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Report on the thesis
Design and computer simulations of the nanodevices to applications in quantum computing
by

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The thesis of **Paweł Szumniak** submitted in June 2013 to the AGH University in Cracow and University of Antwerp for the degree of Doctor of Philosophy in Physics consists of a short introduction, a summary of articles which form the thesis (together 15 pages), and a two pages long summary of the thesis. The main body of the dissertation consists of four research articles, published in years 2010-2013. One paper was published in Physical Review Letters, while two other appeared in Physical Review B.

The thesis deals with theoretical models of nanodevices which potentially could serve as building blocks of a solid state quantum computer architecture. Logical operations are proposed to be performed on a quantum bit formed by the spin of an electron (or a hole) confined in a semiconductor nanostructure. A quantum wave function describing the electron trapped in a quantum well forms a stable wave packet with a soliton-like properties, which can be controlled by applying small electric field.

Main part of the work consisted in solving numerically time-dependent Schrödinger equation in two dimensions for various model interaction Hamiltonians. The key results of the thesis include:

A) Detailed theoretical analysis of a single electron spin nanodevice based on the spin-orbit interaction and device capable to realize non-destructive single electron read-out without application of the magnetic field.

B) Designing a scheme of a quantum logic NOT gate acting on qubit encoded in a single heavy-hole.

C) Investigating a model of a universal nanodevice capable of realizing arbitrary sequences of single-qubit quantum gates, including Pauli X, Y and Z gates.

In all potential schemes of quantum information processing a key role is played by decoherence and possible interaction of the principal system with an environment. The author describes effects related to decoherence due to hyperfine Fermi interaction with nuclear spins of the host material and proposes to suppress the decoherence by encoding the qubit in a valence hole instead of the electron. This promising idea seems not to be thoroughly explored – for instance I have not found in the thesis an attempt to perform direct computations to estimate the decoherence time in the system modeled.

Some further issues which could be discussed include e.g. the dispersion of the quantum wave packet describing the electron in a quantum well. In other words a more detailed analysis of the assumed soliton-like properties of the wave packet corresponding to an electron (or a hole) would be welcome.

The main object of thesis was to design and simulate nanodevices capable to realize an arbitrary sequence of one-qubit logic operations without application of magnetic field. On one hand this aim is successfully achieved. On the other hand, to perform any useful quantum algorithm one needs to control several quantum bits, realize non-local two-qubit quantum gates and deal with quantum entanglement. In my opinion these important issues, crucial for further applications in experimental quantum computing, were not discussed in the thesis deeply enough.

The thesis are constructed according to the so-called 'new rules', which allow to collect together several multi-author articles and combine them to produce a Ph.D. thesis. Such a structure of the thesis is certainly more convenient to the author, who wrote only a concise introduction, an abstract and summary (and translated them into two other languages). However, such a choice does not encourage the author to compose himself the main body of the thesis and to present technical details of the work done, which could not be included into the articles published due to the usual lack of space. Furthermore, several repetitions, acceptable in two separate articles, (see e.g. Eqs. (1,2,3,4,5) in paper [1] and practically equivalent Eqs. (3,4,1,2,5) in paper [2], correspondingly; Figures 2 and 3 in paper [1] versus Figs. 2 and 3 in paper [2] – I appreciate here that the data and the axis labels are different!; Eqs. (1,2,7,8,13) in paper [3] and Eqs. (1,2,12,13) in paper [4]; analogous Figures 1 in paper [3] and paper [4], an so on), are not entirely suitable for a well composed thesis.

The thesis is accompanied with an ample of declarations of co-authors, who explicitly describe their role in producing the papers, which form the opus. However, just by looking for the complementary parts of the work required to complete each paper it is not simple to get a very clear picture of the role of the Ph.D. candidate in preparing each of the papers and the entire thesis. Furthermore, basing on the thesis refereed it is hardly possible to evaluate the author's ability to present results obtained in a written form – a skill indispensable for a successful academic career.

Provided my interpretation of the declaration of the co-authors is correct, practically all numerical results presented in the papers were obtained by Paweł Szumniak. It is therefore fair to say that the candidate has demonstrated a good knowledge of principles of quantum theory and an ability to perform complex numerical computations including numerical solutions of the time-dependent Schrödinger equation.

Results obtained in the articles published are nicely visualized in well prepared graphs and figures. A representative sample of bibliography provided at the end of the thesis shows that its author is familiar with the current literature on quantum information and recent advances in quantum control based on solid state physics.

Let me conclude this report stating explicitly that I do appreciate the scientific merit of the results presented, which may be regarded as a contribution to the theoretical analysis of solid state quantum information processing. Although some critical remarks have been made, I do believe, the thesis refereed meets all international standards for a Ph.D degree in physics. Hence I am pleased to recommend to proceed with further steps of the Ph.D procedure for Mr. **Paweł Szumniak.**

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