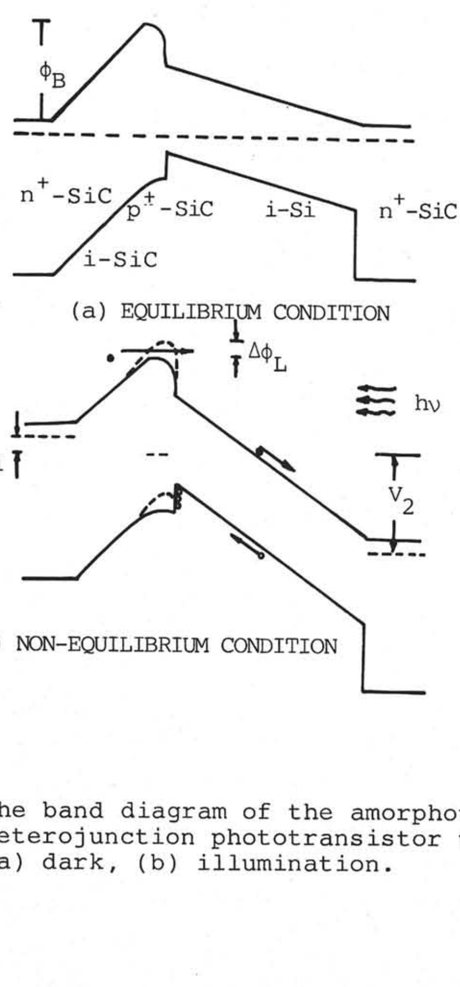


Fig.2 The band diagram of the amorphous heterojunction phototransistor under (a) dark, (b) illumination.

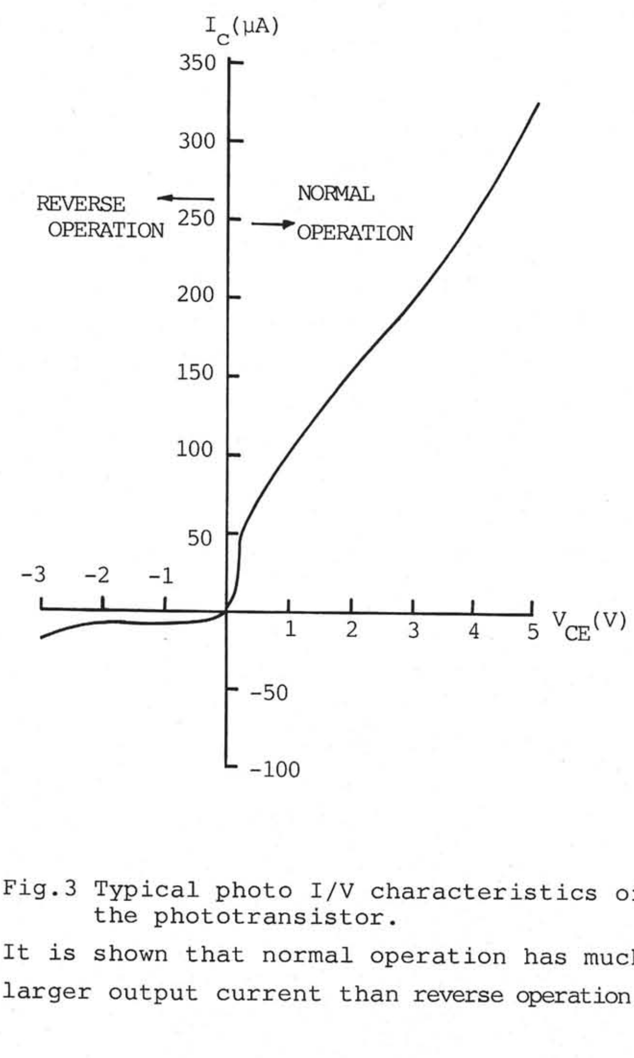


Fig.3 Typical photo I/V characteristics of the phototransistor.

It is shown that normal operation has much larger output current than reverse operation, due to mechanisms of current amplification [2]. In order to study the photo I/V characteristics under illumination, a He-Ne laser with $\lambda=6328\mathring{A}$ was used as signal source, and a Tektronix 177 oscilloscope was used to measure the response of the phototransistor. The laser beam intensity was changed by a variable beam spliter. The graph of the I/V characteristics as a function of incident power is shown in Fig.4.

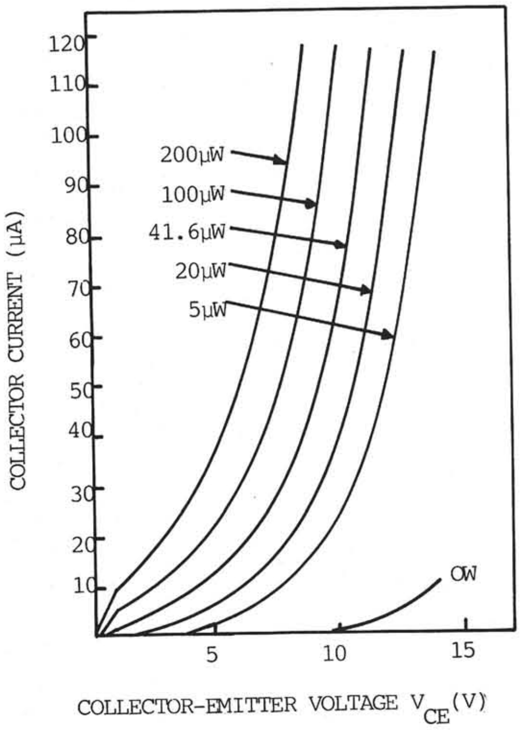
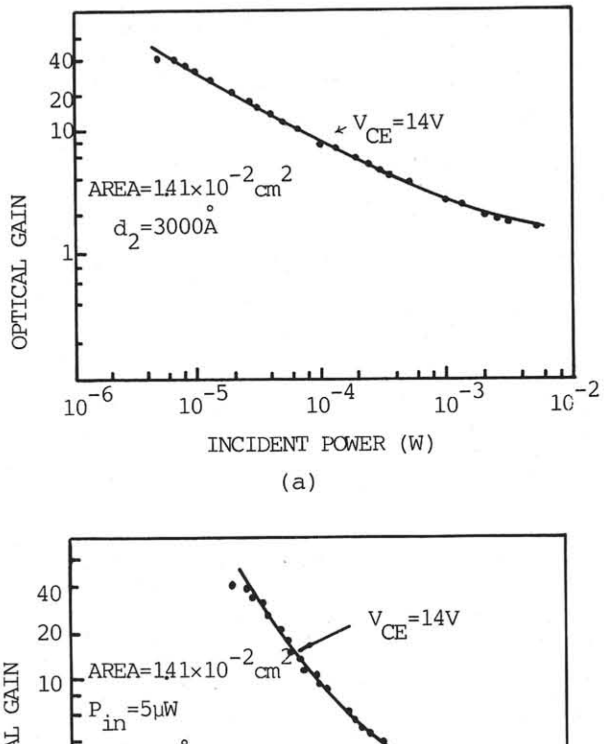
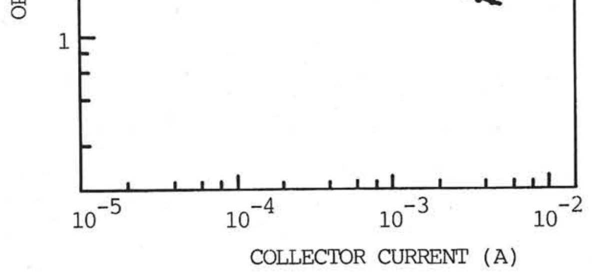


Fig.4. I/V characteristics of the amorphous heterojunction phototransistor at various incident power levels.

As can be seen, the I/V response of amorphous heterojunction phototransistor is similar to that of previous device [1,2], except the strong dependence on bias voltage. For a phototransistor, the optical gain G is the most meritorious parameter and is prime consideration in device design and fabrication, which can be calculated by $G=(I_c/q)/(P_{in}/h\nu)$, where I_c is the collector current, P_{in} is the incident light power, $h\nu$ is the photon energy, and q is the electronic charge. A plot of G as a function of P_i at a bias of 14V is shown in Fig.5(a). As shown in this figure, G increases with decreasing incident power, which is a unique feature of majority-carrier photo-detector [6]. An optical gain of 40 is obtained at an incident power of 5μW, and this is the highest gain which is not reported so far. Even compared to crystalline phototransistor, this high gain is even superior to some heterojunction phototransistor made of III-V alloys by MBE [7,8]. Capasso et al. reported an optical gain smaller than one, and Chen et al. has a maximum gain of 10 at 500μW irradiance. Fig.5(b) is the graph of optical gain versus collector current.



(a)



(b)

Fig.5(a) Dependence of the optical gain on incident power level. (b) Optical gain of the phototransistor vs collector current.

The spectral response was measured by illuminating the top surface of the device with light emitted from a tungsten lamp through a monochrometer. A picture of relative spectral response for device with 3000Å i-layer is given in Fig.6.

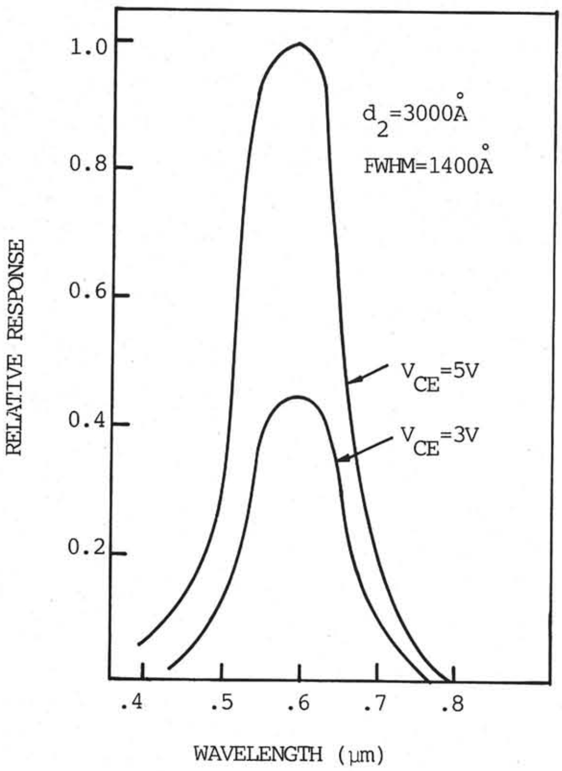


Fig.6. Relative spectral response of the new devices.

It is well known that the spectral response of a phototransistor exhibits falloff at both long wavelengths region and short wavelengths region. Generally, the former is due to samll absorption coefficient of the material used, and the later is limited by the bandgap of window material. Through a detailed analysis, it is found that the spectral response of amorphous heterojunction phototransistor can be adjusted by varying the collector-base undoped layer thickness and applied voltage magnitudes.

§4. Conclusions

This is a first report on the heterojunction amorphous SiC/Si phototransistor which has been successfully fabricated by plasma enhanced chemical vapor deposition and revealed a significant improvement of the previously reported homojunction amorphous phototransistor.

This Al/n^+a-SiC/i a-SiC/p^+a-SiC/i a-Si /n^+a-SiC amorphous heterojunction phototransistor revealed an optical gain of 40 at an incident power of 5μW. This new structure of phototransistor has a very thin a-SiC base (100Å), and a-SiC emitter which provide an effective barrier to accumulate more photo-generated holes at the base and therefore increase the gain significantly. This device has a very promising applications as a flat panel display transistor and a phototransistor in photosensing element/array and photo coupler to replace the p-i-n photodiode.

References:

1) B.S. Wu, C.Y. Chang, Y.K. Fang and R.H. Lee: Proc. 16th Conf. Solid State Devices Mater, Kobe, Japan, p.551, 1984.
2) C.Y. Chang, B.S. Wu, Y.K. Fang and R.H. Lee: IEEE Electron Device Lett. EDL-6, p.149, 1985.
3) C.Y. Chang, B.S. Wu, Y.K. Fang and R.H. Lee: Appl. Phys. Lett. 47(1), p.49,1985.
4) B.S. Wu, C.Y. Chang, Y.K. Fang and R.H. Lee: IEEE Trans. Electron Devices, vol. ED-32, No.11, p.2192, 1985.
5) T. Moriizumi, H. Takahashi: IEEE Trans. Electron Devices, Vol.ED-19, No.2, p. 152, 1972.
6) C.Y. Chen: Appl. Phys. Lett. 39(12), p.979, 1981.
7) F. Capasso, W.T. Tsang, C.G. Bethea, A. L. Hutchinson and B.F. Levine: Appl. Phys. Lett. 42(1), p.93, 1983.
8) C.Y. Chen, A.Y. Cho, P.A. Garbinski and C.G. Bethea: Appl. Phys. Lett. 40(6), p.510, 1982.