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Variability and Self-Average of Impurity-Limited Resistance in Quasi-One Dimensional Nanowires

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Abstract

The impurity-limited resistance in quasi-one dimensional (quasi-1D) nanowires is studied under the framework of the Lippmann-Schwinger scattering theory. The resistance of cylindrical nanowires is calculated theoretically under various spatial configurations of localized impurities with a simplified short-range scattering potential. Then, the relationship between the phase interference and the variability in the impurity-limited resistances is clarified. We show that there are two different and independent mechanisms leading to the variability in impurity-limited resistances; incoherent and phase-coherent randomization processes. The latter is closely related to the so-called "self-average" and its physical origin under nanowire structures is clarified. We point out that the ensemble average also comes into play in long channel nanowires, which leads to the self-average resistance of multiple impurities.

Keywords: nanowire, impurity scattering, variability, phase interference, self-average

1. Introduction

Si nanowires have been receiving great attention in the past few decades because of their possible application of future electronic and photonic devices [1, 2]. However, because of their small structures in size, the device performance often fluctuates over great ranges, depending on the configuration of localized impurities in the substrate [3, 4]. So far, theoretical studies on such variability observed in mobility or resistance of nanowires are limited with large-scale numerical simulations [5, 6, 7, 8, 9, 10]. It has been demonstrated that the transport properties indeed fluctuate in short channel nanowires. Clearly, the phase interference would be of crucial importance in understanding the physics behind such variability.

It should be noted that the phase interference also plays a dominant role in self-averaging the transport properties such as resistance in *long channel* devices, in which many impurities are distributed uniformly in the substrate. Many different configurations of impurities in the substrate allows us to use the space-average impurity scattering rates in calculating the mobility etc, although the precise impurity configuration is different for each device. This is often referred to as 'self-average" and the phase interference is deeply involved in its averaging mechanism [11]. Despite its importance, however, almost no attention has been paid so far on the interference effects among multiple impurities on transport properties under nanowire structures.

In the present paper, we study the interference effects associated with localized impurities on impurity-limited resistances in the quasi-1D nanowires. This is carried out based on the theory employed recently by the present author [12] and we clarify how and why the phase interference leads to the variability in the impurity-limited resistance. Then, the physical origin of "self-average" emerged under the fully coherent circumstances is clarified.

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