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Reduction of Electrical Resistance of Nanometer-Thick $CoSi_2$ Film on CaF_2 by Pseudomorphic Growth of CaF_2 on Si(111)

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1.9-nm-thick epitaxial metal ($CoSi_2$) films were grown on relaxed or pseudomorphic CaF_2/Si(111) and their electrical resistance was measured. It was found that the electrical resistance of the $CoSi_2$ film on pseudomorphic CaF_2 was about half of that on relaxed CaF_2. This result can be attributed to the improved of flatness and crystalline quality of the $CoSi_2$ by using of pseudomorphic CaF_2 instead of relaxed CaF_2 due to the flat pseudomorphic CaF_2 surface and the small lattice mismatch between $CoSi_2$ and pseudomorphic CaF_2.

KEYWORDS: $CoSi_2$/CaF_2 heterostructure on Si, very thin metal film, pseudomorphic CaF_2, relaxed CaF_2

Metal-insulator (M-I) heterostructure is a very attractive material system for ultra-high speed and multifunctional quantum devices due to the high carrier density of the metal, the low dielectric constant of the insulator and the very large conduction band discontinuity at the heterointerface.[1)] We developed an epitaxial growth technique[2)] for nanometer-thick multilayer structures, with $CoSi_2$ and CaF_2 as the metal and insulator, respectively, because they have a fluorite lattice structure and are closely lattice-matched to Si, with mismatches of -1.2% and +0.6%, respectively, at room temperature. Using this technique we demonstrated the primitive action of a hot electron transistor, a resonant tunneling transistor and a quantum interference transistor.[3-5)] In these devices, reduction of electrical resistance in the very thin epitaxial metal film is essential for the improvement of device characteristics.[4,6)] This resistance depends strongly on the flatness and crystalline quality of the CaF_2 layer under the metal film.

In this study, nanometer-thick epitaxial metal ($CoSi_2$) films were grown on relaxed or pseudomorphic CaF_2/Si(111) and their electrical resistance was measured. It was found that the electrical resistance of the $CoSi_2$ film on pseudomorphic CaF_2 was about half of that on relaxed CaF_2.

The epitaxial growth system was equipped with a liquid-nitrogen shroud and was evacuated by ion pump with a background pressure of less than 1×10^{-9} Torr. The CaF_2 layer was deposited from a solid source using a graphite crucible. The $CoSi_2$ layer was deposited from solid sources of Si and Co using electron-gun evaporators. A Si substrate with (111) orientation was chemically cleaned and a protective oxide layer was grown. Then, the substrate was loaded into the growth chamber through a load lock and heated to 750°C with exposure to a Si beam to evaporate the protective oxide layer. This process yielded a well developed 7×7 RHEED pattern.

In the epitaxial growth, 15-nm-thick relaxed or pseudomorphic CaF_2 layer was grown on Si(111) at first. The relaxed CaF_2 was grown at a constant temperature of 650°C, while the pseudomorphic CaF_2 was grown at 770°C for the first 0.6 nm and at 200°C for the remainder of the growth period.[7)]

The $CoSi_2$ was grown on these CaF_2 layers using a two-step growth technique:[2)] firstly, solid-phase epitaxy of the Si layer at 300°C, followed by Co deposition at less than 800°C. Finally, a 5-nm-thick layer of CaF_2 was grown by ionized beam epitaxy at 200°C to protect the fabrication of the measurement samples.[2)] The wafers were not annealed after growth in this experiment.

Figure 1 shows the surface image of the protective CaF_2 layer using scanning electron microscopy (SEM). The sample containing pseudomorphic CaF_2/Si(111) is flatter than the sample containing relaxed CaF_2/Si(111). This may be because larger step-bunching occurs in the relaxed CaF_2, due to its high growth temperature (650°C), compared to that occurring in the pseudomorphic CaF_2 (200°C).

Ohmic contact to the $CoSi_2$ metal layer was made to measure electrical resistance using Au/Cr electrodes using photolithography and selective wet chemical etching processes.[2)] The diameter of each electrode was 20μm and the distance between the electrodes was 1 mm. The resistance was measured at room temperature.

Figure 2 shows the measured distribution of the resistivity of the $CoSi_2$ layers. Average values of resistivity were 60 and 28μΩcm on relaxed and pseudomorphic CaF_2, respectively. The electrical resistivity of the $CoSi_2$ layer on pseudomorphic CaF_2 was about half of that on relaxed CaF_2, and was comparable to that of an annealed $CoSi_2$ layer on relaxed CaF_2.[2)]

This result is interpreted as follows. The flatness of the $CoSi_2$ layer on CaF_2 is better in the sample with pseudomorphic CaF_2, which is deduced from the surface image of the top layer shown above. Moreover, the $CoSi_2$ on pseudomorphic CaF_2 may have better crystalline quality because of the smaller lattice mismatch between $CoSi_2$ and CaF_2 (-1.2%) compared to that between $CoSi_2$ and relaxed CaF_2 (-1.8%). Due to these characteristics the resistivity of the $CoSi_2$ layer was reduced by the use of pseudomorphic CaF_2.

In conclusion, 1.9-nm-thick epitaxial metal ($CoSi_2$) films were grown on relaxed or pseudomorphic CaF_2/Si(111) and their electrical resistance was measured. Electrical resistance of the $CoSi_2$ film on pseudomorphic CaF_2 was about half of that on relaxed CaF_2. This result can be attributed to the improved of flatness and crystalline quality of the $CoSi_2$ due to the use of pseudomorphic CaF_2 instead of relaxed CaF_2.

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Figures:

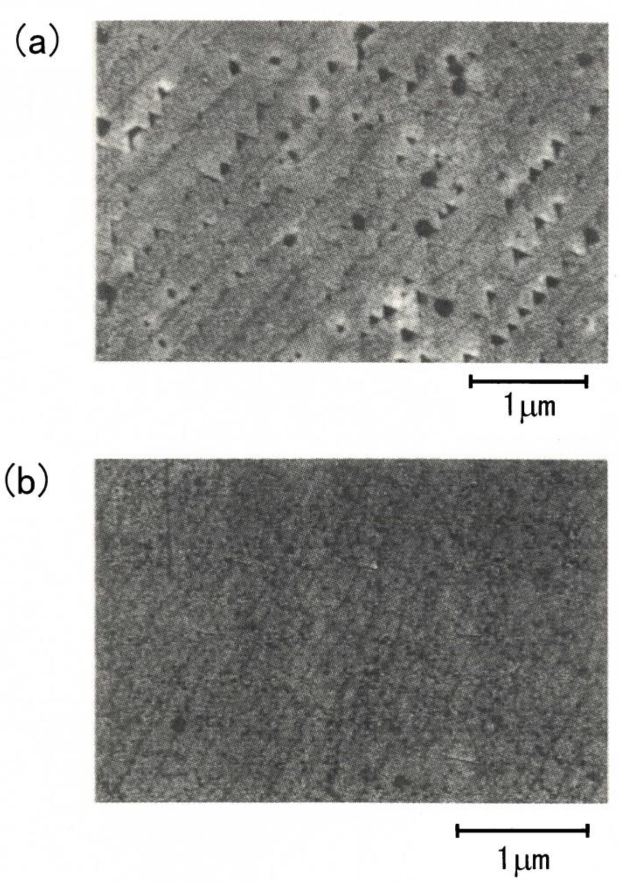

Fig.1. SEM surface view of samples. (a) $CaF_2/CoSi_2/$ relaxed $CaF_2/Si(111)$ and (b) $CaF_2/CoSi_2/$pseudomorphic $CaF_2/Si(111)$.

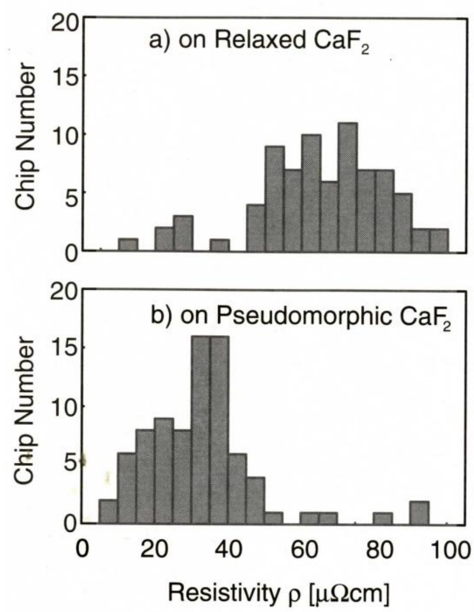

Fig.2. Distribution of resistivity of 1.9-nm-thick $CoSi_2$ films on (a) relaxed and (b) Pseudomorphic CaF_2.

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