Observation of quantum interference effect in solids

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In order to achieve quantum interference of free electrons inside a solid, we have modified the geometry of the solid so that de Broglie waves interfere destructively inside the solid. Quantum interference of de Broglie waves leads to a reduction in the density of possible quantum states of electrons inside the solid and increases the Fermi energy level. This effect was studied theoretically within the limit of the quantum theory of free electrons inside the metal. It has been shown that if a metal surface is modified with patterned indents, the Fermi energy level will increase and consequently the electron work function will decrease. This effect was studied experimentally in both Au and SiO_2 thin films of special geometry and structure. Work function reductions of 0.5 eV in Au films and 0.2 eV in SiO_2 films were observed. Comparative measurements of work function were made using the Kelvin probe method based on compensation of internal contact potential difference. Electron emission from the same thin films was studied by two independent research groups using photoelectron emission microscopy. © *2006 American Vacuum Society.*
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I. INTRODUCTION

The wave properties of electrons inside a solid are well known and understood. There are some nanoelectronic devices, such as resonant tunneling diodes and transistors, superlattices, quantum wells, and others, that are based on the wave properties of the electron.[1] Under certain conditions an electron in a solid can be regarded as a planar wave. The main requirement that should be satisfied is that at least one dimension of the solid should be equal to or less than the mean free path of the electron inside the solid. In this case, the electron can move without scattering and could be regarded as de Broglie wave. It is difficult to satisfy this requirement because the electron mean free path in most solids is in the range of 1–10 nm at room temperature. Transport properties of solids (current and heat transport) are defined by electrons having energies close to the Fermi level, and the mean free path is given for those electrons. Other free electrons inside solids, for example, electrons having energies below Fermi level in metals, do not participate in current and heat transport, because it is quantum mechanically forbidden for them to exchange energy with the environment (all quantum energy levels nearby are occupied), and hence the mean free path of such electrons is formally infinite. Such electrons will remain ballistic inside relatively large structures.[2] In this work we use wave properties of such electrons to change the electronic structure of a solid in the way that the work function of the solid could be reduced and regulated precisely. Such materials will find many applications in devices based on electron emission and electron tunneling,[3] and in semiconductor industry.

We assume a solid with the surface geometry as shown in Fig. 1(a) in which periodic indents are introduced in the flat surface of the solid. Let us consider an electron traveling towards the border of the solid as planar wave 1. Wave 1 will reflect back from the border of the solid because the electron does not have enough energy to leave the solid. Because of the geometry of the surface there will be two reflected waves. One will reflect from the top of the indent (wave 3) and the other will reflect from the bottom of the indent (wave 2). If the indent depth is one quarter of the de Broglie wavelength of the electron, waves 2 and 3 will interfere destructively and there will be no reflected wave. As a result, an electron of certain energy cannot reflect back from the surface because of its wave nature. On the other hand, the electron cannot leave the solid and enter the vacuum because it does not have enough energy to overcome the potential barrier. For obvious reasons, the electron cannot simply stop near the surface either.[3] From the quantum mechanical point of view, we can say that all possible final quantum states for that particular electron are forbidden. As all the final quan-

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