Linking Wigner Function Negativity to Quantum Coherence in a Nanowire

Mauro Ballicchia[1,2], David K. Ferry[3], Mihail Nedjalkov[2], Josef Weinbub[4]

[1]*Department of Information Engineering, Università Politecnica delle Marche, Italy*

[2]*Institute for Microelectronics, TU Wien, Austria*

[3]*School of Electrical, Computer, and Energy Engineering, Arizona State University, USA*

[4]*Christian Doppler Laboratory for High Performance TCAD at the Institute for Microelectronics, TU Wien, Austria*

josef.weinbub@tuwien.ac.at

Quantum information and quantum communication are both strongly based on concepts of quantum superposition and entanglement. Entanglement allows distinct bodies, that share a common origin or that have interacted in the past, to continue to be described by the same wave function until evolution is coherent. When two bodies interact in a quantum manner, they become entangled, which implies that they are now described by a single wave function and are no longer two distinct bodies. Even after they have ceased to interact and have moved some distance away, they remain entangled until some decoherence process acts upon them [1,2]. So, there is an equivalence between coherence and entanglement. However, in experiments, one must face the fact that entanglement is difficult to measure. There is no physical variable whose Eigenvalue yields the entanglement. Hence, researchers have investigated for years to devise measures of entanglement [3]. Most of these, however, do not provide a clear visualization of the entanglement. But, it has been demonstrated that the Wigner function does provide a clear visualization of entanglement [1], and is used intensely today in optics [2]. Expanding upon this notion (and based on a recently formulated Wigner coherence theory [4]), we discuss the relation between quantum coherence and quantum interference and the negative parts of the Wigner quasi-distribution, using the Wigner signed-particle formulation [5]. A straightforward physical problem consisting of electrons in a nanowire interacting with the potential of a repulsive dopant placed in the center of it creates a quasi-two-slit electron system that separates the wave function into two entangled branches, as indicated in Fig. 1. The analysis of the Wigner quasi-distribution establishes that its negative part, Fig. 2, is principally concentrated in the region behind the dopant between the two entangled branches, maintaining the coherence between them. Moreover, quantum interference is shown in this region both in the negative and in the positive part, shown in Fig. 3. Fig. 4 (using a rotated viewpoint) illustrates how this effect is produced by the superposition of Wigner functions evaluated at points of the momentum space that are symmetric with respect to the initial momentum of the injected electrons. This shows that a Wigner signed-particle approach enables to analyze coherence and entanglement in nanoelectronics devices as it allows to directly reconstruct the Wigner quasi-distribution.

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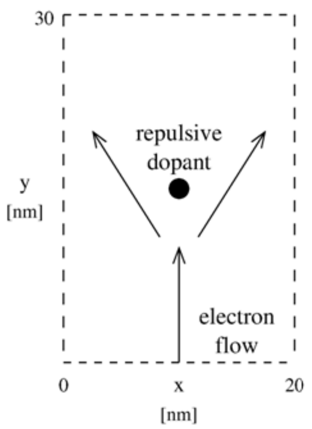

Fig.1: Experimental setup.

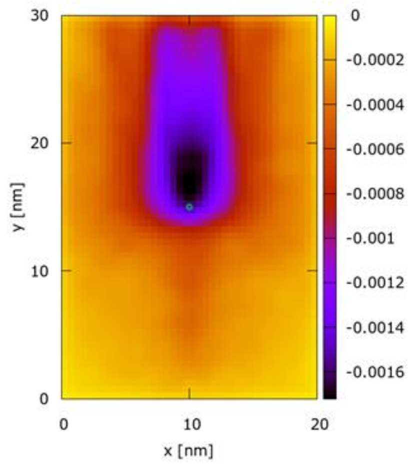

Fig.2: Spatial distribution of the negative part of the Wigner distribution.

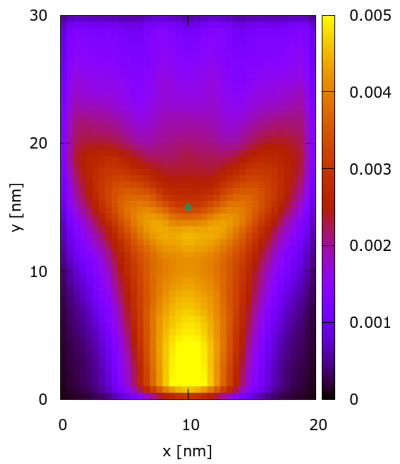

Fig.3: Spatial distribution of the positive part of the Wigner distribution.

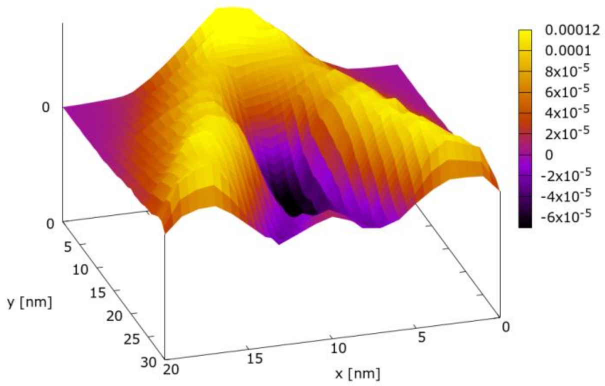

Fig.4 Sum of the Wigner quasi-distribution in the points (k_{x1}, k_{y1}) = $(0.26\ nm^{-1}, 0.89\ nm^{-1})$ and (k_{x2}, k_{y2}).= $(-0.26\ nm^{-1}, 0.89\ nm^{-1})$.