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Superconductivity of In/Mo narrow wires fabricated using focused Ga-ion beam

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HIGHLIGHTS

- Qquasi-1D In/Mo specimens on SiO/Si were fabricated by the FIB milling with Ga ions.
- The q-1D wire affected by Ga-ion irradiation showed superconductivity with $T_{c0} > 5$ K.
- The *R*–*T* data good agreement with thermal activation phase-slip model.

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ABSTRACT

By using a focused-ion-beam (FIB) method with Ga ions, we prepared quasi-one-dimensional (q-1D) In/Mo specimens with widths of ≈200 nm and ≈500 nm from two dimensional (2D) films deposited on a SiO_2/Si substrate. We observed the superconducting transition of q-1D In/Mo, whose transition temperature T_c is higher than $T_c \approx 3.6$ K of a 2D In/Mo specimen on a glass substrate. For specimens fabricated using the FIB method, the element distributions analyzed by energy dispersive x-ray spectroscopy reveal Ga invasion into the q-1D In/Mo region. The gradually changing resistance of q-1D In/Mo at temperatures below T_c can be well explained by the thermal activation phase-slip model with $T_c = 5.1$ K and coherence length $\xi(0) \approx 9.5$ nm.

1. Introduction

Low-dimensional superconductors have attracted widespread attention from the aspect of fundamental interest in the effects of nanostructures on superconductivity. In addition, the fabrication method is of interest because of its applications to nano-electronics [1]. Despite a few decades of continuous investigations of the superconducting characteristics of quasi-one dimensional (q-1D) systems at low temperatures, a full understanding is still elusive [2–4]. To prepare superconducting submicron devices, the focused-ion-beam (FIB) method has been adapted as a milling technique. There have been reports on the preparation of superconducting q-1D nanowires by FIB milling with Ga ions [5–7]. Furthermore, several groups have reported that this method can produce nanostructure superconductors by direct deposition of a precursor gas through an injection nozzle [8,9].

Regarding the transport properties of Ga, it is well-known that an amorphous Ga film prepared on a cooled substrate by a quenched condensation method exhibits superconductivity [10]. A film composed of fine Ga particles prepared by deposition by pouring onto glass shows also superconductivity. Regarding the effects of Ga on the superconductivity of normal conducting materials, Fiedler et al. reported that Ga-rich Si nano-layers fabricated by Ga implantation exhibit superconductivity below 7 K under optimized annealing conditions [11]. Similarly, it has been reported that nano-wires prepared from C–Ga–O or W–Ga–O by FIB direct deposition show superconductivity at $T_c \approx 3$ K or $T_c \approx 7$ K,

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respectively, although these elements do not show superconductivity at temperatures above ≈1.1 K in their pure forms [12,13]. When the FIB method is used to prepare superconducting nano-wires by milling with Ga ions, it has been reported that the introduction of Ga ions decreases T_c and causes microstructure damage in niobium films but increases T_c in lead films [5,6]. In any case, Ga ions play an important role in the appearance of superconductivity in normal materials and also change the characteristics of superconducting materials.

Various materials with different microstructures, such as

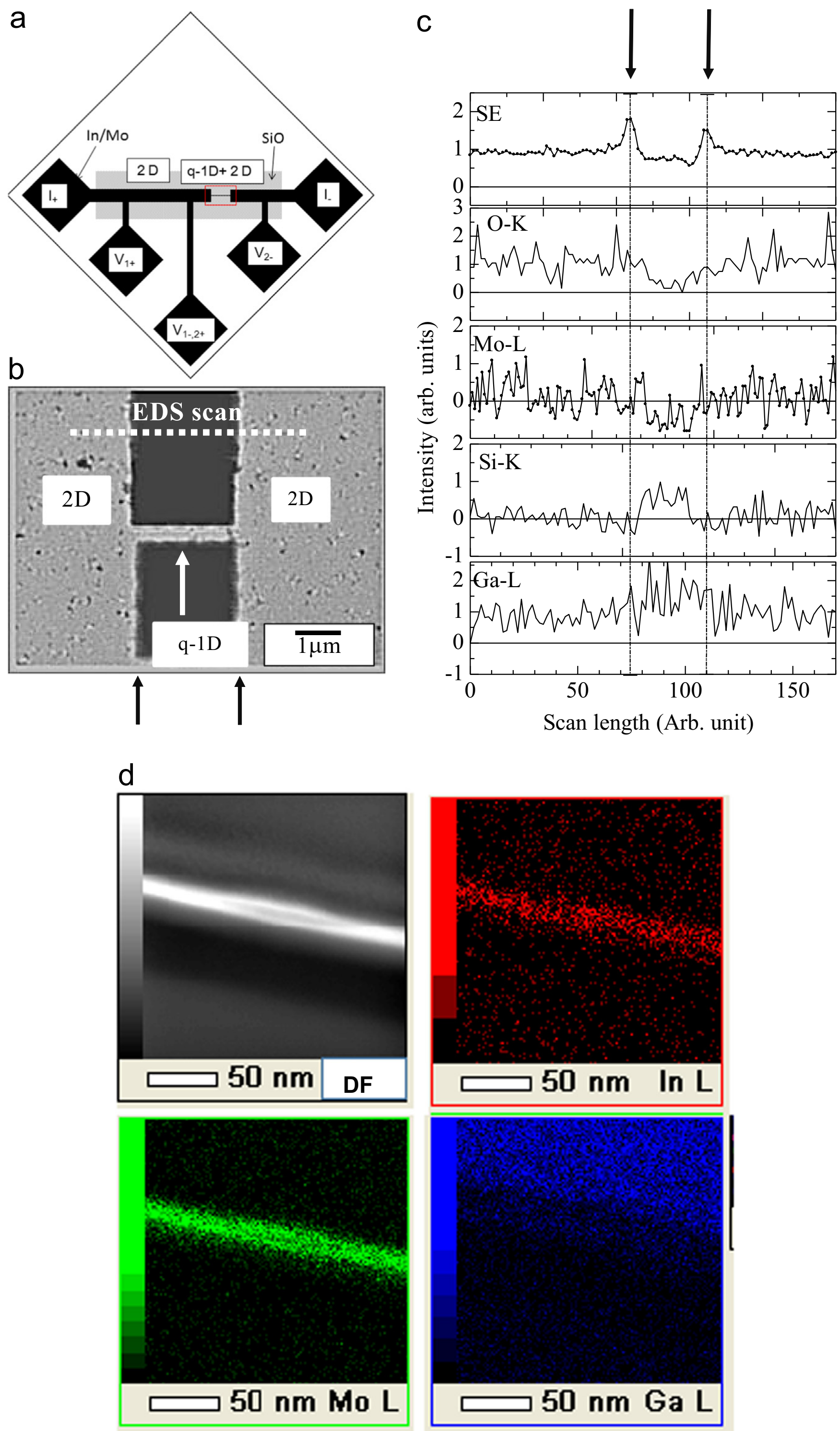

Fig. 1. (a) Geometry for transport measurements of In/Mo specimen with two terminals for current and three terminals for voltage. The gray area corresponds to the thin SiO film used to protect the surface of In/Mo from the Ga irradiation during FIB milling. The left and right sides are the 2D and q-1D+2D parts, respectively. Enclosed area in the latter is the q-1D region fabricated by the FIB milling. (b) Scanning-electron-microscopy image of the enclosed area in (a). The black area marked by two vertical arrows (↑) is the trench etched by FIB. (c) Profiles of some elements measured by electron dispersion spectroscopy (EDS) according to the dotted line in (b). Two vertical arrows (↓) correspond to the two sides of the trench in (b). Symbols denote the element (SE means secondary electron). Each horizontal dotted line shows the zero-signal level. (d) Scanning transmission microscopy (STEM) dark-field image of cross-section view for In/Mo wire (DF) and the STEM-EDS mapping of Indium (In L), Molybdenum (Mo L) and Gallium (Ga L) and for same area.