The electrical resistance of gold-capped chromium thin films

To cite this article: Masashi Ohashi et al 2018 J. Phys.: Conf. Ser. 969 012029

View the article online for updates and enhancements.

You may also like

- Chromium Deposition from Dicumene Chromium to Form MetalSemiconductor Devices
  N. G. Anantha, V. Y. Doo and D. K. Seto

- Study of the formation of thermochemical laser-induced periodic surface structures on Cr, Ti, Ni and NiCr films under femtosecond irradiation
  A.V. Dostovalov, V.P. Korolkov, V.S. Terentyev et al.

- Plasma Processing of Thin Chromium Films for Photomasks
  B. J. Curtis, H. R. Brunner and M. Ebnoether
The electrical resistance of gold-capped chromium thin films

Masashi Ohashi\textsuperscript{1,2}, Masaki Sawabu\textsuperscript{2}, Kohei Ohashi\textsuperscript{2}, Masahiro Miyagawa\textsuperscript{2}, Kae Maeta\textsuperscript{2}, Takahide Kubota\textsuperscript{3} and Koki Takanashi\textsuperscript{3}

\textsuperscript{1}Institute of Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Japan
\textsuperscript{2}Graduate School of Natural Science and Technology, Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Japan
\textsuperscript{3}Institute for Materials Research, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, 980-8577, Japan

E-mail: ohashi@se.kanazawa-u.ac.jp

Abstract. We studied the electrical resistance of polycrystalline chromium films capped by a gold layer. No anomaly was detected by resistance measurements of 10 nm thick film around room temperature, indicating that the antiferromagnetic interaction may be suppressed as decreasing the thickness of the chromium film. The sheet resistance $R_s(T)$ curves differ from polycrystalline chromium films in previous studies because of the electrical current flows through a gold capping layer. On the other hand, the resistance drop is observed at $T_C = 1.15\pm0.05$ K as that of polycrystalline chromium films in the previous report. It means that such resistance drop is not related to the chromium oxide layer on a polycrystalline chromium films. However, it is difficult to conclude that superconducting transition occurs because of the large residual resistance below the temperature where the resistance drop is observed.

1. Introduction

Superconducting thin films have attracted from both pure and applied research perspectives. However, in almost all of the existing studies of thin film superconductors, the superconductivity disappeared when film thickness is decreased\cite{1, 2, 3, 4}. Superconducting electron pairs will likely form when the film becomes thinner than the mean free path of the electrons.

On the other hand, Schmidt et al. reported that thin films of chromium (Cr) metal suppress the antiferromagnetic ordering and become superconductive at $T_C \sim 1.5$ K\cite{5, 6}. Considering that the bulk Cr is antiferromagnetic below $T_N = 311$ K\cite{7} and show no superconductivity, the relationship between film thickness and superconductivity in Cr opposes that in other superconducting thin films.

Assuming that the magnetic correlation interaction is suppressed by controlling the film thickness, tuning the thickness of Cr film might reveal a magnetic order–disorder transition, and unconventional superconductivity may occur at the quantum critical point of $T \to 0$, where quantum fluctuation produces an electron pair. This idea is partially supported by superconductivity in some heavy fermion systems after suppression of magnetism to some extent under pressure\cite{8, 9, 10, 11, 12}. 

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. 

Published under licence by IOP Publishing Ltd
Generally, three-dimensional electronic systems such as bulk compounds and two-dimensional ones such as thin films are described by completely different Hamiltonians. That is, film thickness is an effective parameter that directly controls the dimensionality of the system. Whether Cr is the first case of a new quantum phase transition tuned by film thickness is an interesting conjecture. Moreover, bulk superconductivity in Cr thin film would be remarkable finding, because it has not been reported in strongly correlated 3d transition-metal compounds such as Cr-based superconducting compounds, except for CrAs[13, 14].

However, experimental evidences of superconductivity in Cr thin film, such as resistivity drop and the Meissner effect, are lacking. So, we have studied the electrical resistance of Cr films[15]. Although we observed sudden decrease in the resistance around 1.5 K, it is difficult to conclude whether a superconducting transition occurs because the electrical resistivity is not zero in all films. It may come from the fact that some chromium oxide is produced on a film surface, and that partially show a superconducting transition. In the present study, we perform precise electrical resistance measurements of Cr thin films capped by a gold layer to clarify the electronic state in a wide temperature range.

2. Experimental
Several polycrystalline Cr films were deposited on silicon substrate using ion beam sputtering with a base pressure of about $8 \times 10^{-6}$ Pa. The working deposition gas was argon and a pressure was controlled between $1.15 \times 10^{-2}$ and $1.17 \times 10^{-2}$ Pa. A gold capping layer of 5 nm thick was deposited on the surface of the Cr films to avoid the oxidation. X-ray measurements were performed using a Rigaku SmartLab diffractometer with CuKα1 radiation ($\lambda = 1.54059$ Å). The electrical resistance was measured by a four-point collinear four-probe dc method with the current direction on the film plane. Aluminum wires were bonded on the film plane by wire bonding in the same way of the previous report[15]. The temperature dependence of the electrical resistivity was measured using the Quantum-Design PPMS between 0.5 and 350 K in the low-temperature laboratory, Kanazawa University. The direction of the applied field was perpendicular to the film plane and the electrical current.

3. Results and Discussion

![Figure 1](image-url)  
**Figure 1.** The X-ray diffraction patterns of Cr film of 10 nm and 50 thick capped by a gold layer.

Figure 1 shows the X-ray diffraction pattern of chromium films capped by a gold layer. We can observe the diffractions of Si (400), Au (111) and Cr (110) planes. For 50 nm thick film, the lattice constants of chromium are obtained to be 2.89 Å, which is comparable with that of bulk
chromium 2.88 Å[16] within the experimental error. An unknown peak is also observed around 32.96° which may correspond to Si (200) reflection.

Figure 2 shows the sheet resistance $R_s$ of 10 nm thick Cr film capped by a gold layer as a function of temperature between 0.5 and 350 K. The value $R_s = 46.4 \, \Omega/\square$ at 300 K is much smaller than that of a 10 nm thick polycrystalline film reported in the previous study[15]. Moreover, $R_s$ decreases with decreasing temperature while that of a 10 nm thick film in the previous study show a semiconducting behavior. It suggests that the electrical current of the gold-capped Cr film of 10 nm thick flows through both a Cr film and a gold capping layer in parallel. No hump is observed around 300 K related to the magnetic phase transition in the $R_s(T)$ curve, which is consistent with previous study.

![Figure 2. Sheet resistance $R_s$ of Cr film of 10 nm thick capped by a gold layer as a function of temperature.](image1)

Figure 3 shows the sheet resistance $R_s$ of 50 nm thick Cr film capped by a gold layer as a function of temperature between 0.5 and 350 K. The value $R_s = 14.0 \, \Omega/\square$ at 300 K is close to that of a 50 nm thick film reported previously[15]. $R_s$ increases with decreasing temperature between 10 and 350 K. Taking account that the fact the 50 nm thick Cr film is 10 times thicker than that of a gold-capping layer, the semiconducting conductivity of the 50 nm thick Cr film reported previously[15] may contribute to the electrical resistance compared with the metallic behavior of a gold-capping layer. Below 10 K, on the other hand, $R_s$ decreases with decreasing temperature.

A hump is observed around room temperature in the $R_s(T)$ curve. The inset of figure 3 shows the temperature differential of the electrical resistivity $dR_s/dT$ as a function of temperature. $dR_s/dT(T)$ curve shows a maximum at around 296 K. It may be related to the antiferromagnetic phase transition, which is observed in bulk Cr with $T_N = 311$ K[7, 17, 18].

Figure 4 and 5 shows the sheet resistance $R_s$ of 10 and 50 nm thick Cr film capped by a gold layer at low temperature, respectively. We found that the resistance drops are observed at $T_C = 1.15 \pm 0.05$ K for both films. However, $R_s$ is not zero in both films below $T_C$, and the magnitude of the resistivity drop ratio is very small, i.e., 0.16 and 0.05 % for the films of 10 and 50 nm thick, respectively. Similar behavior is also observed in polycrystalline Cr films although $T_C = 1.5$ K[15] differs from that of this work. It means that such resistance drop is not related to the presence or absence of chromium oxide layer on polycrystalline Cr films. On the other
hand, taking account that aluminum becomes superconductive at $T_C = 1.1 \text{ K}[16]$, aluminum wires bonded on a sample may contribute to the electrical resistance. Although Schmidt et al. also reported that thin films of Cr metal suppress the antiferromagnetic ordering and become superconductive at $T_C \sim 1.5 \text{ K}[5, 6]$, it is difficult to conclude whether superconducting transition occurs.

Figure 4. Sheet resistance $R_s$ of Cr film of 10 nm thick capped by a gold layer at low temperature. Arrow shows the temperature where $R_s$ shows a sudden decrease.

Figure 5. Sheet resistance $R_s$ of Cr film of 50 nm thick capped by a gold layer at low temperature. Arrow shows the temperature where $R_s$ shows a sudden decrease.

Figure 6 and 7 shows the sheet resistance $R_s$ of 10 and 50 nm thick Cr film capped by a gold layer as a function of magnetic field at 0.5 K, respectively. We found that the slope $dMR/dH$ is positive and the MR tends to saturate above 2 kOe. At the 3 kOe field, the MR obtained is 0.16 and 0.05 % for samples 10 nm and 50 nm thick, respectively, which is identical to the magnitude of the electrical resistivity drop, as mentioned in Figs. 4 and 5. If we assume that the upper critical field $H_{C2} \sim 2 \text{ kOe}$ where the MR saturates for 10 nm thick Cr film, Ginzburg-Landau coherence length is obtained as $\xi = 162 \text{ Å}$ according to this relationship: $\mu_0 H_{C2}(0) = \Phi_0/2\pi \xi^2$, where $\Phi_0 = 2.067 \times 10^{-15} \text{ Wb}$ is the magnetic flux quantum.

4. Summary
In this study, we performed the electrical resistance measurements on polycrystalline chromium films capped by a gold layer. The sheet resistance $R_s(T)$ curves differ from polycrystalline chromium films in previous studies because of the electrical current flows through a gold capping layer. On the other hand, the resistance drop is observed at low temperature. It means that the resistance drop is not related to the chromium oxide layer on a polycrystalline chromium films. However, it is difficult to conclude that superconducting transition occurs because of the large residual resistance below the temperature where the resistance drop is observed. To make it clear, more precise experiments are planed to clarify the transport properties of single crystal chromium films at low temperature.

Acknowledgments
This work was performed under the inter-university cooperative research program of the Cooperative Research and Development Center for Advanced Materials, Institute for Materials
Figure 6. Sheet resistance $R_s$ of Cr film of 10 nm thick capped by a gold layer as a function of magnetic field at 0.5 K.

Figure 7. Sheet resistance $R_s$ of Cr film of 50 nm thick capped by a gold layer as a function of magnetic field at 0.5 K.

Research, Tohoku University (Proposal No. 16G0039). This work was supported in part by Futaba Electronics Memorial Foundation.

References

[1] Chakravarty S, Ingold G L, Kivelson S and Luther A 1986 Phys. Rev. Lett. 56 2303
[2] Orr B G, Jaeger H M and Goldman A M 1985 Phys. Rev. B 32 7586(R)
[3] Jaeger H M, Haviland D B, Orr B G and Goldman A M 1989 Phys. Rev. B 40 182
[4] Haviland D B, Liu Y, Nease B and Goldman A M 1990 Physica B 165-166 1457
[5] Schmidt P H, Castellano R N, Barz H and Matthias B T 1972 Physics Letters 41A 367
[6] Schmidt P H, Castellano R N, Barz H, Cooper A S and Spencer E G 1973 J. Appl. Phys. 44 1833
[7] Koehler W C, Moon R M, Trego A L and Machintosh A R 1966 Phys. Rev. 151 405
[8] Uwatoko Y, Umehara I, Ohashi M, Nakano T and Oomi G 2012 Handbook on the Physics and Chemistry of Rare Earths vol 2 (Amsterdam: North-Holland) chap 252, p 1
[9] Nakano T, Ohashi M, Oomi G, Matsubayashi K and Uwatoko Y 2009 Phys. Rev. B 79 172507
[10] Miyagawa H, Oomi G, Ohashi M, Satoh I, Komatsubara T, Hedo M and Uwatoko Y 2008 Phys. Rev. B 78 064403
[11] Ohashi M, Oomi G, Koiwai S, Hedo M and Uwatoko Y 2003 Phys. Rev. B 68 144428
[12] Ohashi M, Oomi G and Satoh I 2007 J. Phys. Soc. Jpn. 76 114712
[13] Wu W, Cheng J, Matsubayashi K, Kong P, Lin F, Jin C, Wang N, Uwatoko U and Luo J 2014 Nature Communications 5 5508
[14] Kotegawa H, Nakahara S, Tou H and Sugawara H 2014 J. Phys. Soc. Jpn. 83 093702
[15] Ohashi M, Ohashi K, Sawabu M, Miyagawa M, Kubota T and Takanashi K 2016 Physics Letters A 380 3133
[16] Kittel C 1996 Introduction to Solid State Physics 7th ed (John Wiley & Sons, Inc.)
[17] McWhan D B and Rice T M 1967 Phys. Rev. Lett. 19 846
[18] Ohashi M and Oomi G 2009 Jpn. J. Appl. Phys. 48 070221