Fano Resonance in Ultra-Thin Body Double-Gate MOSFETs

P. B. Vyas†, M. L. Van de Put*, M. V. Fischetti*

† *Department of Electrical Engineering,* **Department of Materials Science and Engineering*

The University of Texas at Dallas, 800 W. Campbell Rd., Richardson, TX 75080, USA

pbv130130@utdallas.edu

We report the numerical prediction of the Fano interference [1] phenomenon in ultra-thin body (UTB) double-gate (DG) MOSFETs. Fano interference has previously been reported in quantum waveguides [2] and coupled quantum dot systems [3]. Therefore, our observation of this purely quantum phenomenon in a realistic CMOS device structure presents a novel and intriguing case. Antiresonance is seen in the transmission spectra of electrons injected ballistically into the device at the energies of the quasi-bound states in the channel.

The device structure is shown in Fig. 1. Ballistic electron-transport in the device is simulated by solving the Schrödinger and Poisson equations self-consistently [4] in the two-dimensional plane of the device using the effective mass approximation. We follow the popular Quantum Transmitting Boundary method [5] to enforce *open* boundary conditions. Our self-consistent scheme bears resemblance to the method proposed by Fischetti [6].

Figures 2(a) and 2(b) show the transmission coefficient and local density-of-states (LDOS) in the simulated device. The LDOS distribution highlights the presence of quasi-bound states in the channel, while sharp dips of the transmission-coefficient plot indicate the occurrence of antiresonance at these bound-state energies. At a sufficiently high gate bias, the simulated current-density distribution in the device (Fig. 5(a)) shows the presence of channel inversion. At resonating frequencies, destructive interference between electrons traveling through the two coupled inverted channels causes the antiresonance 'dips' to appear in the transmission spectra. In the presence of this Fano interference, vortices are seen in the overall current density (Fig. 5(b)) at cryogenic temperatures. Moreover, when asymmetry is introduced by applying an unequal gate bias in this case, the transmission dips broaden (Fig. 3) and vortices in the current appear even at room temperature (Fig. 5(c)). We thus conjecture that, under the right conditions, the phenomenon can be observed experimentally. Finally, we will investigate if the antiresonance persists in the presence of electron-phonon scattering, modeled by incorporating the solution of Pauli's master equation into our self-consistent scheme.

[1] U. Fano, Phys. Rev. **124**, 1866 (1961).
[2] W. Porod *et al*., Phys. Rev. B **48**, 8495 (1993).
[3] K. Kobayashi *et al*., Phys. Rev. B **70**, 035319 (2004).
[4] P. B. Vyas *et al*., 2018 SISPAD, 1 (2018).
[5] C. S. Lent and D. J. Kirkner, J. Appl. Phys. **67**, 6353 (1990).
[6] M. V. Fischetti, J. Appl. Phys. **83**, 270 (1998).

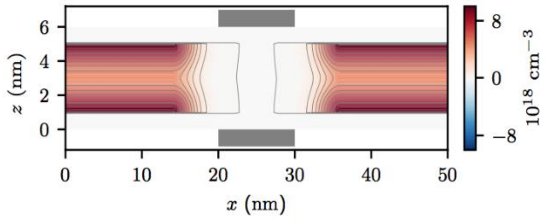

Fig. 1: Doping profile of 10 nm *UTB DG nMOS. The white region and the grey patches at the top and bottom represent the 1 nm thick gate oxide and gate terminals, respectively.*

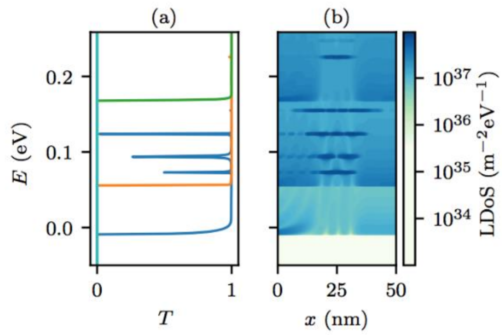

Fig. 2: (a) Transmission coefficient (T) vs. injection energy (E), (b) LDOS averaged over device thickness. The darker regions correspond to the quasi-bound states.

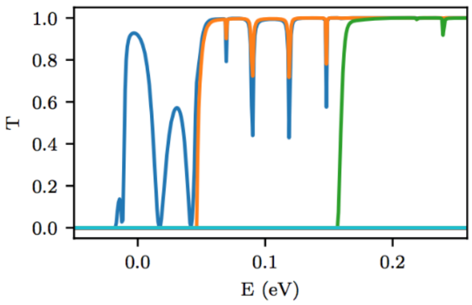

Fig. 3: Antiresonance features in the transmission spectra broaden in the presence of an asymmetric gate bias. The potential difference between the gates is 0.4 V.

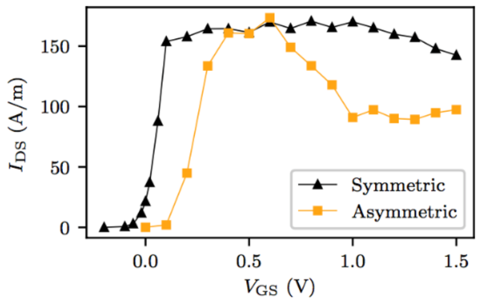

Fig. 4: Transfer characteristics of the device with equal (symmetric) and unequal (asymmetric) gate biases applied. Potential difference between gates is 0.4 V *for the latter case.*

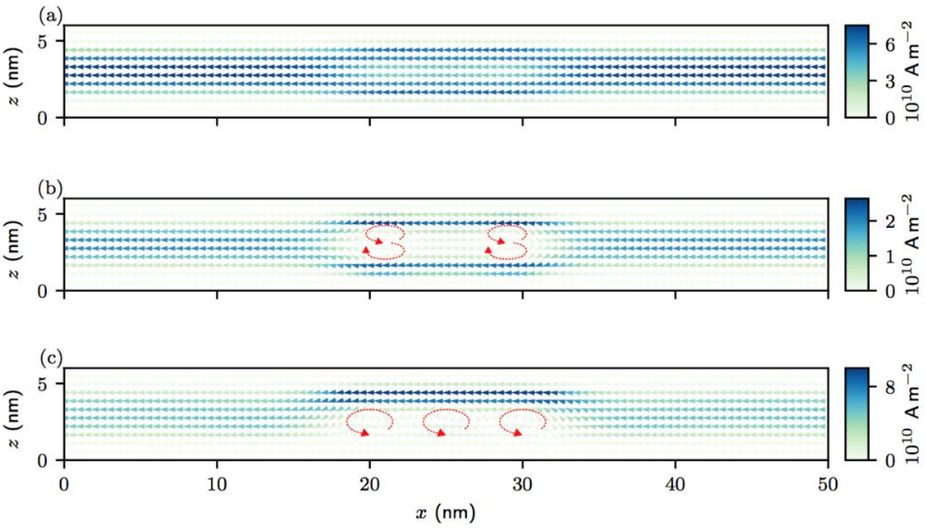

Fig. 5: Current-density distribution in (a) device with symmetric gate bias at 300 K*, (b) device with symmetric gate bias at 10* K*, and (c) device with asymmetric gate bias at 300* K*. The red arrows highlight the direction of vortices in the current density.* V_{DS}=10 mV.