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# On the origin of the 1/*f* noise in shallow germanium $p^+$-*n* junctions

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The low-frequency noise of shallow germanium $p^+$-*n* junctions is studied, for diodes with or without a nickel-germanide Ohmic contact. It is shown that the application of NiGe not only reduces the series resistance, resulting in a higher forward current, but also results in a lower 1/*f* noise at forward bias. From the observed geometry dependence, it is concluded that germanidation suppresses the 1/*f* noise generated in the series resistance, leaving surface-state-assisted generation-recombination at the junction perimeter as the dominant flicker noise source. © *2007 American Institute of Physics*. [DOI: 10.1063/1.2431759]

From the early days of semiconductor devices, 1/*f* or flicker noise has been an issue in germanium *p*-*n* junctions.[1–4] It soon became clear that this excess noise source is generally related to the material characteristics and more, in particular, to the presence of defects in the bulk or at the surface/interface. In more recent years, Ge *p*-*n* junctions have been utilized for special applications such as infrared avalanche photodiodes[5,6] and nuclear-radiation detectors,[7] where noise minimization is of key importance. Recent interest in high-mobility substrates has brought germanium back on the microelectronics stage as a potentially important high-mobility-channel material. The development of high-performance metal-oxide-semiconductor field-effect transistors requires the fabrication of shallow *p*-*n* junctions with low series resistance.[8–11] This can be achieved by the implementation of a nickel-germanide contacting scheme, offering the advantage of self-alignment and low thermal budget.[12–15]

In the past, it has been shown that the 1/*f* noise of silicon *p*-*n* junctions is sensitive to the substrate type, i.e., the crystal growth technique, orientation, and the processing.[16–18] It was also demonstrated that cobalt silicidation can have a strong impact on the current noise spectral density $S_I$ in the forward operation.[19] In other words, studying the low-frequency (LF) noise of *p*-*n* junctions can provide useful information on the basic transport mechanisms and more, in particular, whether defects in the bulk or at the surface in the peripheral diode region contribute to the fluctuations in the current.

In this letter, the LF noise behavior of shallow $p^+$-*n* junctions fabricated in 1.6 $\mu$m Ge layers epitaxially deposited on 200 mm diameter silicon wafers is investigated in the forward operation. Both square and perimeter types of diodes have been studied in order to have an idea about the geometrical origin of the noise.[20] Junctions with and without a nickel-germanide contact are compared. It is shown that devices with NiGe exhibit a lower $S_I$ at a frequency $f=1$ Hz compared with their nongermanided counterparts. This is ascribed to the lower series resistance, leaving defect-assisted carrier fluctuations as the main origin of the 1/*f* noise.

Junctions were formed in relaxed germanium epitaxial layers on silicon containing a density of threading dislocations in the range of $\sim 10^7-10^8$ cm$^{-2}$. A 570 keV P implantation to a dose of $5\times10^{11}$ cm$^{-2}$ was employed to form the *n*-well region. This was followed by a 35 keV Ge preamorphization followed by 7.5 keV B to a dose of $4\times10^{15}$ cm$^{-2}$. Junction activation was performed by a 500 °C 5 min anneal in $N_2$ ambient. A layer of 30 nm Ni was sputtered, followed by a rapid thermal anneal step at 350 °C to form a germanide. Nongermanided samples have a TiN-based back-end metallization. The noise measurements have been performed in the forward bias between the top junction and the bottom substrate in the bias range from 0 to 0.8 V in steps of 50 mV, using a probe station, BTA hardware, and the NoisePro software from Cadence.

As shown in Fig. 1, the noise spectra are of the $1/f^\gamma$ type, with $\gamma$ close to 1, while the frequency-independent shot noise occurs outside the accessible frequency range ($>10^5$ Hz). Occasionally, Lorentzian humps due to

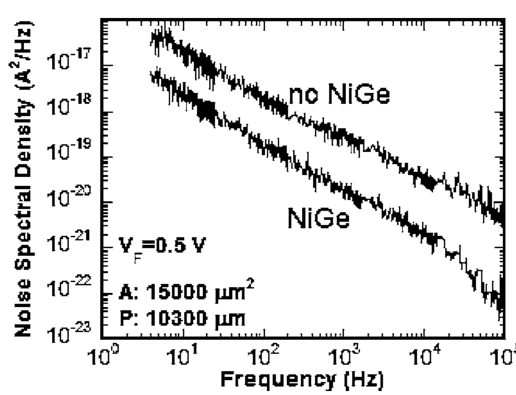


FIG. 1. Low-frequency noise spectra for a germanided and a nongermanided $p^+$-*n* junction at a forward bias of 0.5 V. The area is 15 000 $\mu$m$^2$ and the perimeter $P=10\,300$ $\mu$m.

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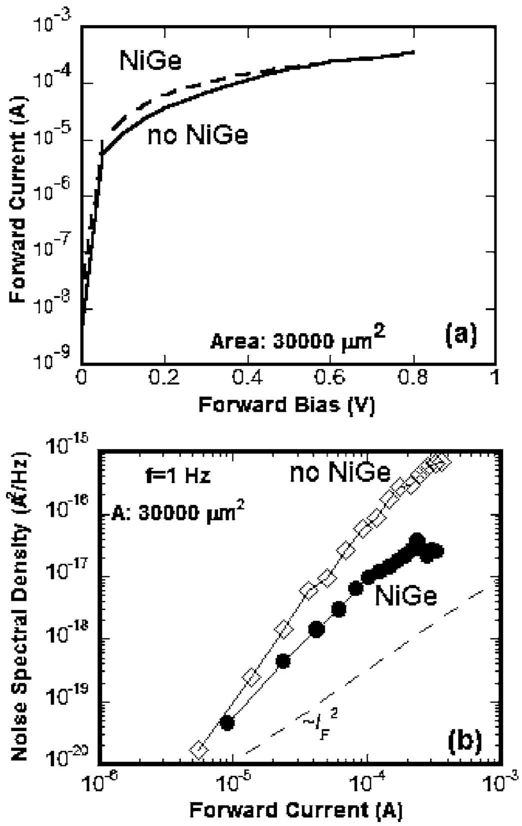


FIG. 2. (a) $I_F$ vs $V_F$ and (b) $S_I$ at 1 Hz vs $I_F$ for a large-area square diode ($A=30\,000$ $\mu$m$^2$) with or without NiGe.

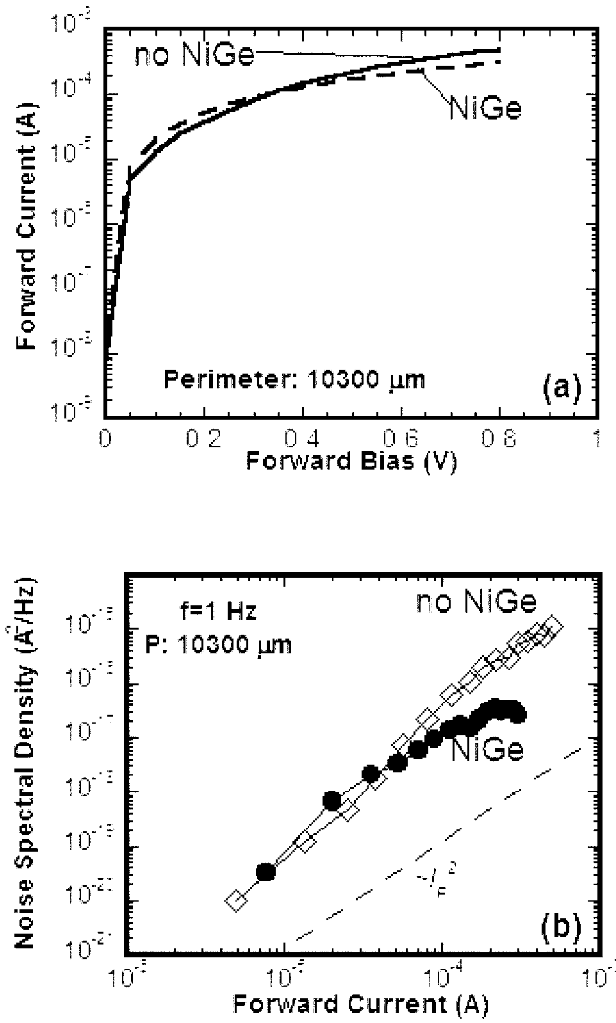


FIG. 3. (a) $I_F$ vs $V_F$ and (b) $S_I$ at 1 Hz vs $I_F$ for a large-perimeter diode ($P=10\,300$ $\mu$m) with or without NiGe.

generation-recombination noise have been found. When comparing the germanided with the nongermanided junctions in Fig. 2 or 3, it is first of all clear that the NiGe helps reducing the series resistance. This follows from the higher forward current observed in Fig. 2(a) or 3(a) at a $V_F$ in the range of 0.1–0.4 V. The improvement appears to be more significant for the square large-area diode of Fig. 2 compared with the large-perimeter diode of Fig. 3.

The current noise spectral density $S_I$ at 1 Hz versus $I_F$ follows approximately an $I_F^2$ dependence over most of the forward current range studied. This rules out mobility fluctuations (or more general, diffusivity fluctuations) as the origin. It has been demonstrated that the $1/f$ noise current spectral density due to "surface state" generation-recombination follows an $I_F^{2/m}$ power law, with $m$ the diode ideality factor.[21] As the experimental $m$ is close to 1, the observed quadratic law is close to what is expected from theory for $1/f$ noise generated at the periphery of the diodes. A similar power law has also been demonstrated for pure $1/f$ noise due to defect-assisted generation-recombination (GR) events in the bulk depletion region of the junctions.[22] At the same time, as derived from the forward characteristics in Figs. 2(a) and 3(a), the series resistance of the junctions causes a deviation from the ideal forward behavior at high forward bias, which translates in a reduction of the dependence on the current of $S_I$.

Secondly, the noise spectral density for the germanided samples is smaller than for the nongermanided counterparts, whereby the difference increases for increasing $I_F$. At the same time, the $1/f$ noise improvement is more pronounced for the large-area junctions compared with the large-perimeter ones.

In order to further identify the origin of the $1/f$ noise in the Ge $p^+$-$n$ junctions the noise spectral density versus the junction area $A$ at a fixed current $I_F=100$ $\mu$A has been studied (Fig. 4). The germanided diodes exhibit a clear increase with $A$, which follows a power law, i.e., $S_I$ is proportional with $A^{0.39}$. Taking account of the $S_I \sim I_F^2$ dependence, one would expect the noise spectral density to vary with $1/A$ if the area component dominates the $1/f$ noise.[23] From this, we conclude that there is a significant contribution from the peripheral current component (surface or interface state com-

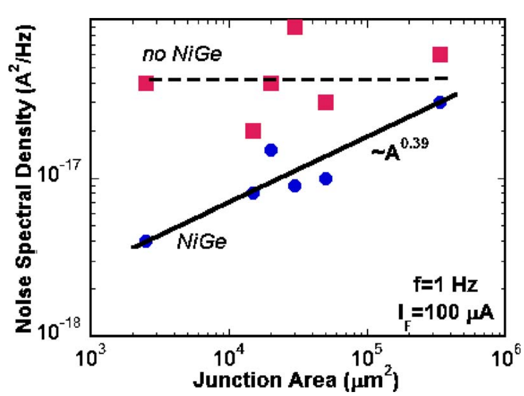


FIG. 4. (Color online) $S_I$ at 1 Hz and 100 $\mu$A for the germanided and nongermanided $p^+$-$n$ junctions vs area.

ponent) to the $1/f$ noise in the germanided Ge $p^{+}$-$n$ diodes. This comes as no surprise, given the high density of interface traps typically measured at the dielectric/Ge interface.

On the other hand, there is no straightforward area dependence for the nongermanided junctions in Fig. 4. This strongly suggests that the $1/f$ noise is dominated by fluctuations in the series resistance.[18,24]

In summary, it can be stated that the application of nickel-germanide Ohmic contacts not only lowers the series resistance of a Ge $p^{+}$-$n$ junction but also improves markedly the $1/f$ noise. In germanided samples, the $1/f$ noise is shown to be governed by defect-assisted GR events in the junction peripheral region.

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