

A Combined UHV-CVD and Rapid Thermal Diffusion Process for SiGe Esaki Diodes by Ultra Shallow Junction Formation

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High performance SiGe tunnel diodes have recently been demonstrated by Molecular Beam Epitaxy [1,2]. The role of the Ge is to increase the current density via reduction of the band gap and electron effective mass. In this paper we show that SiGe Esaki diodes can be fabricated by ultra-high vacuum chemical vapor deposition (UHV-CVD), which opens a new possibility for the integration of the diodes into VLSI-circuits.

The epitaxial growth was carried out in an UHV-CVD hot wall reactor, with a base pressure of 1.2×10^{-8} mbar. Silane (SiH_4), germane (GeH_4 , 10% diluted in H_2), and diborane (B_2H_6) were used as material sources. The structures were grown on 100 mm B-doped ($\rho = 0.0008$ - $0.0012 \Omega\text{cm}$) Si (100) wafers. Prior to growth, the wafers were cleaned in 3:1 $\text{H}_2\text{SO}_4/\text{H}_2\text{O}_2$ mixture and then etched in 5% HF solution for 1 minute to remove the native oxide and to hydrogen passivate the surface. The wafers were loaded at 450°C and an (<10 nm) undoped silicon buffer layer was grown while ramping the reactor temperature from 450 to 620°C . All the additional layers were grown at 620°C . The chemical composition and the thickness of the Ge layer were determined from secondary ion mass spectrometer (SIMS) measurements.

Generally, UHV-CVD produces sharp heterostructure interfaces, high B-doping levels and abrupt doping profiles, which are crucial for the Esaki diodes. However, it is well known that it is troublesome to realize high P-doping with this method due to memory effects in the reactor and surface poisoning. For the n-type doping, we have instead employed a post-growth proximity, rapid-thermal-diffusion process based on a spin-on doping source [3, 4]. The combination of these techniques provides a new way to realize SiGe Esaki diodes.

The design of the diodes employ a 25-nm-thick $\text{i-Si}_{0.7}\text{Ge}_{0.3}$ layer capped with 10 nm i-Si grown on top of the B-doped substrate, as shown in the inset of Figure 1. The ultra shallow junction is formed via proximity diffusion of P in a rapid thermal process using a spin-on dopant source. In Figure 1 we compare data for diodes diffused under various conditions, including diodes where we etched off the top Si cap layer with a selective etch (1 $\text{NH}_4\text{OH} : 2 \text{H}_2\text{O}$). Tunnel diodes with a maximum current density of 167 A/cm^2 and a peak-to-valley current ratio about 1.6 were fabricated upon diffusion at 900°C after etching the top Si cap. Diffusion at 900°C in the non-etched structure resulted in tunnel diodes with a substantially lower peak current (about 2.4 A/cm^2) with a peak-to-valley current ratio of 1.3.

Tunnel diodes require: (a) degenerate doping levels, (b) steep doping profiles and, in the case of SiGe diodes, (c), a matching of the location of the junction with the SiGe layer. In Figure 2 we show calculated band structures where the slope or the position of the n-type (P) doping profile has been altered. A precise control of the junction is required to reduce the tunneling distance and increase the current density. A fine-tuning of the process parameters should lead to a substantial increase in the measured current density of the tunneling devices.

References:

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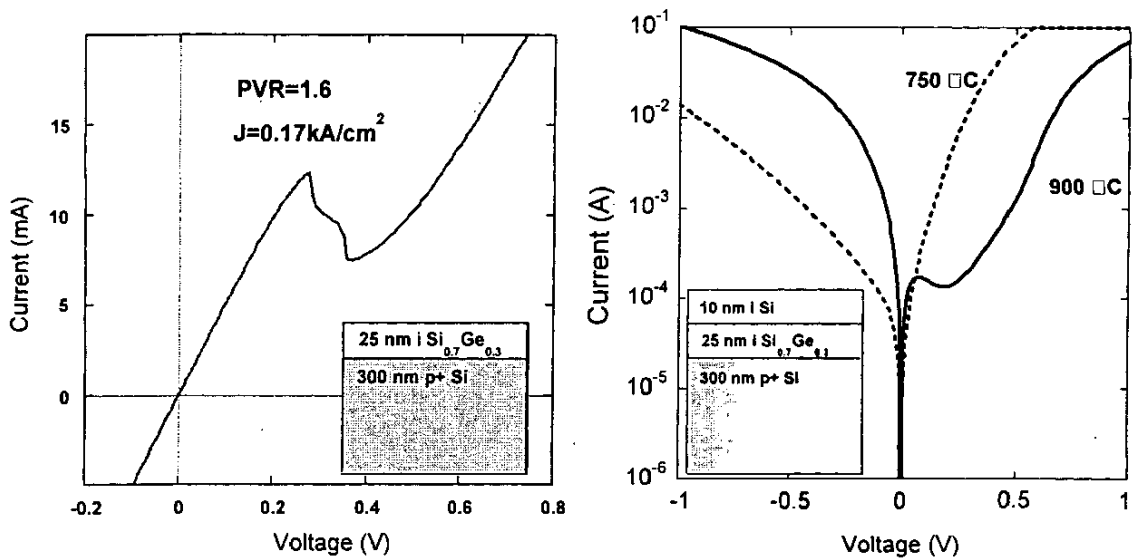


Figure 1 Measured I-V characteristics of diodes processed under varying conditions with operating devices diffused at 900°C. The inset shows the heterostructure after rapid thermal diffusion of P at 900°C for 1s. In one case the Si cap layer was removed by selective etching prior to the P diffusion; in the other the Si cap was not removed prior to the diffusion. A diffusion at 750 °C for 1 s results in a thermionic characteristics (dashed line).

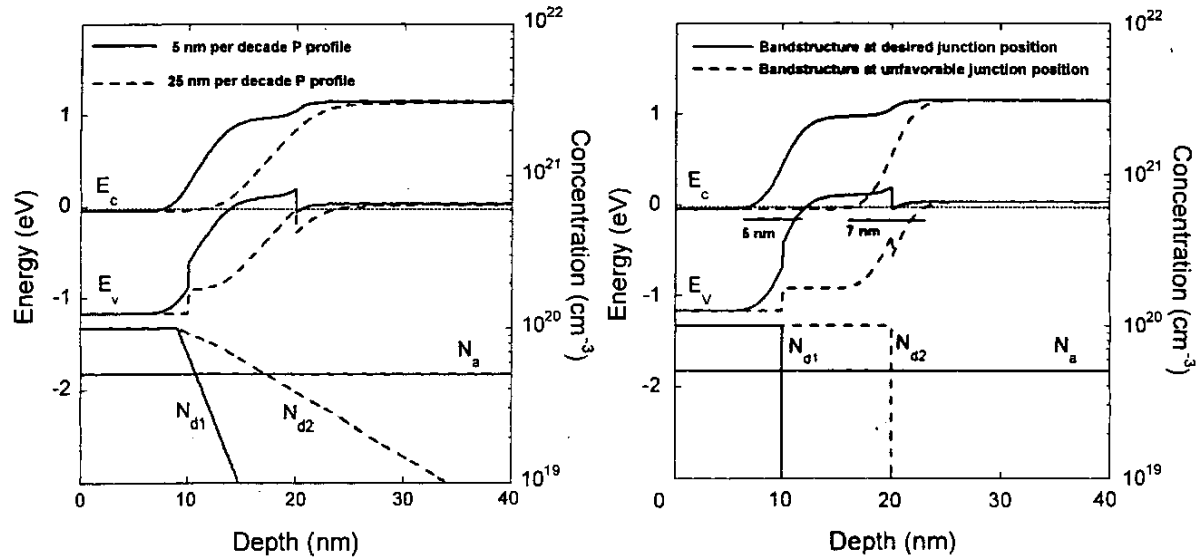


Figure 2 Calculated band structure for SiGe Esaki diodes showing a strong dependence on the doping profile (a) and the position (b). An increase of the doping slope from 5 nm per decade to 20 nm per decade increases the estimated tunneling distance from 6 nm to 12 nm. If an abrupt junction is formed at the lower SiGe interface a tunneling distance of 7 nm is calculated whereas the corresponding value at the upper SiGe layer is only 5 nm. The position and the slopes at the junction are thus critical parameters to control.