Optical Properties of Quantum-Dimensional Probes of Scanning Probe Microscopes

Theoretical approach

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Abstract—The main idea of a quantum computer is the use of a solid-state matrix with embedded array of quantum dots. Such quantum dots could theoretically be the tips of the probes of scanning probe microscopes. Here we consider some theoretical approaches in order to describe optical properties of the tip. First, we consider a tip as a box with infinitely high potential at the faces. Then, in the same way we consider cylindrical and cone shapes.

Keywords—quantum dot; optical properties; potential well; dipole moment

I. INTRODUCTION

One of the fundamental ideas of implementation of a quantum computer is engineering a solid-state matrix with embedded array of quantum dots. In order to properly process and storage information quantum dots are required to be of the same sizes and shapes. The tips of the probes of scanning probe microscopes could act as such quantum dots. Different ways to produce matrices of tips have been already proposed; see for instance [1]. Hypothetically one could produce single probes one by one. In this case quantum dots would emerge with unacceptably large dispersion of sizes as well as in the process of growing matrices. Thus, one should separate proper, of the same sizes and shapes, probes from undesirable ones. It could be made, for example, by utilizing optical properties of such quantum-dimensional structures. However, today scientific literature lacks theoretical considerations on optical properties of probe tips. This paper is aimed to fulfill this lack by considering several theoretical approaches to the real shape of the probe tip. First we consider a box model with infinitely high potential at the faces. Then in the same way we consider cylindrical and cone shapes.

II. GENERAL CONSIDERATIONS

In this paper we suggest a probe selection/adjusting method based on optical spectroscopy of the tips of the probes [2]. An experimental implementation and preliminary theoretical estimates for such spectroscopic study are given in [2]. Here we proceed with developing the theoretical model and bring it closer to practice. The idea of selecting probes is the following. Each probe is illuminated by a broadband beam of light and light scattered by the probe is detected. Information about optical transitions taking place in the tip of the probe is imprinted on the detected radiation. These transitions are expected to reflect the discrete nature of levels of the tip. The discrete nature is the consequence of small sizes of the tips, typically 20 nm and smaller. The situation is similar to physics of quantum wells in semiconductors. The tip represents exactly such a type of a potential well for electrons though not in a semiconductor but in a metal (tungsten in our case). Thus, the motion of electrons in this well is quantized. As a theoretical goal we need to find energies of electron transitions between the quantized levels and characterize strengths of these transitions, i.e. find corresponding dipole moments. Preliminary estimates show that tips of 10-20 nm exhibit strong transitions in the infrared band. Note also, that tips with sizes larger than 20 nm cannot be described as quantum wells, because the De Broglie length in metals is restricted by a value around 20 nm. Finally, the theory establishes a one-to-one correspondence between the spectrum of the radiation emitted (or absorbed) by the probe and its geometrical dimensions. Thus, we establish the way giving us information on the dimensions from the spectroscopic measurements. Our goal is to appropriately quantize the electron transitions in the tips of the probes. The better the theory, the more accurate calibration of probes can be made.

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REFERENCES

