Silicide/$Si_{1-x}Ge_x$ Schottky-Barrier Long-Wavelength Infrared Detectors

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Abstract

In this paper, we demonstrate for the first time both $Pd_2Si/Si_{1-x}Ge_x$ and $PtSi/Si_{1-x}Ge_x$ Schottky-barrier long-wavelength infrared detectors. By employing a thin silicon sacrificial cap layer for silicide formation, Ge segregation effects and consequent Fermi level pinning when metal directly reacts with $Si_{1-x}Ge_x$ alloy are eliminated. The Schottky barrier height of the silicide/$Si_{1-x}Ge_x$ detector measured by internal photoemission decreases with increasing Ge fraction, allowing tuning of its cutoff wavelength. The cut-off wavelength has been extended beyond 8 μm in $PtSi/Si_{0.85}Ge_{0.15}$ detectors. It has been shown that high quantum efficiency and ideally low leakage can be obtained from these detectors. The fabrication processes are easily integrable with the current PtSi/Si focal-plane-array technology.

Introduction

The state-of-the-art silicide infrared Focal-Plane-Array (FPA) technology is based on the PtSi/Si Schottky-barrier detector which has a cut-off wavelength of $\sim 5\mu$m. The PtSi/Si detector offers relatively high quantum efficiency, high uniformity, and it is compatible with standard CMOS process technology. For many applications, it would be advantageous to be able to extend the cutoff wavelength of the silicide Schottky-barrier infrared detector into the 8–12 μm long-wavelength band. Strained $Si_{1-x}Ge_x$ on Si has a smaller band-gap than silicon with most of the band offset in the valence band [1]. It is expected from the Schottky-Mott model that a silicide/$Si_{1-x}Ge_x$ junction will have a smaller p-type Schottky-barrier height than the silicide/Si, therefore a longer cutoff wavelength [2]. The operation principle of the silicide/$Si_{1-x}Ge_x$ infrared detector, which was first proposed by Kanaya *et al.* [2], is the same as that of a conventional silicide/Si Schottky-barrier detector (i.e., photo-emission of holes from the silicide to the semiconductor)(Fig. 1(a)). No reverse bias electrical data or photo-response has ever been reported for a silicide/$Si_{1-x}Ge_x$ detector, however. Several later studies found that during the metal-$Si_{1-x}Ge_x$ reaction, palladium and platinum preferentially react with Si, causing Ge segregation [3,4]. This creates defects which consequently pin the Fermi level [4] near midgap leading to a high Schottky barrier height. In this work, by employing a thin silicon sacrificial layer for silicide formation on $Si_{1-x}Ge_x$, operation of $Pd_2Si/Si_{1-x}Ge_x$ and $PtSi/Si_{1-x}Ge_x$ Schottky-barrier long-wavelength infrared detectors has been demonstrated.

Experiments and Results

Our samples were grown by Rapid Thermal CVD on lightly doped p-type (100) substrates at 600–700°C [5]. The structure consists of a fully strained $Si_{1-x}Ge_x$ alloy layer on top of a strained graded composition $Si_{1-y}Ge_y$ ($y : 0 \rightarrow x$) layer. The graded layer is used to prevent a parasitic hole barrier at the substrate/$Si_{1-x}Ge_x$ interface. The $Si_{1-x}Ge_x$ is capped by a thin sacrificial silicon layer (40–100Å) which will be consumed later in silicide formation. After an oxide layer was deposited and windows were opened in this oxide, silicide was selective formed inside these windows using standard e-beam evaporation and annealing processes. We have fabricated both $Pd_2Si/Si_{1-x}Ge_x$ and $PtSi/Si_{1-x}Ge_x$ detectors. In the palladium devices, the silicon sacrificial layer thickness was 100Å, and the deposited palladium was 150Å. In the platinum devices, the sacrificial layer was 40Å, and the metal was 25Å. The deposited metal thicknesses were chosen so that the silicon sacrificial cap layer was all consumed in the silicide formation process. This process ensures a Schottky contact with a pure silicide film (without Ge) and, at the same time, eliminates the Ge segregation at the interface which could cause Fermi level pinning. The schematic band diagram and the device cross section of a silicide/$Si_{1-x}Ge_x$ Schottky-barrier infrared detector is shown in Fig. 1.

For comparison, devices without the silicon sacrificial layer were also fabricated in an otherwise identical processes sequence. Shown in Fig. 2 are measured photo-responses of three different palladium-silicide de-

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vices. While direct metal-$Si_{1-x}Ge_x$ reaction produces an increased barrier-height compared to the Pd_2Si/Si control device presumably due to Ge segregation and consequent Fermi level pinning, a silicon sacrificial layer eliminates such effects yielding a reduced Schottky-barrier height as desired.

To demonstrate that the cutoff wavelength of this type of detector can indeed be tuned by Ge fraction, $Pd_2Si/Si_{1-x}Ge_x$ detectors of various compositions with Si sacrificial layers were fabricated and characterized. The spectral responses of three different $Pd_2Si/Si_{1-x}Ge_x$ detectors measured by FT-IR spectroscopy at 77K are shown in Fig. 3. The conventional Pd_2Si/Si Schottky diode has a barrier height of 380 meV, which gives a cutoff wavelength of 3.3μm. As Ge is introduced, the cutoff wavelengths of the $Pd_2Si/Si_{0.8}Ge_{0.2}$ and $Pd_2Si/Si_{0.65}Ge_{0.35}$ detectors have been pushed to 4.5μm and 6.6μm, which correspond to barrier height reductions of 105 meV and 190meV, respectively (Fig. 6). To the first order, the amount of barrier height reduction is proportional to the Ge fraction.

Low dark current is very important for an infrared detector because it directly affects the detectivity. The leakage levels in these detectors were examined in the temperature range of 90–250K. The reverse bias I-V characteristics of a $Pd_2Si/Si_{0.80}Ge_{0.20}$ detector at various temperatures are shown in Fig. 4. By fitting the temperature dependent leakage currents (at 2V reverse bias) with the thermionic emission theory, we obtained barrier heights in very good agreement with those found from photoresponse, indicating ideally low leakage levels (Fig. 5(a)).

It is clear from Fig. 6 that in order to have a cutoff wavelength beyond 10μm in a $Pd_2Si/Si_{1-x}Ge_x$ detector, a Ge fraction of more that 0.50 is required. Since the $Si_{1-x}Ge_x/Si$ is not a lattice matched system, it is desirable to use as little Ge as possible in the silicide/$Si_{1-x}Ge_x$ detectors to minimize problems associated with strain in this system. Platinum silicide has a lower barrier height to p-type silicon than does the palladium silicide (250 meV vs. 380 meV). Therefore, it is expected that the same cutoff wavelength can be achieved in the $PtSi/Si_{1-x}Ge_x$ detectors with a lower Ge fraction. The spectral response of a $PtSi/Si_{0.85}Ge_{0.15}$ detector is shown in Fig. 3(b) along with that of a PtSi/Si control device. The cutoff wavelength is extended from 5.0μm to 8.3μm with only 15% Ge in the alloy, corresponding to a barrier height reduction of 100 meV (Fig. 6). From simple extrapolation, a cutoff wavelength beyond 10μm is expected for a $PtSi/Si_{1-x}Ge_x$ detector with as little as 20% Ge in the alloy. The temperature dependent dark currents of the PtSi devices are shown in Fig. 5(b). The somewhat lower barrier height for the $PtSi/Si_{0.85}Ge_{0.15}$ device found from leakage current (103meV) versus that found from photo-response (150meV) is thought to be due to parasitic edge leakage associated with the lack of a diffused guard ring. The measured responsivities of the $PtSi/Si_{1-x}Ge_x$ detectors are shown in Fig. 7. The $PtSi/Si_{0.85}Ge_{0.15}$ detector has peak responsivity of 0.1A/W at 2.5μm, which is 2.5 times higher than that of the Si control device.

In the standard PtSi/Si array process, the platinum silicide is selectively formed in active areas after all the high temperature CMOS processes (for readout circuitry) are completed. Modifying this process flow for the $PtSi/Si_{1-x}Ge_x$ detectors requires only one extra process step, the low temperature epitaxial growth of the $Si_{1-x}Ge_x$ alloy layers and the Si sacrificial cap layer before the PtSi formation. Since this step is done at 600–700°C, the CMOS circuitry will not be adversely affected, and since subsequent back-end steps are at low temperatures, strain relaxation of the $Si_{1-x}Ge_x$ should not be a concern.

Summary

In summary, we have demonstrated for the first time $Pd_2Si/Si_{1-x}Ge_x$ and $PtSi/Si_{1-x}Ge_x$ Schottky-barrier long-wavelength infrared detectors. A silicon sacrificial layer was used to eliminate Ge segregation and Fermi level pinning. The cutoff wavelength is tunable by the amount of Ge: cutoff wavelengths over 8μm have been obtained, and extension to $> 10\mu$m should be straight forward. Ideally low leakage currents have been measured and an external responsivity of 0.1A/W at 2.5μm was obtained in the $PtSi/Si_{0.85}Ge_{0.15}$ detectors. This responsivity is 2.5 times higher than that of the PtSi/Si control devices. The $PtSi/Si_{1-x}Ge_x$ detector is compatible with PtSi/Si focal-plane-array technology.

Acknowledgements

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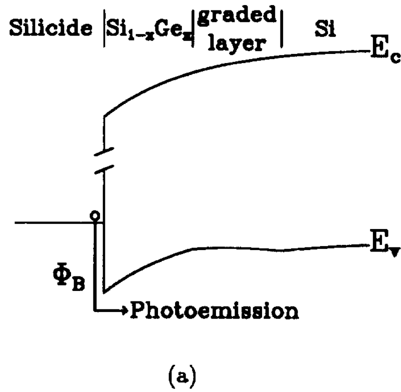
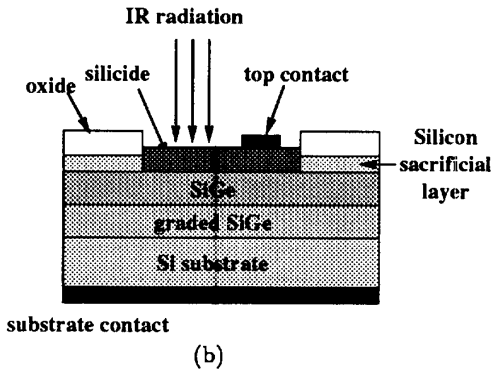


(a)



(b)

Figure 1: Schematic diagrams of a silicide/$Si_{1-x}Ge_x$ Schottky-barrier long wavelength infrared detector. (a) band diagram, (b) device cross section.

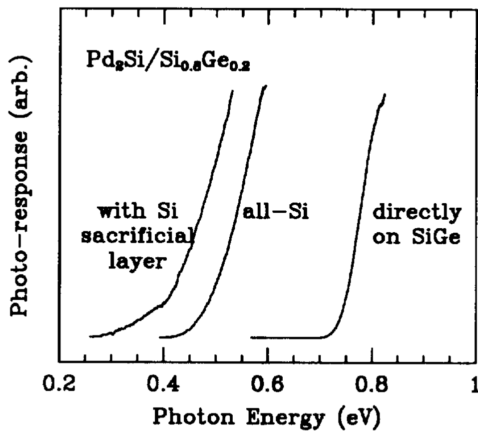
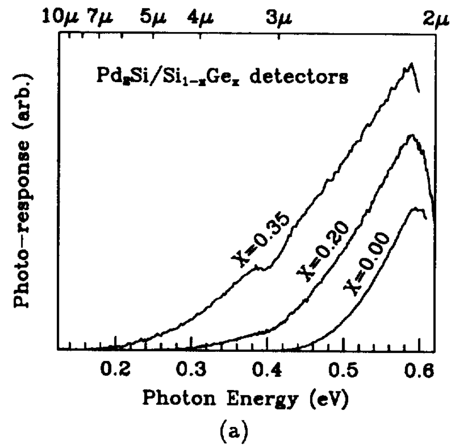
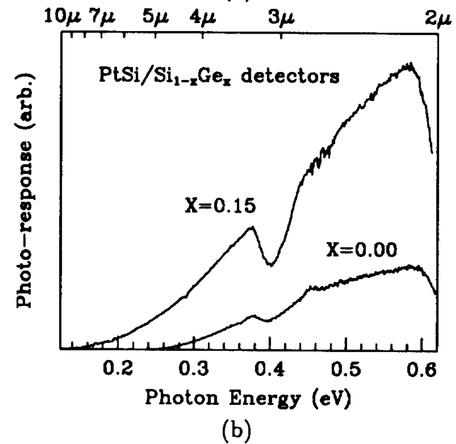


Figure 2: Measured photo-response for three different palladium-silicide structures. While direct metal-SiGe reaction produces an increased barrier height due to Ge segregation, a silicon sacrificial layer gives a reduced barrier height as desired.



(a)



(b)

Figure 3: Infrared photo-response at 77K of (a) $Pd_2Si/Si_{1-x}Ge_x$ and (b) $PtSi/Si_{1-x}Ge_x$ Schottky-barrier detectors. The cutoff wavelength gives the barrier height of the corresponding silicide/$Si_{1-x}Ge_x$ Schottky junction.

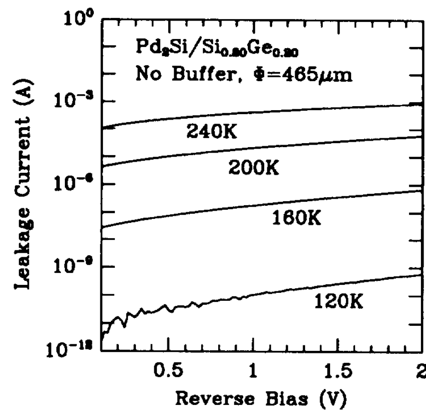
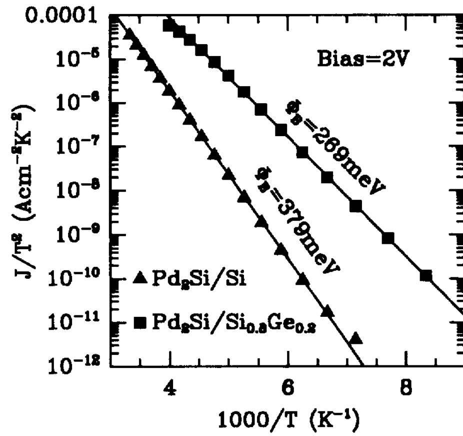


Figure 4: Reverse bias I-V characteristics of a $Pd_2Si/Si_{0.80}Ge_{0.20}$ detector at various temperatures.



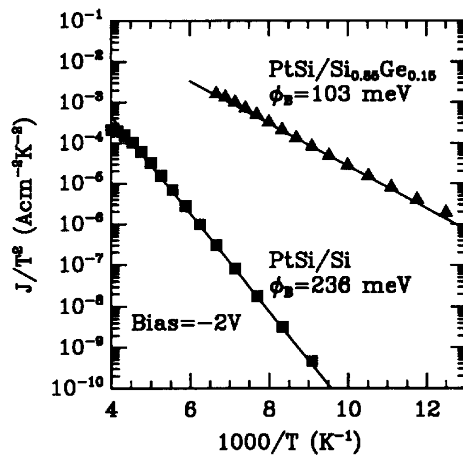


Figure 5: Temperature dependent dark current densities of (a) $Pd_2Si/Si_{1-x}Ge_x$ and (b) $PtSi/Si_{1-x}Ge_x$ detectors at 2V reverse bias. Schottky-barrier heights obtained from these I-T data (except for the $PtSi/Si_{0.85}Ge_{0.15}$ device) agree with those obtained from optical measurements within 15 meV.

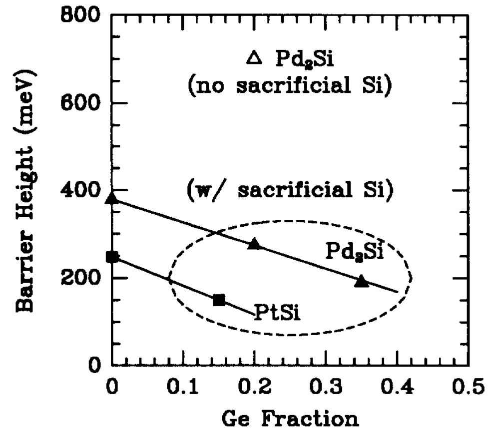


Figure 6: Schottky-barrier heights as functions of Ge fraction of both $Pd_2Si/Si_{1-x}Ge_x$ and $PtSi/Si_{1-x}Ge_x$ detectors obtained from photo-response measurements.

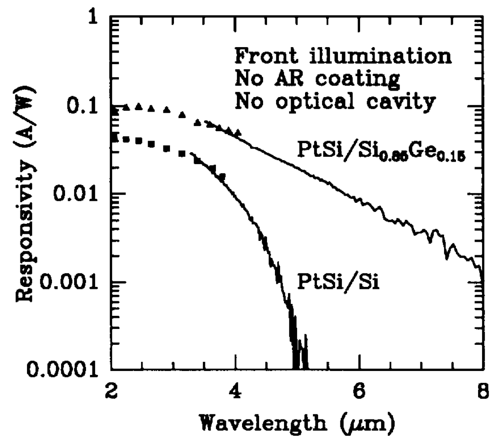


Figure 7: Comparison of measured external responsivities of $PtSi/Si_{0.85}Ge_{0.15}$ and PtSi/Si infrared detectors. Points represent data obtained with a calibrated infrared monochromator (40K), while lines are scaled results from FTIR measurements.