

Chapter 6

Conclusions and perspectives

Time brings truth to light

Aristotle

The most significant contribution of this thesis concerns the temperature dependence of the electron phase coherence time τ_ϕ in confined systems. We have observed a low-temperature saturation of τ_ϕ in each of our InGaAs open quantum dots, over a wide range of temperature. We could rule out any ‘extrinsic’ origin, related to the substrate material or the measurement system. We found that it is the dwell time that limits the measured phase coherence time, *i.e.* $\tau_\phi^{sat} = \tau_d$ (where τ_ϕ^{sat} is the saturated coherence time and τ_d is the dwell time). Electron interferences can only occur during the average time spent by electrons inside the quantum dot. The observed saturation is therefore directly related to the measurement method.

As a consequence, our work questions the experimental evidences for the existence of a low temperature intrinsic saturation of τ_ϕ in confined systems. The conclusion of our work implies that the saturation of the ‘true’, or intrinsic, coherence time has not been observed yet in any experiment on quantum dots, since we are able to explain all experimental reports of saturation of the coherence time in these systems, and the only available experiment on samples with a virtually infinite dwell time (*i.e.* closed dots) did not reveal any saturation of the intrinsic τ_ϕ .

Furthermore, it might be necessary to reconsider previous experimental reports of saturation of the coherence time in many other confined systems, such as quantum wires. Indeed, a dwell time can also be defined in such systems, but has never been taken into account in the extraction of τ_ϕ , as

far as we know. Therefore, our conclusions for quantum dots are likely to lead to a similar study in quantum wires (in particular short wires, with a small dwell time), for which many report of low temperature saturation of τ_ϕ have been published.

Our work also clears up the way for theoretical works. Previous experimental reports on quantum dots put constraints on a possible theory of the real saturation of τ_ϕ . As we could attribute previous observations in quantum dots to an intrinsic, but sample-specific origin, part of these constraints is lifted. Even though we do not bring the proof for the existence or nonexistence of an intrinsic saturation of τ_ϕ , our findings help to discriminate between experiments reporting a 'real' or 'artificial' - sample specific - saturation.

In addition, we provide new τ_ϕ vs T data for open quantum dots, in unexplored ranges of mean energy level spacings, number of modes, and materials parameters. In the temperature-dependent regime, we found that, in one sample, τ_ϕ vs T follows quantitatively the theoretical prediction for decoherence by electron-electron interactions in two-dimensional disordered systems. In the other samples, discrepancies were observed, that we attribute to the population of the second subband in the quantum well. However, theoretical work is needed to confirm the latter hypothesis.

In chapter 4, we study phase coherence and spin-orbit coupling in Bi films and in a single-crystal Bi cavity. We show that the cavity is quasi-ballistic and zero-dimensional for phase coherent processes. Our work therefore provides the first insight into the transport properties of this type of Bi systems. τ_ϕ in films is significantly larger than in the cavity, while the spin-orbit scattering time τ_{so} is similar in both systems. The reason for this difference remains to be investigated. A large unexplained discrepancy is also found between our τ_ϕ data and the prediction of the 2D Nyquist theory, although the temperature dependence ($\tau_\phi \propto T^{-1}$) is consistent with this model in the films and the dot.

Beside the questions over the origin of these discrepancies, our work on Bi samples raises a large number of interesting perspectives. In particular, we believe that the technique developed to obtain films with large crystallites can be further improved. Another substrate material could be used instead of SiO_2 , with a lattice parameter closer to that of bismuth. This could be combined with a slower deposition process at higher temperature, and a thermal treatment to align the crystallites along the same direction in the plane of the film (which would suppress the uncertainty over the crystal orientation in the cavity). This would allow to produce monocrystalline devices on thinner films, *e.g.* in the vicinity of the semimetal-semiconductor

transition. The influence of the lateral size of the cavity on the weak antilocalization effect is another interesting problem to study. As explained in chapter 1, weak antilocalization can be suppressed in GaAs quantum dots with a lateral size smaller than L_{so} . One can naturally wonder if a similar suppression would occur in the same conditions in a Bi sample. In view of the L_{so} values that we found, ballistic bismuth cavities with dimensions smaller than L_{so} are possible to fabricate using the process that we developed. Such a small cavity, with a small electron dwell time would also allow to test our explanation of the saturation of τ_ϕ .

In the last part of the thesis, we discuss the nonlinear transverse voltage-longitudinal current characteristics of ballistic cross junctions. We show that the conductances measured between the channels of the junctions are crucial to the understanding of the nonlinear behaviour. Reversals of the slope of the transverse voltage are observed in some cases, coinciding with a decrease of the longitudinal conductance. Furthermore, the sign and the amplitude of the nonlinear transverse voltage can be tuned by changing the conductances (or the width) of the branches in the junction. Theories based on an energy-dependent Landauer-Büttiker formalism or on energy-dependent collimation effects can not fully explain these observations. We suggest that Monte Carlo (MC) methods are better suited to study the behavior of our structures. MC simulations of our cross structures have recently been undertaken in the group of Profs. Javier Mateos and Tomas Gonzalez in Salamanca University. We hope that the result of these simulations will help to explain our data.

