Analysis of phonon assistance as a function of temperature in inter-band tunneling in 2D Si lateral Esaki diodes

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Introduction

Inter-band tunneling in Si is a key phenomenon for high-speed applications, such as tunnel field-effect transistors (TFETs) [1,2] and Esaki diodes [3,4]. Although Si is advantageous as a CMOS-compatible material, its indirect bandgap and phonon assistance limit the tunneling current. As device dimensions are scaled down, however, phonon assistance may significantly change. Here, we report a study of temperature dependence of 2D lateral Si Esaki diodes that reveals the impact of 2D quantization on phonon assistance.

Negative differential resistance at low *T*

Figure 1 shows the I_p-V_p characteristics (*n*-side grounded) of lateral highly-doped *pn* tunnel diodes fabricated in a thin (t_{Si}≈9.0 nm) silicon-on-insulator layer [5]. Negative differential resistance (NDR) is clearly seen as a signature of inter-band tunneling [as illustrated for explanation in Fig. 2(a)]. Insets on the right in Fig. 1 zoom in at low biases, showing also conductance, to identify fine features (humps or inflections).

These features can be ascribed to transport via 2D-quantized levels [6]. This significantly affects the behavior of phonon assistance in transport. At low *T* (5.5 K) [(a)], mainly phonon emission events (or non-phonon events) contribute to transport [5]. However, at higher *T*, phonon absorption plays an increasing role and the number of features increases, as well [(b)].

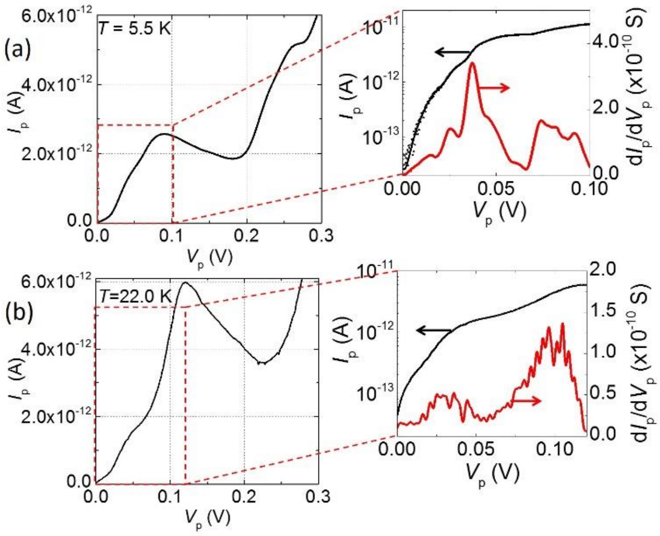

Fig. 1. Lateral 2D-Si (t_{Si}≈9 nm) Esaki diodes in forward bias, with zoom-ins at low biases (I_p and dI_p/dV_p) at different temperatures (*T*): (a) 5.5 K; (b) 22.0 K. Number of fine features increases with *T*.

Evolution with temperature

Figure 2 shows schematically the band diagram for forward-bias, mainly with non-phonon (NP) assistance. Phonon assistance, shown in Fig. 2(b), leads to downward and upward offsets in measured energy spectra.

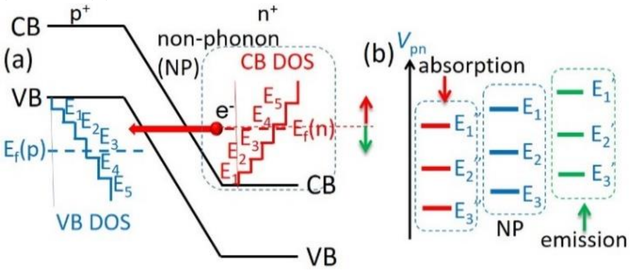

Fig. 2. (a) Band diagram for forward low-bias regime, emphasized to include 2D DOS quantization and (b) phonon offsets (caused by phonon emission at low *T*, but also by absorption, at higher *T*).

As *T* is further increased up to room temperature, these effects and regular *pn* diode behavior become more prominent and the characteristics evolve as shown in Fig. 3. An analysis of this dependence will be presented to clarify phonon assistance in inter-band tunneling up to elevated temperatures.

This analysis can open new possibilities for manipulation of phonons in low-dimensional structures for practical purposes.

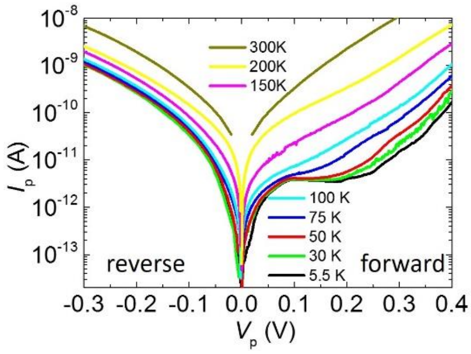

Fig. 3. Temperature dependence in forward and reverse-bias regimes, up to room temperature, showing the evolution of tunneling behavior.

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