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Room Temperature Photodetector Based on ANISOTYPE (n-p) Ge-Si Heterojunction

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Abstract

In this work we present a detailed study on anisotype nGe-pSi heterojunction (HJ) used as photodetector in the wavelength range (500-1100 nm). I-V characteristics in the dark and under illumination, C-V characteristics, minority carriers lifetime (MCLT), spectral responsivity, field of view, and linearity were investigated at 300K. The results showed that the detector has maximum spectral responsivity at λ=950 nm. The photo-induced open circuit voltage decay results revealed that the MCLT of HJ was around 14.4 μs.

كاشف التوصيلية الضوئية الهجين (n-p) للأساس Ge-Si عند درجة حرارة الغرفة

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الخلاصة

في هذا البحث تم تصنيع ودراسة خصائص الكاشف الضوئي نوع المفرق الهجيني nGe-pSi للمدى الطيفي (500-1100 nm)، جرى قياس كل من خصائص تيار – جهد في حالة الظلام والاضاءة، خصائص سعة – جهد، فترة حياة حاملات الشحنة الاقلية، الاستجابة الطيفية، مجال الرؤيا والخصائص الخطية في درجة حرارة الغرفة. لقد اوضحت النتائج ان الكاشف يمتلك اقصى استجابية طيفية عند الطول الموجي λ = 950 nm وكذلك اوضحت النتائج بان فترة حياة حاملات الشحنة الاقلية للكاشف المصنع كانت بحدود 14.4 μs.

Introduction

The formation of junctions (both isotype and anisotype) between semiconductors of dissimilar band gaps have been of general interest. The application of such heterojunction is well known to have many possible heterostructure combinations. However, only those for which the lattice mismatch is smaller than (1%) are of practical interest [1]. This limitation stems from the large concentration of surface states. That from at junctions between the crystals that is poorly lattice matched. These states, are carrier traps, are located at dislocations [1-3]. Ge-Si heterostructures have been of considerable interest both a model systems for epitaxial growth and because of their potentially useful optical and transport properties. Although the large lattice mismatch parameter between Si and Ge (~4%), high quality layers of Ge-Si spanning the entire range of alloy compositions have been utilizing strained epitaxy technique. This development greatly expands the range of material properties obtainable in Ge-Si [4], a material that has shown considerable promise for high-power device [5].

Molecular Beam Epitaxy (MBE) have opened the possibility of extending the spectral response of Si photodetector in 1.3μm spectral region through the use of heterostructures composed of Ge and Si. Such detector, combining the best features of Si and Ge devices, would be of interest in a variety of optical communication applications in which that the Si bandgap larger than the energy of photon in the range of fiber transparency [6].

The growth of Ge on Si, which was first motivated by a search for a suitable substrate for the subsequent growth of GaAs [6] has opened a new material study not only as a typical model system of Lattice-mismatched heteroepitaxy, but also for its wide of application to high performance optical and the electronic devices [7], such as IR detector and heterobipolar transistor [8, 9]. The silicon technology has not been able to produce an on-chip IR photodetector for fiber-optics communication. The major difficulty lies in the fact that silicon bandgap larger than energy of the photon in the range of fiber transparency.

The only practical method of employing silicon technology for fiber-optics communications has been to combine silicon integrated circuits with germanium or InGaAsP detectors on a separate chip [8].

The purpose of this paper is directed to a comprehensive room temperature characterization of photodetector based on heteroepitaxial Ge film grown on single crystal silicon surface by vacuum deposition technique.

In the present work, the minority carrier lifetime was obtained for Ge-Si by using photo-induced open circuit voltage decay technique. The lifetime can be computed from the following expression[10].

$$\tau_C = \frac{kT}{q}\left|\frac{1}{dV_{oc}/dt}\right| \quad \ldots (1)$$

where

k: Boltizmann constant J.K^{-1}.

T: Operating temperature K.

q: electron charge (C).

dV_{oc} /dt: slope of plot of V_{oc} vs. Time in the decay mode.

Experimental Details

Mirror polished p-type Si (111) wafers with dimensions (5x5x0.3) mm^3 with electrical resistivity at 300 K (3-5) Ω.cm were used as substrates. The substrates were immersed in Cp-4 etchant to remove the native oxides on the surface, and then rinsed in ethanol solution. After etching process, the substrates immediately transfered to vacuum chamber. The vacuum pressure was down 10^{-6} Torr. High purity of germanium (99.99%) was evaporated by thermal resistive technique with thickness of 200 nm on silicon substrate at 300 K. To investigate the electrical properties of Ge-Si HJ detector, ohmic contacts were applied by evaporating Al and Sn electrodes onto Si and Ge respectively.

The spectral responsivity of the photodetector was obtained using monochromator with tungsten lamp, the measurements carried out under normal illumination from Ge side as shown in Fig(l).

A photo-induced open circuit voltage decay technique was to determine minority carrier lifetime (τ_C) of HJ. The procedure is to exposure the photodetectetor with a flash from a stroboscope model (DAWE-l2l4B) and then monitor the decay of the open-circuit voltage (V_{oc}). The decay was monitored with a Tektronix storage oscilloscope.

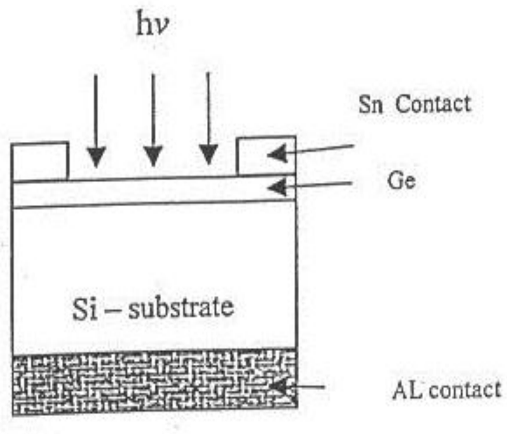

Fig. (1): The Configuration of Ge-Si Photodetector.

Results and Discussion

Fig.(2) shows the I-V characteristics of HJ in the dark condition, the forward-bias case occurs when the Ge is biased-ve w.r.t the silicon substrate. The I-V plot in the forward bias show that in the low-voltage region V < (3kT/q) at 300K the current contribution is mainly due to the recombination-limited and it follows the following equation:

$$I \ \alpha \ \exp \frac{qV_a}{\beta kT} \qquad \ldots(2)$$

where (β) is a parameter related to various properties of HJ and usually called ideality factor, and V_a is forward bias voltage. The results showed that the value of (β) of anisotype Ge-Si HJ was about 2.6 while in the high-voltage region the current is due to tunneling dominates across the junction and can be given by [11, 12]:

$$I = \alpha \ \exp(AV_a)\exp(BV_a) \qquad \ldots(3)$$

where A and B are constants essentially independent of voltage and temperature. Forward-bias characteristic exhibits turn-on voltage $\approx$ 1.6V.

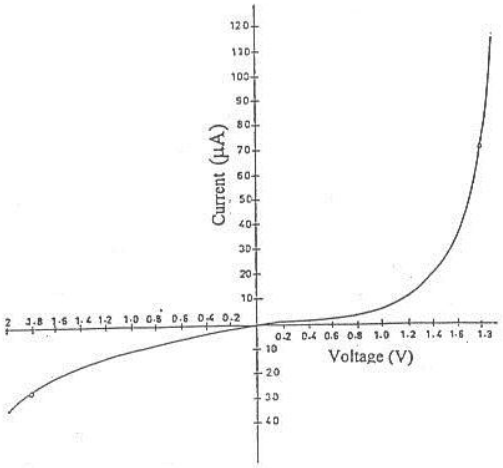

Fig. (2): Dark I-V Characteristics of HJ.

The reverse bias characteristics of Ge-Si HJ shows a linear variation at low voltage and a power law variation (I αV^m with m>1) for high reverse voltage.

The I-V characteristics of HJ exhibits poor rectification resulted from lattice mismatch between Ge and Si (4%) [3]. Under illumination condition we concentrate on the detector operating in both photocurrent and photovoltage modes. The photocurrent generated by the n-p Ge-Si HJ photodetector as a function of reverse bias voltage on a linear scale is shown in Fig.(3) for various powers of optical illumination. It is clear from Fig.(3) that the photocurrent has increased linearly with optical power, and there is no saturation region has been observed. The dependence of V_{oc} and I_{sc} on light power is illustrated in Fig(4).

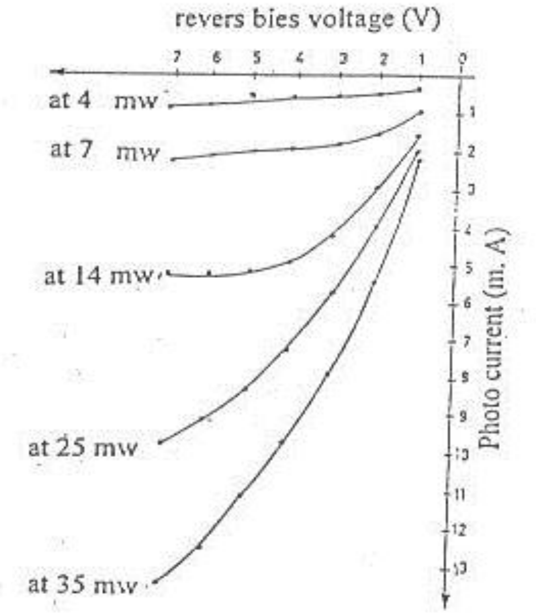

Fig. (3): I-V Characteristics under Illumination Condition for Different Values of Optical Power.

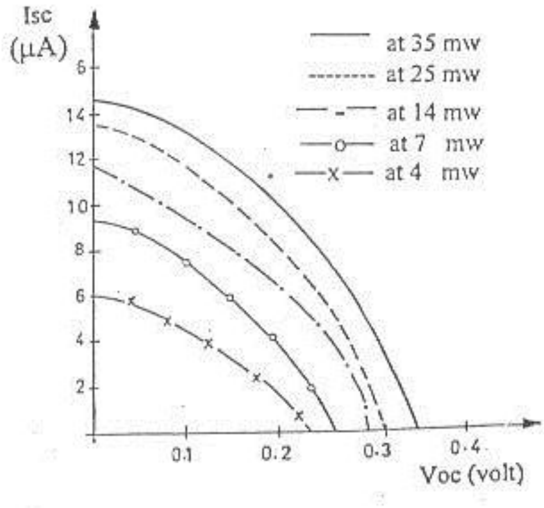

Fig. (4): The Dependence of Voc and Isc on Optical Power

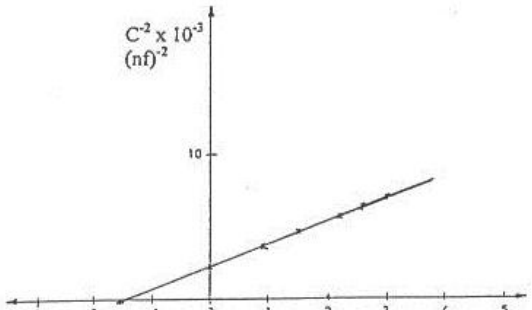

Fig. (5): Presents a Plot of C^{-2} as a Function of Reverse Voltage (V_R).

The capacitance of anisotype HJ without the effect of interface states is given by [9]:

$$C = \left\{ \frac{qN_D N_A \varepsilon_1 \varepsilon_2}{2(\varepsilon_1 N_D + \varepsilon_2 N_A)} \right\}^{1/2} (V_{bi} - V_R)^{-1/2} \quad ...(4)$$

Where

N_D:Concentration of electrons in Ge (cm^{-3})
N_A:Concentration of holes in silicon (cm^{-3})

ε_1 : dielectric constant of Ge

ε_2 : dielectric constant of Si

V_{bi}: built-in junction potential (V)

The total built-in potential of HJ is equal to the sum of the partial $V_{bi1} + V_{bi2}$ where V_{bi1} and V_{bi2} are the electrostatic potentials of equilibrium in Ge and Si respectively. From Fig.(5), it is obvious that the junction is abrupt type due to linear variation of C^{-2} vs. V_R. The value of V_{bi} which can obtained by extrapolating the curve at point ($1/C^2 = 0$) was around 1.5V.

Fig.(6) shows the photo-induced open circuit voltage decay. The decay region has up to three distinct regions. The first region corresponds to a condition of high-level injection where the excess minority carriers concentration exceeds the equilibrium majority carrier concentration in the region of HJ.

The second region of the decay curve corresponds to a condition of intermediate injection, where the excess minority carrier concentration in the substrate region is greater than the thermal-equilibrium majority carrier concentration.

Finally, in the third region of decay mode, a low-injection condition exists, where the excess minority carrier concentration is less than the equilibrium minority carrier concentration. Here as V_{oc} becomes much less than (kT/q).

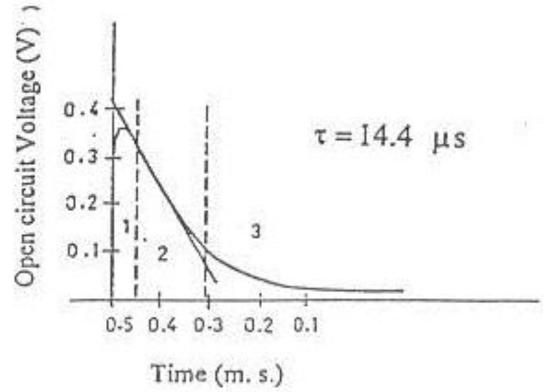

Fig. (6): Plot of Photo-Induced Open Circuit Voltage Decay.

From Fig.(6) the value of MCLT of HJ which obtained from the second decay region was about 14.4µs.

The relative spectral responsivity of HJ photodiode at 300K is shown in Fig.(7), it exhibited maximum value at wavelength 950nm. This is corresponded to germanium bandgap width, i.e. The absorption of light occurred in the diffusion length region (L_h) of Ge layer [4]. No other peak has been observed in spectral responsivity distribution.

The data shown in Fig.[7] were corrected for spectral distribution of incident optical power (Tungsten lamp).

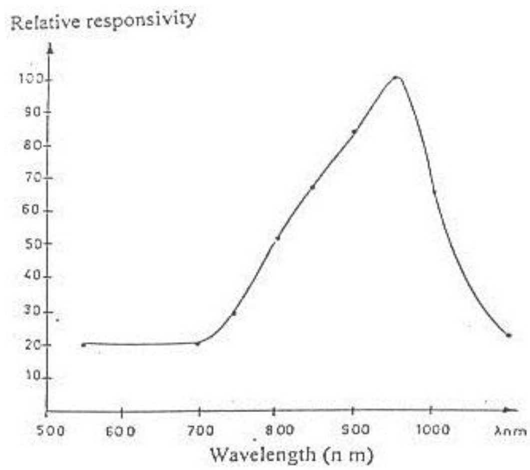

Fig. (7): Optical Photoresponse of Ge-Si Heterojunction.

The field of view (FOV) of the detector represents one of the major important parameter, which limit the background noise. Fig.(8) shows the relative sensitivity vs. incident angle of the light. The FOV of the detector obtained from Fig.(8) was around 100^{o}.

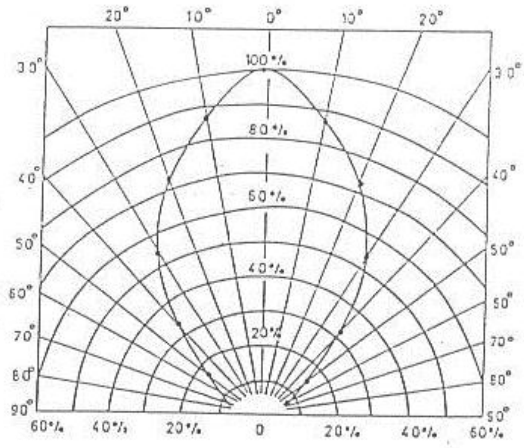

Fig.(8): Field of View of Ge-Si Heterojunction.

Conclusions

We have demonstrated the feasibility of fabrication a photodetector operated at 300 K for visible and near infrared wavelengths based on Ge-Si anisotype heterojunction. Our approach, based on deposition of n-type germanium layer on p-type silicon substrate, we have fabricated heterojunction photo-detector with maximum spectral responsively at λ=950nm. The detection of long-wavelength (1.2-1.5μm) with Ge-Si Hj photodetector (window effect) is currently in progress.

References

[1] H. J. Leany, C. J. Doherty & G. K. Celler, "Cellular Solidification of Laser Processes Ge-Si Heterojunctions", Laser Electron Beam Processing of Materials Ed. By C. W. white and P. S. peercy, 1980. p.581.

[2] O. Nur & M. Willander, $CoSi_2$ /Si_{1-x} Ge_x/ Si (001) Heterostructures Formed Through Different Reaction Routes". J.Appl. Phys. 78(12), 1995, p.7063.

[3] 3- Y. Hida, T. T. Tamagawa & C. Tastuyama, "Strain Velaxation of Ge Films Grown on a Si (001) -2x1 Surface by MBE", J. Appl. Phys. 67(12), 1990, 7247.

[4] 4- J. Berk & B. A. Davidson, "Ge-Si Layered Structures: Artificial Crystals and Complex Cell Ordered Superlattices", Appl. Phys. Lett. 49(5), 1986, p.286.

5- K. James, "New Semiconductor Alloy Promises Powerful Devices", Vacuum Solutions 9(5), 1999, p.5.

6- B. Y. Tsaur. J.cc. Fan, and R.P. Gale "Solid-Phase Heteropitaxy of Ge on <100> Si", Appl. Phys. Lett. 38, 176, 1981.

7- B. J Mrstik, "Leed and Aes Studies of the Initial Growth of Ge Epilayers on GaAs <100>" Surf. Sci-124, 253, 1983.

[5] 8- S. Luryi, A-Kastalsky, and J. Bean, "New Infrared Detector on A Silicon Chip", Trans. On Elec. Devices, Vol. ED-31, No.9, 1984, p.1135.

[6] A. F. Khokhlov, A. I. Mashin. and N.I. Mashin "Electrical and Optical Properties of Semiconductor a-Si_{1-x} Ge_x", Sov. Phys. Semicond. 20, 812, 1986.

[7] R. J. Bassett, "Observation on A Methods of Determining the Carrier Lifetime in p+-p-n* Diodes", Soild-State Electronics, Vol. 12, 1969, p.383.

[8] B. L. Sharma and R. K. Purohit, "Semiconductor Heterojunction", Pergamon press. 1974. p.94.

[9] D. V. Morgan and R. H Williams "Physics and Technology of Heterojuntion Devices", Peter Per Egrinus Ltd., 1991, Ch.1.