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Low temperature injected-caused charge carrier instability in n-type silicon below insulator-to-metal transition

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Abstract

We report on the electric transport properties of Si heavily doped with Sb at concentration just below the insulator-to-metal transition in the temperature range 1.9–3.0 K for current density $J < 0.2$ A cm^{-2}. The change in the sign of the temperature dependence of the differential resistivity $\mathcal{R}$ was observed: the $\mathrm{d}\mathcal{R}/\mathrm{d}T$ is positive if $J < 0.045$ A cm^{-2} whereas it becomes negative at $J > 0.045$ A cm^{-2}. The effect is explained assuming the exchange by electrons between the upper Hubbard band (UHB) and the conduction band. The obtained J dependencies of the activation energy, nonequilibrium concentration, mobility and scattering time of the conduction electrons correspond well to this hypothesis. The reason for charge instability is the Coulomb repulsion between electrons occupying states both in the UHB and conduction band. The estimated J dependencies of the conduction electrons lifetime and concentration of the D^- states in the UHB strongly supports this assumption.

Keywords: charge carrier instability, upper Hubbard band, delocalization, temperature coefficient of differential resistivity, correlated electron system

(Some figures may appear in colour only in the online journal)

1. Introduction

The physical mechanisms and effects associated with the manifestation of charge instability and an electronic Mott insulator-to-metal transition (IMT) in correlated electron systems are still the subject of intensive investigation [1–3]. The hallmark of the IMT is a change from the case of strong localization of charge carriers and the gap in the density of states (DOS) (insulating side of the IMT) to complete or partial delocalization and the disappearance of the gap (metallic side of the IMT). The reasons for this transition may be different and depend on the material and systems under investigation. Numerous studies are traditionally conducted on silicon doped with elements such as Co [4], S [5, 6], Ti [7, 8], Se [9], Bi [10, 11] and V [12]. These works mainly address the issues of obtaining hyperdoped silicon and physics of IMT research in it related to the creation of the intermediate band in the band gap of silicon.

Observation of the Mott insulator state in underdoped high temperature superconductors (HTSC) and transition to the superconducting state in optimally doped HTSC [13] expanded the class of materials that are inherent in the IMT. Nowadays, it is reliably established that the IMT is a characteristic feature of a granular and homogeneously disordered superconducting thin films [14], networks of superconducting nanowires [15], vortex systems [16], quantum spin liquids [17], layered perovskite oxides [18]. Various relevant drives can be applied to induce the IMT. Among them, it is worth

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