Eliminating Quantum Uncertainty in Quantum Electron Devices: Leveraging Classical and Quantum Computing

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Today, there is a lively debate in the scientific community on whether quantum computing will offer better capabilities in the coming future compared to the existing classical computing. While some corporations and research centres are advocating the enormous potential of quantum computing, others are trying to push the limits of the classical computing strategies to its apex. Nowadays, classical and quantum computations are performed using quantum devices following three main steps: initial preparation of the quantum state, unitary evolution of the state and the final measurement of the state. The last step implies quantum uncertainties in outputs - due to the so-called wave function reduction - that causes inconveniences to the device engineers due to the undesired quantum noise [1] at the device output. This quantum noise can only be eliminated when the final state is an eigenstate of the observable of interest. In this conference, we will present a new protocol which ensures that the final state of a quantum device is an eigenstate of the current operator eradicating the quantum uncertainty in the practical implementation of the last measurement step for either classical or quantum computing. For a single electron, the measured current has an unavoidable quantum uncertainty. However, due to central limit theorem, when the number of electrons in the device becomes very large, the measured current due to all electrons (normalized to the number of electrons) approaches a single eigenvalue, without quantum uncertainty. Thus, the physical implementation of our protocol just requires increasing the number of involved electrons and normalizing the current. Its final success, however, requires that electrons behave as non-interacting quasi-particles [2]. Practical examples of the advantages of this protocol for classical (with resonant tunnelling diode (RTD)) and quantum (Mach-Zehnder interferometer (MZI)) computing will be discussed. In Fig. 1, we test how the effective number of particles required to ensure an acceptable low level of quantum noise depends on several device properties of a RTD (like transmission coefficient, doping, temperature, etc.). Similar arguments can be used in the context of current computation in a quantum computing device such as the MZI [3] (Fig. 2). In Fig. 3(a), the computation of the electrical current for a varying magnetic field is plotted which leads to Aharonov-Bohm oscillations in the device, which is a clear-cut signature of quantum interferences [3]. In Fig. 3(b), we plot the instantaneous current for different injection times (which is inversely proportional to the number of particles): the lower number of electrons, the noisier the device. In summary, we show the utility of a new protocol for device engineers, to minimize quantum uncertainty at the outputs of classical or quantum computing devices, at the price of involving a large number of transport electrons.

[1] X. Oriols et al, PRL **98**, 066803 (2007); D. Marian et al, PRL **116**, 110404 (2016)
[2] D.Pandey et al, *arXiv preprint arXiv:1812.10257* (2018)
[3] L Bellentani et al, Phys. Rev. B **97**, 205419 (2018)

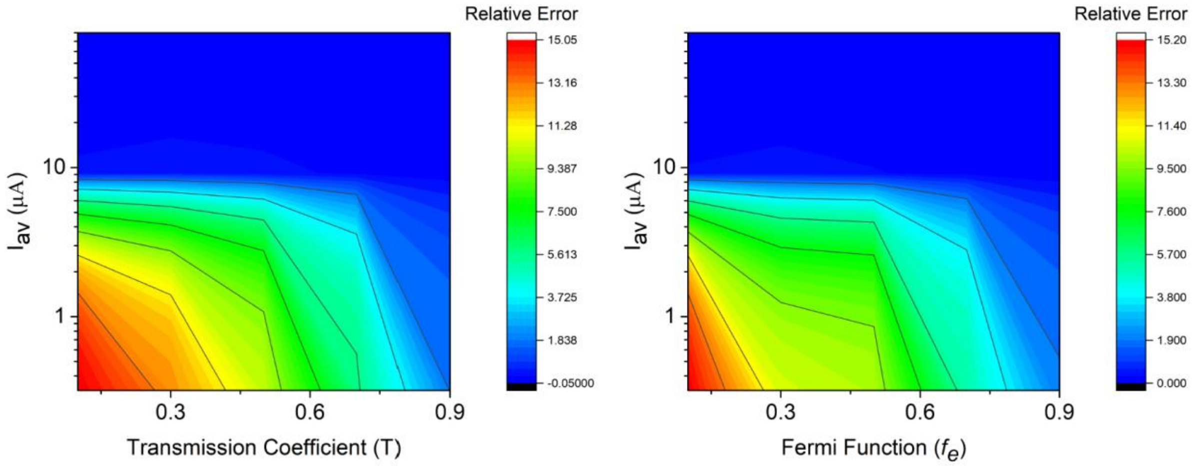

Figure.1 Plot of the relative noise in a Resonant tunneling device associated to the current with respect to the device transmission coefficient, temperature, doping and the electron saturation velocity. Figure (a) is plotted at a constant temperature while figure (b) is plotted with a constant transmission coefficient. As indicated in the text, the device with less electrons (pertaining to the low transmission coefficient, low fermi energy and low average current) is noisier.

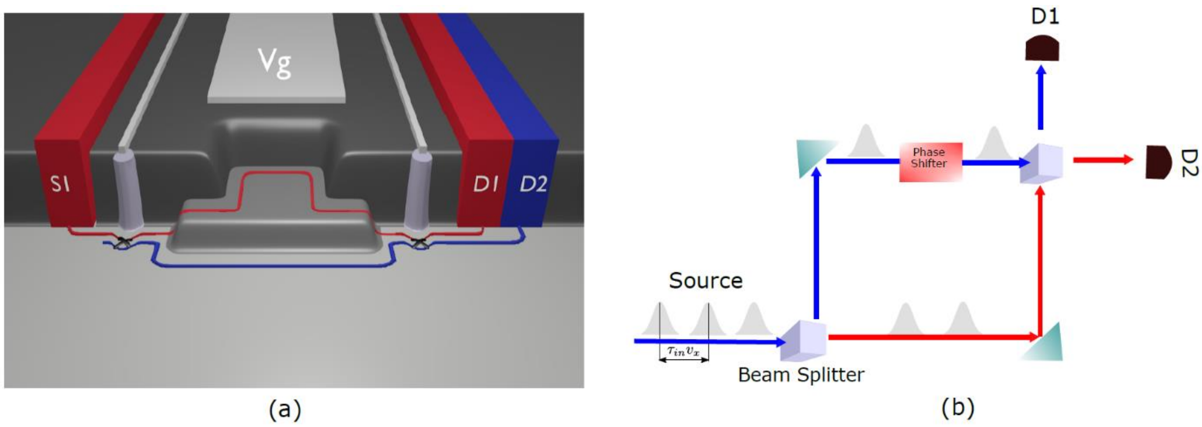

Figure.2 (a) 3D-view of the potential landscape generated by top gates in a realistic Mach-Zehnder interferometer. (b) Figure describing schematic of the device with the blue and red solid lines representing the different paths where the electrons are partitioned because of the beam splitter. The phase shifter is responsible for the interference of the wavepacket and the Aharonov-Bohm oscillations in Fig 3b.

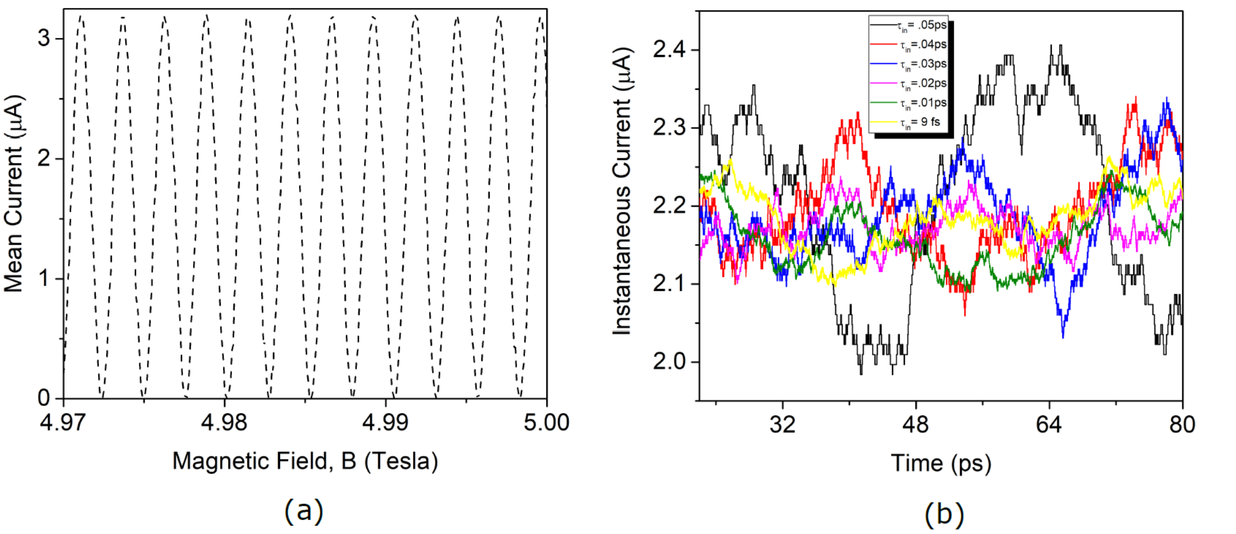

Figure.3 (a) The Aharonov-Bohm Oscillations of the mean current resulting due to the interference of the wavepackets at the output of the Detector 2 oscillating between the maximum and minimum limit of the mean current. (b) The normalized instantaneous current at the output of the detector 2 of the Mach-Zehnder interferometer with respect to the simulation time for a magnetic field of 1 T. The injection time varies from 9 fs to .05 ps which has an inverse correspondence to the number of electrons in the device. The plots are normalized in terms of the minimum current obtained. As expected, the noise in the current reduces with the increase in the number of transport electrons due to the elimination of quantum uncertainty demonstrating the successful implementation of the protocol discussed in the text.