Concurrent effects of Pauli and Coulomb interactions in resonant tunneling diodes at low bias and low temperature

Giuseppe Iannaccone
Dipartimento di Ingegneria dell’Informazione: Elettronica, Informatica, Telecomunicazioni, Università di Pisa

Massimo Macucci
Dipartimento di Ingegneria dell’Informazione: Elettronica, Informatica, Telecomunicazioni, Università di Pisa

Giovanni Basso
Dipartimento di Ingegneria dell’Informazione: Elettronica, Informatica, Telecomunicazioni, Università di Pisa

Bruno Pellegrini
Dipartimento di Ingegneria dell’Informazione: Elettronica, Informatica, Telecomunicazioni, Università di Pisa

Proceedings of the
17th International Conference

Noise and Fluctuations

August 18-22 2003,
Charles University Conference Centre
Prague, Czech Republic

ICNF 2003
PRAGUE

Editor

Josef Sikula
Czech Noise Research Laboratory
Brno University of Technology
CONCURRENT EFFECTS OF PAULI AND COULOMB INTERACTION IN RESONANT TUNNELING DIODES AT LOW BIAS AND LOW TEMPERATURE

G. IANNACCONE*, M. MACUCCI, G. BASSO, B. PELLEGRINI

Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Pisa,
Via Diistretto, 2 I-56122 Pisa, Italy
*E-mail: gianuomuccaci@et.unipi.it

In this talk we present a model for the physical simulation of noise in resonant tunneling diodes, based on the self-consistent solution of the Poisson-Schrödinger equation in one dimension. We focus on suppression of shot noise at low bias, as a concurrent effect of Pauli exclusion and Coulomb interaction, and show that such effect may be observable even at 77 K in a thin barrier AlGaAs-GaAs resonant tunneling diode, that we are presently investigating also from the experimental point of view.

1. Introduction

Deviations of the power spectral density of shot noise with respect to the value associated to a Poisson process have been investigated in several device structures and operating conditions. Such deviations are extremely interesting, since they are in most cases due to electron-electron interaction, of which they can represent a very sensitive probe.

Electrons typically interact through the electrostatic force and through Pauli exclusion, which tend to broaden the distribution of electrons in the phase space. Depending on the device structure and on the operating conditions, such interactions may alter the statistical properties of current fluctuations with respect to the case of non interacting electrons, in a way that is intimately related to the microscopic transport mechanisms.

When electrons are non-interacting, the transport process is Poissonian, and the power spectral density of the noise current is $S_{\text{shot}} = 4qI$, where $q$ is the electron charge, and $I$ is the DC current through the device. The Fano factor, defined as the ratio of the power spectral density of the noise current to $S_{\text{shot}}$, is the most used parameter for measuring the deviations with respect to a Poisson process. A broad review of many cases observed in the last ten years of noise literature can be found in Ref. [1].

In this talk, we want to describe the concurrent effects of Coulomb and Pauli interactions in a resonant tunneling diode at low bias and low temperature. The effect has been first predicted in Ref. [2], and has been studied from the analytical point of view in Ref. [3], but has not yet been observed in experiments, given the very low bias current and associated low differential conductance. Here, we consider a device with much thinner barriers with respect to those considered in Ref. [2], in order to verify whether the effect is still present in a device with higher differential conductance at low bias, and therefore easier to characterize at those regimes.

2. Model and Discussion

In order to investigate from a quantitative point of view such effects, we have developed a self-consistent 1D Poisson-Schrödinger solver which allows us to simulate DC and noise properties of resonant tunneling diodes. We shall refer to a particular structure, that we are presently investigating from the experimental point of view: it is an AlGaAs-GaAs double...
The model and the derivation of (1) is described in detail in Refs. [4] and [5] and will not be repeated here. The theoretical J-V characteristics are shown in Fig. 2 at 77 and 300 K.

![Figure 2](image)

Fig. 2. Theoretical J-V characteristic of the resonant tunnelling, obtained with the 1D PS solver, at the temperature of 300 K and 77 K.

It is worth noticing that already at 77 K, the noise suppression factor, i.e. the ratio of the power spectral density of the noise current to \( S_{\text{fluct}} \), plotted as a function of the applied voltage in Fig. 3, exhibits a shallow peak of a few percent.

![Figure 3](image)

Fig. 3. Theoretical current density and noise suppression factor as a function of the applied voltage at 77 K.

Such a peak has been associated [2] to the transition between a regime in which Pauli exclusion dominates electron-electron interaction (on the left of the peak), to a regime in which Coulomb repulsion dominates electron-electron interaction (on the right of the peak). This effect has never been observed experimentally, and was predicted at much lower temperatures, close to 4.2 K. It is worth noticing (see Fig. 3) that the peak occurs for a current density of \( 10 \text{ } \text{A/m}^2 \), which corresponds, for a typical device with area 1 \( \mu \text{m}^2 \), to a current of 1-10 nA, and a resistance of 100 MD-1 GΩ, which can be character-
ized with very low noise measurement setup [6]. Work is presently in progress to observe this effect experimentally.

Acknowledgments

This work has been supported by the EU through the project NANO-CAD (IST-1999-10828).

References


1. Introduction

Low frequency noise, LFN, measurements in MOSFETs have been extensively used to extracting some of the devices characteristics, in particular the density, $N_s$, of electrical active defects located in the vicinity of the channel/gate dielectric interface. The carrier number component of the $1/f$ noise is usually significant for that purpose [1-3]. The accuracy and reliability of that procedure has significantly improved, first, thanks to the progress in the measuring techniques (cf. e.g. [4,5] and references therein), and, secondly, because the device miniaturisation entails an increase in the LFN level.

We discuss, emphasizing the problems remaining to be solved, some LFN results obtained on three groups of advanced MOSFET devices, (1) thin gate oxide insulated MOSFETs; (2) High-$	ext{f}_	ext{ox}$ (HfO$_2$) MOSFETs; and (3) buried SiGe channel, oxic MOSFETs. We use the same technique for their LFN characterisation, that of the power spectral density, PSD, measurements in an extensive current range and the analysis [4] based on the McWhorter’s approach [1]. All the data were taken with a new programmable point probe noise measuring system, 3PNMS [5].

2. Thin Gate Oxide Dielectric MOSFETs

For the gate oxide thinner than 20Å the gate tunneling currents reduce the precision of charge pumping, CP, technique and the LFN methods have become increasingly attractive for the determination of $N_s$. In standard MOSFETs the LFN method has been shown to give much lower $N_s$ values [6] than does the CP technique. We have examined this issue using a lot of thin-gate transistors fabricated at the LETI/CEA-DTS in Grenoble [7]. Figure 1 shows typical data obtained on a device with 25Å-thick gate oxide (multiple runs). The solid line presents the results of the calculation based on...