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A High Performance Thin Film Platinum Silicide Schottky-Barrier IR Detector

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A high performance thin film PtSi Schottky-barrier IR detectors are described. Quantum efficiencies are 31% and 22% at a wavelength of 2um and the quantum efficiency coefficients are $1.05eV^{-1}$ and $0.88eV^{-1}$ for Schottky-barrier detectors with the platinum silicide thickness of 6nm and 8nm, respectively. The cause of this high quantum efficiency is believed to be due to the favorable momentum distribution of excited carriers in the very thin PtSi film and improvement of process related to the platinum silicide formation.

1. Introduction

It is now well recognized that the operation of the Schottky-barrier infrared detector is based on the internal photoemission of hot carriers across the Schottky barrier. After the germination of the concept of the internal photoemission in the sixties, some theoretical developments were done in the early seventies [1,2]. Elabd and Kosonocky developed a new quantum efficiency model for thin film enhancement in terms of multiple reflections [3]. However, theoretical development has been remained relatively stagnant over the last few years.

The performance of silicide Schottky-Barrier Diode (SBD) as an IR detector has been increased and SBD find wide applications as an IR sensing element of IR Image Sensors (IRIS). There have been many efforts to increase the fill factor and to reduce the fixed pattern noise. However, most of the efforts have been focused on the increase of quantum efficiency of SBD. A strong impetus for continuing to improve the quantum efficiency of IR detectors is its low contrast. Platinum silicide technology has shown steady advances and recently, Kosonocky et al. reported a high performance SBD with the quantum efficiency of about 15% at a wavelength of 2um and C_1 of $0.542eV^{-1}$[3].

In this paper, we will briefly review the photoemission theory. The most commonly used expression for quantum efficiency of SBD is the equation of Cohen so the parameters of our devices are calculated from the equation of Cohen [4]. The photoemission phenomena of very thin film SBD will be discussed with the concept of favorable momentum distribution in the very thin silicide film, and the performance of our devices will be presented.

2. Photoresponse of an SBD

Photoresponse of an SBD IR sensor is a three-step process, involving the generation of hot carriers due to photo-excitation and the scattering process of hot carriers in the metal (silicide) film and the eventual escape of hot carriers from silicide into the silicon substrate across the Schottky barrier.

Cohen et al. assumed that the density of states dN/dE, the probability of excitation of hole, and the mean free path are constant over the excitation range for the typical infrared ray frequencies ($h\nu \ll E_f$) and also assumed that the momentum distribution of the excited carriers is isotropic [3,4]. From the above assumptions, they derived the external quantum efficiency equation,

$$Y = C_1 \frac{(h\nu - \Psi_{ms})^2}{h\nu}$$

$$C_1 = A(\lambda)/8\,\Psi_{ms} \qquad (1)$$

where Ψ_{ms} is the Schottky-barrier height in eV and C_1 is the quantum efficiency coefficient in eV^{-1}. The factor C_1 depends on the absorptance of the metal (silicide) film, $A(\lambda)$ and the Ψ_{ms}.

In the case of thin film SBD, Elabd et al. drived a completely different photoresponse model in terms of multiple reflections from the walls of thin silicide film [3]. Quantum efficiency equation for the thin film SBD is of the same form as that of thick film SBD except for the value of quantum efficiency coefficient C_1.

$$Y = C_1 \frac{(h\nu - \Psi_{ms})^2}{h\nu}$$

$$C_1 = \frac{A(\lambda)\cdot G}{8\,\Psi_{ms}} \qquad (2)$$

where G is the gain coefficient.

Gain coefficient G is a function of thickness of the silicide, Schottky barrier height Ψ_{ms}, and the attenuation length L.

Equation (1) and (2) both indicate that one must lower the Schottky barrier height Ψ_{ms} and increase the IR absorption in silicide layer to increase the quantum efficiency of the SBD. Therefore, it is necessary to fabricate an optical filter to increase the IR absorption in the silicide film [5]. It is also needed that one should precisely control the process related to the platinum silicide formation to get the desired Schottky barrier height.

3. Detector Structure

The structure of the thin-film PtSi SBD with optical filter and anti-reflection layer is shown in Fig.1. This structure is designed to optimize the IR absorption in the PtSi film. Optical filter consists of a dielectric (silicon dioxide)-metal (Aluminum) combination on top of the platinum silicide and thermally grown silicon dioxide are used as an antireflection layer at the silicon-air interface.

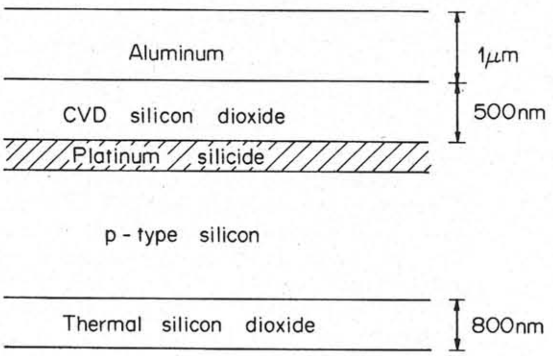

Fig.1. Optimized structure of the Schottky-barrier IR detector

The thickness of the dielectric layer gives a strong effect on the IR absorption in the PtSi film. And aluminum enhances the IR absorption in PtSi film. The effects of optical filter on the IR absorption in PtSi film were simulated using characteristic matrix method [6]. It was done using measured values of refractive index of PtSi [7]. The results of simulation confirm that 1) There is an optimum thickness of dielectric layer (optical filter) for the operating wavelength of 1um-3um. 2) Aluminum enhances the IR absorption in PtSi film by a factor of 2 and 1.5 at the wavelength of 2um and 3um, respectively, with a 500nm dielectric (silicon dioxide) layer.

Another important design consideration is the anti-reflection layer at the silicon-air interface. We experimentally determined the optimized structure and conditions for the maximum IR transmission. The experimental results are shown in Fig.2.

Quantum efficiency enhancements follow from improved processing techniques which assure a undamaged and clean silicide/silicon interface. The starting wafer is an p-type silicon wafer with (100) orientation and the resistivity of 4-8 ohm-cm. First, a 800nm field oxide is grown by steam oxidation and the frontside oxide is removed. p^+ channel stop predeposition is carried out with boron and n^+ guard ring is formed around the PtSi Schottky diode to reduce the peripheral leakage current. (p^+ channel stop and n^+ guard ring region are not shown in Fig.1) After opening the Schottky window, Pt is formed by sputter deposition without surface sputter etch and sintering at 600°C in nitrogen ambient. The unreacted Pt on oxide layer is removed by aqua regia etching. Undoped 500nm silicon dioxide is deposited by CVD method and after Al metallization, thermal annealing is carried out at 450°C in nitrogen ambient.

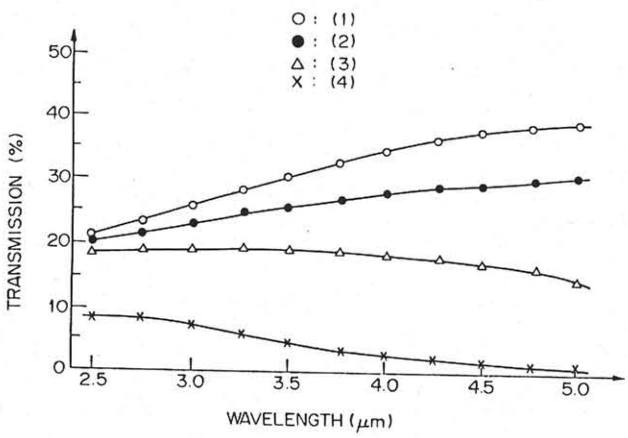

Fig.2. IR transmission with respect to the conditions of silicon-air interface (without the optical filter and PtSi film)
(1) Backside thermal silicon-dioxide: 800nm
(2) Bare silicon
(3) Slightly doped with boron without silicon-dioxide layer
(4) Heavily doped with boron without silicon-dioxide layer

4. Results and discussion

The measured values of quantum efficiencies for the thick film SBD (PtSi: 280nm) and the thin film SBD (PtSi: 30nm) are compared in Fig.3. In the case of the thick film SBD, the structure of SBD is not optimized but the optical filter and anti-reflection layer are formed in the thin film SBD. The quantum efficiency of thin film SBD (PtSi: 30nm) of 1.27% at a wavelength of 2um is about 10 times higher than that of thick film SBD (PtSi: 280nm). From the results of computer simulation, we know that the improvement by a factor of 1.5 is attributed to the increase of injection efficiency, and the additional improvement by a factor of 7 is caused by the increase of IR absorption in the PtSi film.

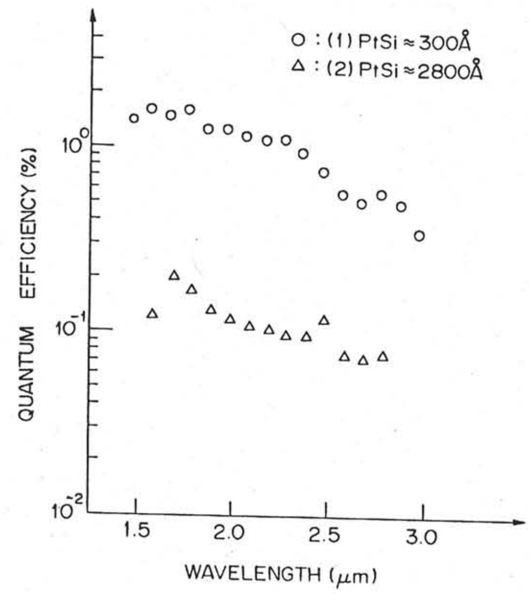

Fig.3. Quantum efficiency comparison between thin film SBD and thick film SBD

The very thin film SBD's(< 10nm) were fabricated and its quantum efficiencies were measured. The results are presented as a modified Fowler plot $(Y\cdot h\nu)^{\frac{1}{2}}$ vs $h\nu$ in Fig.4. Fitting to the equation (2), the Schottky barrier height is evaluated to be 0.22eV, quantum efficiency coefficient is $1.05eV^{-1}$ for 6nm PtSi SBD. And for 8nm PtSi SBD, the Schottky barrier height is 0.24eV, quantum efficiency coefficient C_1 is $0.88eV^{-1}$. At the same time, quantum efficiencies are 31% and 22% at a wavelength of 2um for 6nm and 8nm, respectively.

Many authors developed models for the quantum efficiency of SBD. The model of thin film SBD is based on that of thick film SBD with some modifications. All of models ignored the important influence of the quantum effects of excited carriers in a thin film SBD. For an excited carrier in a thin film SBD whose momentum distribution will not be isotropic but anisotropic, ie excited carriers have a

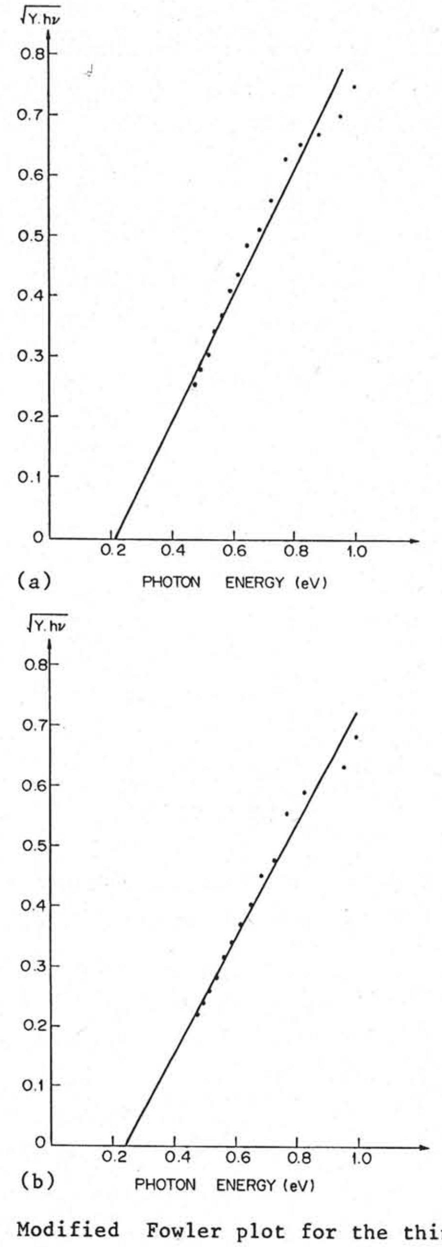

Fig.4. Modified Fowler plot for the thin film SBD's

a) 6nm PtSi SBD — Ψ_{ms} 0.22eV, C_1 : 1.05eV^{-1}

b) 8nm PtSi SBD — Ψ_{ms} 0.24eV, C_1 : 0.88eV^{-1}

favorable momentum distribution normal to the silicide-silicon interface.

Because the attenuation length L is an order of hundred angstrom, this favorable momentum distribution normal to the interfaces increases the emission probability of hot carriers, so enhances the quantum efficiency. It is apparent from the above discussion that there is an additional factor to be considered in the case of the modelling of quantum efficiency of thin film SBD.

5. Conclusion

Recently, we sucessfully fabricate the high performance thin film PtSi Schottky barrier IR detectors. Quantum efficiencies of our devices are about 2 times higher than ever reported values. We suppose that this results are consequence of the improvement of process related to the formation of platinum silicide.

From now on, reported photoemission theory did not be examined the effect of the favorable momentum distribution on the quantum efficiency. It is suggested that one should consider the quantum effects of excited carriers in modelling the quantum efficiency of thin film silicide Schottky barrier IR detector.

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