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Current–voltage studies on β-$FeSi_2$/Si heterojunction[†]

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Abstract. ***I–V* characteristics of both β-$FeSi_2$/n-Si and β-$FeSi_2$/p-Si were studied at room temperature. The junctions were formed by depositing Fe on Si selectively followed by thermal annealing and some samples were later treated by pulsed laser. Temperature of thermal annealing and diode area were also varied. *I–V* studies on all these samples were done and ideality factors were computed. Results obtained were interpreted.**

Keywords. **Silicide; semiconducting silicide; heterojunction; pulsed laser; *I–V* characteristics.**

1. Introduction

β-$FeSi_2$ is a semiconducting silicide having direct band gap of around 0·85 eV and high optical absorption coefficient (Bost and Mahan 1985). It is thus an attractive candidate for optoelectronic component compatible with the well known technology for Si devices. The material is found to be heavily doped p-type semiconductor (Dimitriadis *et al* 1990) without intentional doping. So the growth of β-$FeSi_2$ films on n-type Si substrate results in anisotype heterojunction which might be of considerable interest. Also isotype junction on p-type Si is possible and can be studied. However, the current is affected by the interface states formed due to the lattice and thermal coefficient mismatch between two semiconductors. The purpose of the present work is to examine the current transport through both isotype and anisotype polycrystalline β-$FeSi_2$/Si heterojunctions with different process conditions and varying junction areas.

2. Experimental

Thin films of β-$FeSi_2$ were prepared on two types of substrates: (i) p-type ⟨100⟩ with $\rho = 7$–$14\ \Omega$-cm and (ii) N/N^+ Si ⟨100⟩ with $\rho = 0{\cdot}02\ \Omega$-cm for heavily doped ($N^+$) back side and $\rho = 0{\cdot}48$–$0{\cdot}72\ \Omega$-cm for N epilayer. 5 N purity iron was selectively deposited in the form of circular dots using a mask on both types of substrates by electron beam evaporation technique using an Edward 306A system at a pressure lower than 10^{-5} torr. Dot area was varied as $0{\cdot}0188\ cm^2$ and $0{\cdot}027\ cm^2$. The samples were subsequently annealed at a temperature of 850°C for 2 h in Ar + H_2 ambient. Some samples were annealed at 750°C for 2 h. XRD analysis confirmed the formation of polycrystalline β-$FeSi_2$. The ohmic contact on back side was done by depositing Al by thermal evaporation technique. Some identical samples were sorted out and the junctions were pulse laser irradiated. Excimer laser (XeCl) with intensity of $0{\cdot}75$–$0{\cdot}90\ J/cm^2$ was used for pulsed laser source. These samples were again thermally treated (at 500°C for 1 h) for passivation of laser-induced damage. In all the cases *I–V* characteristics of β-$FeSi_2$/Si heterojunction were studied. Also junctions were illuminated with white light and the resulting characteristics were taken. A normal lamp was used as white light source and it was kept at a safe distance from the sample to avoid thermal generation of carriers. An HP 4061A model Semiconductor Component/Test system was used for the purpose. In this system, the sample is attached to a circular metal chuck using vacuum and the chuck also provides the back electrical contact. Front electrical contact is taken on the area of diode by pressing a metal probe over it and voltage is applied in between the back contact and the front one. Measurement and data processing is computer controlled.

3. Results and discussion

I–V measurements on both β-$FeSi_2$/n-Si and β-$FeSi_2$/p-Si using a press contact probe showed an exponential behaviour nearly up to 0·1 V and deviated at higher voltages due to the series resistance effect. The forward characteristics were fitted to the standard diode equation

$$J = J_0 \exp(qV/nkT).$$

Ideality factors were calculated from the slope of $d(\ln J)$ vs V graph and using the relationship $n = (q/kT)\, dV/d(\ln J)$. Barrier heights were determined from thermionic emission model using the relationship

$$\varphi = (kT/q) \ln(A^{**}T^2/J_0).$$

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Figure 1 shows one typical *I–V* characteristics of β-$FeSi_2$/n-Si heterojunction up to 2·0 V in forward direction where linearity up to 0·1 V is shown clearly. It is found that current through the junction is larger when applied voltage on the silicide is positive. This finding shows that as grown β-$FeSi_2$ is a p-type semiconductor. So it is an indirect way to confirm the formation of β-$FeSi_2$. Voltage range up to 0·2 V is amplified graphically in figures 2 and 3 for both β-$FeSi_2$/n-Si and β-$FeSi_2$/p-Si junctions, respectively. The ideality factors calculated for β-$FeSi_2$/n-Si junction are mentioned in figure 2 for a fixed diode area of 0·0188 cm^2. It was seen that *n* value for thermally annealed sample increased when irradiated by pulsed laser and then decreased to the minimum value after further thermal annealing. In case of β-$FeSi_2$/p-Si junction (shown in figure 3), the series resistance effect was severe for laser treated samples. However, it was lower for thermally annealed sample and the value of *n* calculated from the initial linear portion of the *I–V* curve was ~ 1·08. Erlesand and Ostling (1996) studied β-$FeSi_2$/p-Si and β-$FeSi_2$/n-Si junctions down to 175 K and concluded that dominant current transport mechanism across the β-$FeSi_2$/p-Si junction was thermionic in nature and tunnelling was the dominant mechanism in current transport for β-$FeSi_2$/n-Si junction. For β-$FeSi_2$/n-Si junction, the mechanism was clearly established earlier by Dimitriadis (1991) also. Due to low hole barrier the series resistance at higher temperature usually affects the evaluation of *n* for β-$FeSi_2$/p-Si junction. Series resistance may further increase with laser treatment, which makes it more critical for finding out *n*. In case of β-$FeSi_2$/n-Si junction, the contribution of tunnelling to current transport is substantial even at room temperature and therefore effect of series resistance is not that prominent here. Since the model for thermionic emission can be applicable for β-$FeSi_2$/p-Si

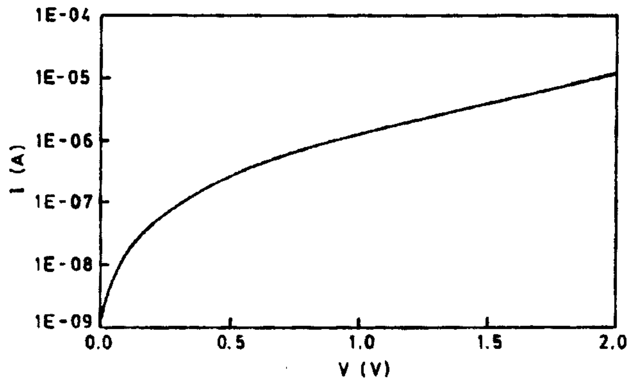

Figure 1. A typical *I–V* characteristics for β-$FeSi_2$/n-Si heterojunction up to 2·0 V.

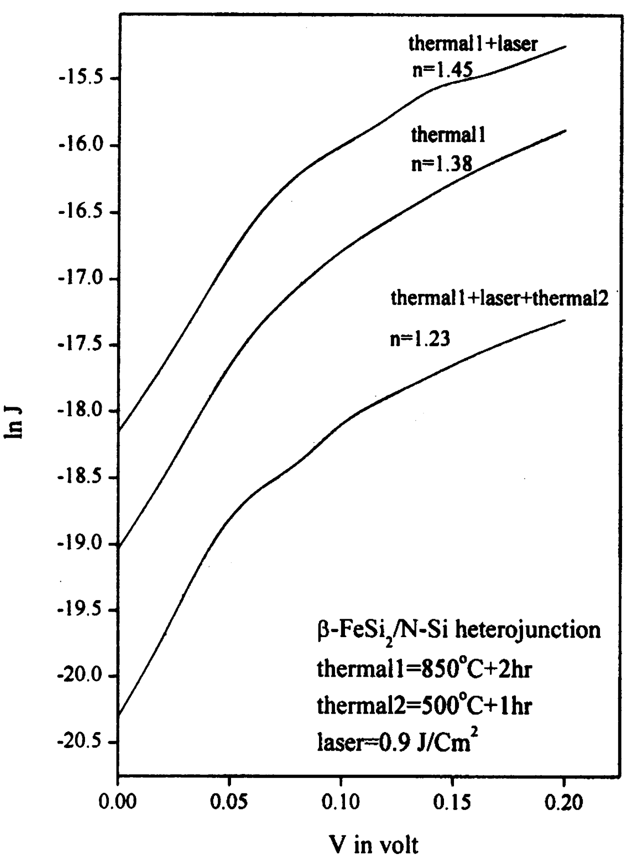

Figure 2. *I–V* characteristics for β-$FeSi_2$/n-Si heterojunction.

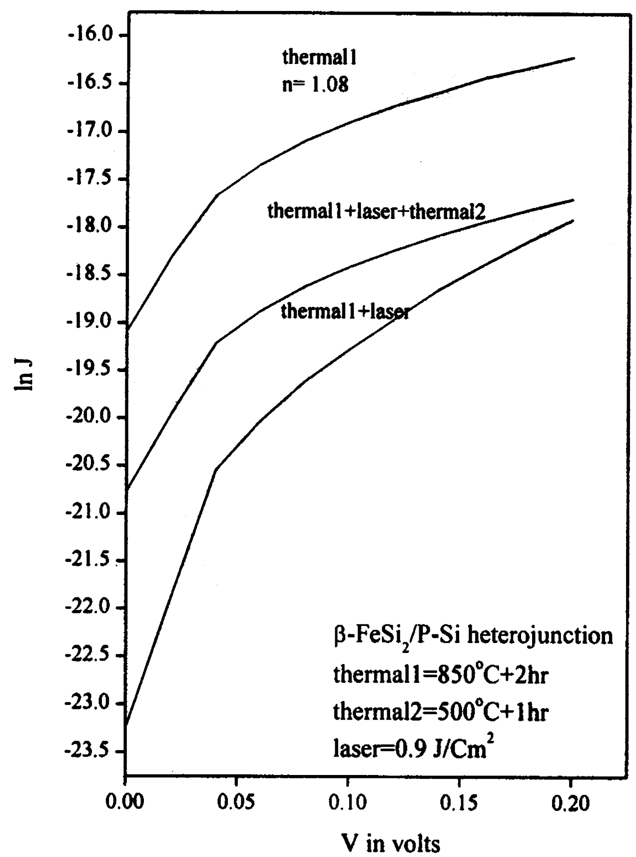

Figure 3. *I–V* characteristics of β-$FeSi_2$/p-Si heterojunction.

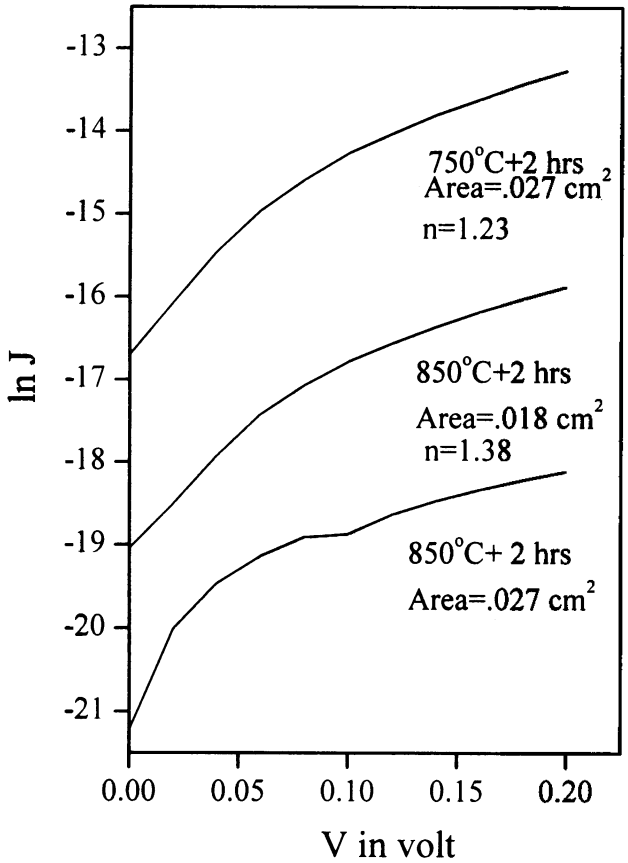

Figure 4. *I–V* characteristics of β-$FeSi_2$/n-Si heterojunction prepared at different annealing temperatures and of varying junction areas.

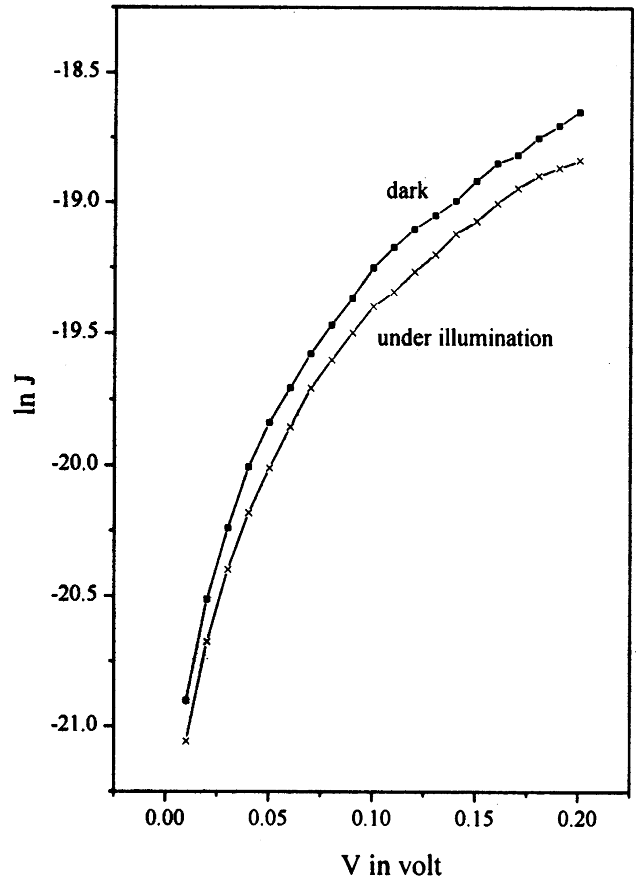

Figure 5. *I–V* characteristics of β-$FeSi_2$/n-Si heterojunction under illumination.

junctions, our calculated value for barrier height (1·01 eV) might be reasonable. However for β-$FeSi_2$/n-Si junctions, barrier height calculated from the same model would be quite erroneous. Figure 4 cites *I–V* curves of some β-$FeSi_2$/n-Si junctions with varying diode areas (0·0188 and 0·027 cm^2). Two identical samples with diode area 0·027 cm^2 were annealed at 850°C and 750°C for 2 h. The sample annealed at 750°C showed better characteristic in all respects which proves that the annealing at lower temperature has better electrical properties. This similar observation was also reported by Dimitriadis *et al* (1990) for resistivity and mobility values. But the diode with same area when annealed at 850°C showed very high resistance which may be due to larger amount of defects and interface states created by annealing at higher temperature. However, the diode with smaller area showed somewhat better feature because of relatively lower defect density. β-$FeSi_2$/n-Si junction was also studied under white light illumination. But a decrease in current for both forward and reverse directions was noticed under illumination. The reverse characteristic of both dark and illuminated junction has been shown in figure 5. There is a depletion region mostly in n-Si because silicide is heavily doped. Under illumination carriers are created in this region and the electric field due to ionized impurities in Si yields a current in the opposite direction to that caused by applied voltage. In this way the negative photoresponse here is justified. Similar result was also reported by Lefki *et al* (1991). Regolini *et al* (1992), however, reported an increase in reverse current and explained it as due to generation of *e–h* pairs.

4. Conclusions

Ideality factor for β-$FeSi_2$/n-Si junction was found to decrease for the laser annealed junction after further thermal annealing. For β-$FeSi_2$/p-Si junction, effect of series resistance affects the calculation for *n*. For both types of heterojunctions (anisotype and isotype), *n* was calculated for thermally annealed junction. It is imperative from the results that thermionic emission is dominant in β-$FeSi_2$/p-Si junction but tunnelling effect plays an important role for β-$FeSi_2$/n-Si junction even at room temperature. Junction annealed at lower temperature showed better characteristics. The diode having lower area also showed better performance than that having larger area. A net decrease of current was observed in both directions when the β-$FeSi_2$/n-Si junction was illuminated by white light.

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