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# A 0.5-$\mu$m-thick polycrystalline silicon Schottky diode with rectification ratio of $10^6$

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Polycrystalline Si films, 0.5-$\mu$m thick, were obtained as a result of metal-induced growth by sputtering from a Si target on 25 nm thick Ni prelayers at 525 °C. Silicon grew heteroepitaxially on the $NiSi_2$ layer formed due to the reaction between the sputtered Si atoms and Ni. Schottky diodes were fabricated on the Si films by deposition of a Schottky metal on the front surface of the film while Ni disilicide provided an intimate ohmic contact at the back. A Pd/$n$-Si diode using an $n$-Si film annealed for 2 h at 700 °C in forming gas demonstrated a rectification ratio of $10^6$, while an as-deposited $p$-Si film provided an Al/$p$-Si diode with rectification of five orders of magnitude. Schottky barrier properties are briefly discussed.
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Despite the fact that the III–V and II–VI compounds for fast-switching and photonic devices have attracted considerable interest in recent years, silicon remains one of the most reliable materials in a mainstream semiconductor technology. Among Si-based microelectronic devices, Schottky diodes are particularly promising for the high-speed applications due to the majority carrier transport mechanism and related to that virtual absence of minority carrier storage which limits the frequency response. The quality of a Schottky contact is extremely critical for the performance of high frequency and microwave devices, such as diodes, metal–semiconductor field effect transistors, high electron mobility transistors, and static-induced transistors. Both the rectification ratio and the cut-off frequency depend on the interface between the semiconductor surface and the deposited Schottky metal, interdiffusion between these materials, and quality of a semiconductor itself. There is a major trend to reduce the density of interface and semiconductor bulk states which contribute to the parasitic capacitance and leakage current. In order to obtain a low noise and high quality rectifier, a structurally perfect semiconductor material with no deep levels in the energy gap is needed. To date, semiconductor layers thinner than 0.5 $\mu$m provided reliable Schottky contacts only when grown by high-temperature epitaxy, such as molecular-beam epitaxy, liquid phase epitaxy, and metal–organic vapor phase epitaxy.[1–3] Accordingly, there is a tradeoff between the Schottky quality and a common microelectronics trend to reduce the device cost by substituting expensive thick crystalline layers with microcrystalline thin films and the use of low-cost low-melting point substrates.

Previously, we have demonstrated the properties of polycrystalline Si (polysilicon) films produced by metal-induced growth (MIG) on foreign substrates below 600 °C.[4] Fully crystallized Si films were obtained by Si deposition on a thin Ni prelayer, where Si columnar grains were shown to grow heteroepitaxially on the lattice-matched $NiSi_2$ crystals nucleated at the Ni–Si interface. Moreover, $NiSi_2$ on the back surface of such a Si film provided an excellent ohmic contact to the film. This letter reports the performance of Schottky diodes fabricated on 0.5 $\mu$m thick MIG-polysilicon films of both the $n$ and $p$ type.

In our approach, the starting substrate was a single crystal Si wafer coated with a 300 nm thick $SiO_2$ by plasma-enhanced chemical vapor deposition. This substrate was chosen for convenience and can be replaced by a thin metal, glass, plastic, or polymer substrate. A 25 nm thick Ni was thermally evaporated on a $SiO_2$/Si substrate at a base pressure in the lower $10^{-6}$ Torr range. Silicon was deposited directly on the Ni surface by dc magnetron sputtering from a 99.99% Si target in a 5% $H_2$/Ar gas mixture at a pressure of 1 mTorr (after a vacuum level of $1\times10^{-7}$ Torr or lower was achieved). In all cases, the magnetron power and the sub-

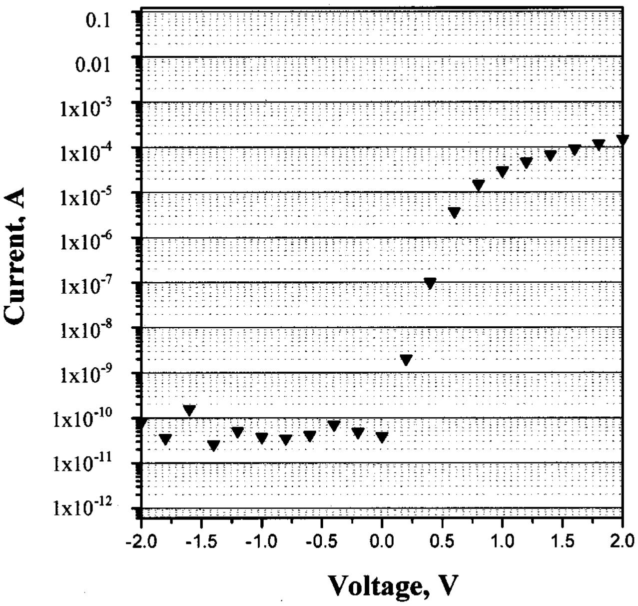

FIG. 1. The room-temperature performance of the best Schottky diode obtained on an $n$-type MIG-polysilicon film, demonstrating a rectifying ratio of $\sim10^6$. The diode area is 2 $mm^2$.

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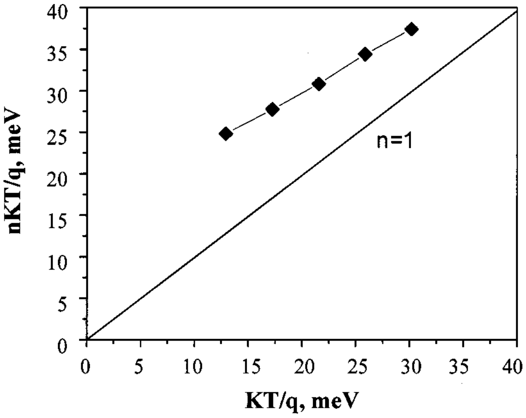

FIG. 2. Experimental values of $nkT/q$ as a function of temperature for a typical Pd/*n*-Si diode.

strate temperature were kept at 50 W and 525 °C, respectively, which provided a deposition rate of ~0.5 μm/h. Both *n*-type (P-doped) and *p*-type (B-doped) Si targets with the respective resistivity values of 0.006 Ω cm, and 0.001 Ω cm were used. Because of the intimate self-organized back ohmic contact, Schottky diodes were produced by fabrication of rectifying contacts on the front surface of the Si films using metals with the suited work function, i.e., Pd for *n* type and Cr and Al for *p*-type Si films, respectively. The area of all diodes was 2 mm$^2$. The current–voltage ($I-V$) characteristics were measured in dark with an automated data acquisition system employing a Keithley 230 voltage source and a Keithley 617 multimeter.

The attempt to fabricate a Schottky junction on an as-deposited *n*-type polysilicon film was not successful. The annealing study was conducted on several samples, and the annealing variables were chosen to be the annealing temperature and the annealing ambiance. In order to reduce the number of variables, the annealing time was fixed at 2 h for all experiments. At a temperature of 700 °C, annealing in either air or pure nitrogen failed to show the presence of a slightest barrier after the Schottky metal was deposited. A 5% $H_2$/Ar mixture provided a weak rectification, and, finally, Forming gas (10% $H_2/N_2$) resulted in a well-defined junction. These results may imply that the diode efficacy improves by increasing the hydrogen content in the annealing environment which may be further explained by the saturation of dangling bonds at the grain boundaries closer to the surface. A moderate rectification result was achieved for the samples annealed at 650 °C in Forming gas, whereas a temperature of 700 °C provided Si films for the Schottky diodes with a rectification ratio of $10^3$–$10^6$ ($I_R/I_F$ taken at −1 V/1 V). The potential of MIG to provide high electronic quality Si films is demonstrated in Fig. 1 showing the log(*I*)–*V* characteristic of a Schottky diode with the rectification of six orders of magnitude taken at room temperature.

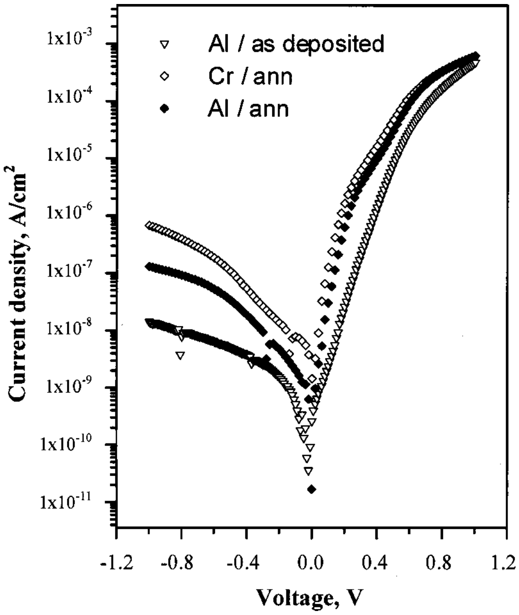

FIG. 3. The room-temperature $J-V$ characteristics of the Schottky diodes fabricated on the *p*-type MIG-polysilicon.

The carrier transport in Pd/*n*-polysilicon Schottky structures was studied by taking temperature-dependent current–voltage ($I-V-T$) characteristics. The typical values for the ideality factor $n$, saturation current density $J_S$ and Schottky barrier height $\varphi_B$ computed from the $I-V-T$ characteristics for an average Pd/*n*-Si diode are shown in Table I. In the pure thermionic emission theory, both barrier height and ideality factor decrease when temperature increases. An abnormal increase in barrier height with temperature has been observed before,[5,6] and the phenomenon was attributed to the electron states present at the metal–semiconductor interface due to inhomogeneities of the Schottky contact. In addition, the observed $\varphi_B$ is smaller than the theoretical $\varphi_B$ due to the image force barrier lowering. Figure 2 shows the $E_0 = nkT/q$ values versus $kT/q$. Figure 2 indicates that the transport mechanism involved in the diode is dominated by thermionic emission (TE) at higher temperatures with a smooth transition to the start of thermionic field emission (TFE) at lower temperatures. It is worth mentioning here that the data listed in Table I were collected for a typical, or average, diode, and the performance of MIG-polysilicon films can be further improved, as becomes evident from Fig. 1.

The fabrication of Schottky diodes based on the *p*-type polysilicon utilized two metals, Cr and Al. As compared to the *n*-type Si films, both annealed and as-grown *p*-type Si films provided reasonable rectifying devices. The reason for

TABLE I. Schottky parameters extracted from the $I-V-T$ characteristics of a Pd/*n*-Si Schottky diode.

| Temperature (K) | Rectifying ratio, $I_{-1\,\mathrm{V}}/I_{1\,\mathrm{V}}$ | Ideality factor | Saturation current density (A/cm$^2$) | Barrier height (eV) |
|---|---|---|---|---|
| 150 | up to $10^6$ | 1.92 | $2.2\times10^{-14}$ | 0.596 |
| 200 | 10000 | 1.61 | $3.3\times10^{-12}$ | 0.720 |
| 250 | 2500 | 1.43 | $9.2\times10^{-10}$ | 0.786 |
| 300 | 1300 | 1.33 | $2.7\times10^{-9}$ | 0.925 |
| 350 | 125 | 1.24 | $3.3\times10^{-7}$ | 0.944 |

TABLE II. Schottky parameters extracted from the $I-V-T$ characteristics of an Al/$p$-Si Schottky diode.

| Temperature (K) | Ideality factor | Saturation current density (A/cm$^2$) | Barrier height eV |
|---|---|---|---|
| 125 | 2.08 | $1.3\times10^{-19}$ | 0.623 |
| 150 | 1.84 | $1.2\times10^{-16}$ | 0.665 |
| 175 | 1.65 | $1.0\times10^{-14}$ | 0.713 |
| 200 | 1.54 | $2.0\times10^{-13}$ | 0.768 |
| 225 | 1.45 | $2.8\times10^{-12}$ | 0.817 |
| 250 | 1.41 | $2.0\times10^{-11}$ | 0.870 |
| 275 | 1.36 | $9.0\times10^{-11}$ | 0.906 |
| 300 | 1.33 | $7.0\times10^{-10}$ | 0.959 |

such a difference in the performance of *n*- and *p*-type polysilicon films is currently under investigation. Figure 3 shows the room-temperature current density–voltage ($J-V$) characteristics of three samples, fabricated on: an as-grown *p*-Si film using Al, an annealed film using Al, and an annealed film using Cr (no rectification was achieved on as-grown *p*-Si film using Cr). Annealing was done at 700 °C for 2 h in forming gas. It is seen in Fig. 3 that the diode based on an as-grown film exhibited the best properties, with a rectification ratio of five orders of magnitude. The Schottky parameters extracted from the $I-V-T$ characteristics of this device are listed in Table II. However, the conduction mechanism in all three Schottky structures in Fig. 3 is similar to that in the Pd/*n*-Si diode, with the TFE mechanism dominating at lower temperatures and the TE mechanism dominating at higher temperatures.

In summary, Schottky diodes were fabricated on 0.5 $\mu$m thick polysilicon films produced by Si sputtering on 25 nm thick Ni prelayers. The electrical characterization of the diodes indicated the capability of the MIG technique to produce high quality thin film silicon at low temperatures. A Pd/*n*-Si diode fabricated using the Si film deposited at 525 °C and annealed for 2 h at 700 °C in forming gas demonstrated a rectification ratio of $10^6$, while an Al/*p*-Si diode on the as-deposited Si film provided rectification of five orders of magnitude. The performance of the Schottky diodes reported here is among the best results achieved on sub-1-$\mu$m-thick nonepitaxial Si films produced in a low-temperature process.

[1] T. L. Lin, and J. M. Iannelli, Appl. Phys. Lett. **56**, 2013 (1990).

[2] J. R. Lothian, F. Ren, J. M. Kuo, J. S. Weiner, and Y. K. Chen, Solid-State Electron. **41**, 673 (1997).

[3] N. S. Peev, Microelectron. Eng. **43**, 599 (1998).

[4] E. Guliants and W. A. Anderson, J. Appl. Phys. **87**, 3532 (2000).

[5] H. Hong, W. A. Anderson, J. Haetty, A. Petrou, E. H. Lee, H. C. Chang, M. H. Na, H. Luo, J. Peck, and T. J. Mountziaris, J. Appl. Phys. **82**, 4994 (1997).

[6] J. Osvald, J. Appl. Phys. **85**, 1935 (1999).