

行政院國家科學委員會專題研究計畫 成果報告

奈米及介觀導體之量子電、熱傳輸性質之研究(2/2)

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計畫主持人：林志忠

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行政院國家科學委員會補助專題研究計畫 成果報告
 期中進度報告

奈米及介觀導體之量子電、熱傳輸性質之研究(2/2)

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計畫主持人：林志忠教授

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成果報告類型(依經費核定清單規定繳交)： 精簡報告 完整報告

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執行單位：國立交通大學物理研究所

中華民國 94 年 11 月 8 日

一、研究計畫中英文摘要：

關鍵詞：奈米結構、介觀物理、量子傳輸、低溫熱電勢

本計畫擬進行奈米複合物以及介觀導體中的新穎物理性質的發掘與量測，包括低溫電傳輸性質，和低溫熱傳輸性質。我們的樣品將為利用濺鍍方法製成之金屬-絕緣體複合物（如 Cu-SiO₂），其中金屬和介電質的顆粒大小各僅約為~2 nm。在電傳輸性質方面，我們將進行低溫電阻、磁電阻、和（巨大）霍耳效應的量測與研究。在熱傳輸性質方面，我們將進行低溫（量子）熱電勢的量測與研究。同時藉由樣品中金屬顆粒與介電質顆粒之體積比的改變，樣品可橫跨金屬與絕緣體兩個區域—「金屬-絕緣體轉變」是凝體物理中的一個恆久而尚未全然理解的課題。在本計畫裡，我們將集中於探討靠近於金屬-絕緣體轉變之「臨界點」處的電子行為。除了金屬-絕緣體複合物之外，我們也將製作並且量測金屬薄膜、細導線、以及其他微小金屬結構的低溫電子傳輸性質。

Keywords: nanostructures, mesoscopic physics, quantum transport, low-temperature thermopowers

In this project, we propose to study the low-temperature quantum electrical- and heat-transport properties of nano granular systems such as the metal-insulator composites Cu-SiO₂. Our samples, to be prepared by dc/RF sputtering deposition technique, are expected to comprise very small metal and insulator grains of only ~ 2 nm in diameter. The resistivities, magnetoresistivities, (giant) Hall effects, and thermoelectric powers in such samples will be measured at liquid-helium temperatures down to well below 1 K. By varying the volume fraction of the metal (or insulator) grains, the samples can be made to span from the metallic regime to the insulating regime. We also plan to study the electronic transport properties at the critical regime near the metal-insulator transition. In addition to metal-insulator composites, we will investigate the quantum electronic transport properties of metal thin films, narrow wires, and other novel mesoscopic structures.

二、研究成果：

本項計畫已經順利執行完畢，並且完成發表了兩篇國際期刊學術論文。列舉如下：

1. *Electronic transport studies on $Sb_{1-x}(SiO_2)_x$ films*, J. Du, Z.Q. Li, J.J. Lin, H. Liu, R.K. Zheng, P. Chen, R. Rosenbaum, and X.X. Zhang, *J. Phys.: Condens. Matter* **17**, 2553 (2005).
2. *Electron-phonon-impurity interference effect in disordered $Au_{56}Pd_{44}$ and IrO_2 thick films*, S.S. Yeh, J.J. Lin, X. Jing, and D.L. Zhang, *Phys. Rev. B* **72**, 024204 (2005).

第二篇論文附錄如下：

Electron-phonon-impurity interference effect in disordered Au₅₆Pd₄₄ and IrO₂ thick filmsS. S. Yeh¹ and J. J. Lin^{1,2}¹*Institute of Physics, National Chiao Tung University, Hsinchu 30010, Taiwan*²*Department of Electrophysics, National Chiao Tung University, Hsinchu 30010, Taiwan*

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We have fabricated a series of Au₅₆Pd₄₄ thick films with a wide range of residual resistivity ρ_0 varying from 40 to 280 $\mu\Omega$ cm. The resistivities of these films were measured between 15 and 300 K. We found that at temperatures below about $0.1\theta_D$ (θ_D is the Debye temperature), the interference mechanism between the elastic electron scattering and electron-phonon scattering (the electron-phonon-impurity interference effect) contributes significantly to the measured resistivities. Our results support the current theoretical idea that this interference-mechanism-induced resistivity varies with $\rho_0 T^2$, where T is the temperature. Similar observation has also been made in disordered, conducting transition-metal oxide IrO₂ thick films.

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I. INTRODUCTION

The magnitude and temperature behavior of the electrical resistivity $\rho(T)$ in metals are extremely difficult to calculate quantitatively. In the most standard model for the electrical transport in metals, $\rho(T)$ is presumed to comprise of two terms: the residual resistivity ρ_0 due to electron scattering from random potential and the temperature dependent part of resistivity due to scattering from lattice vibrations (phonons). The latter contribution is known as the Bloch-Grüneisen term, denoted by $\rho_{BG}(T)$. In Matthiessen's rule, these two contributions are expected to be independent of each other, and thus $\rho(T) = \rho_0 + \rho_{BG}(T)$. However, it has been known for years that deviations from the Matthiessen's rule exist in many real conductors.¹ Recently, it becomes clear that such deviations can be particularly noticeable in impure conductors. Theoretically,² it was proposed that the interference mechanism between the elastic electron scattering and the electron-phonon scattering would lead to an additional contribution to the resistivity. The contribution due to this so-called electron-phonon-impurity interference effect can dominate over the Bloch-Grüneisen term especially at temperatures below about $0.1\theta_D$, where θ_D is the Debye temperature. The measured resistivity of a *disordered* metal should then be written as²

$$\rho(T) = \rho_0 + \rho_{\text{int}}(T) + \rho_{BG}(T), \quad (1)$$

where ρ_{int} is due to the electron-phonon-impurity interference mechanism, which was not considered in the Matthiessen's rule.

In this work, we shall concentrate on the temperature regime above 15 K where the corrections to the residual resistivity due to the weak-localization and electron-electron interaction effects³ are essentially negligible (or, the minor contributions of which can be safely subtracted from the measured resistivities).

II. THEORY

In disordered metals, the electron-phonon interaction is mainly due to two processes. The first process is the usual "pure" electron-phonon scattering similar to that in clean metals. The second process is due to the *inelastic* electron scattering from *vibrating* impurities. As a consequence, a variety of interference processes are generated due to the coexistence of the elastic electron scattering, the "pure" electron-phonon scattering and the inelastic electron scattering. Reizer and Sergeev² took into account of all possible electron scattering channels and calculated the contribution from those interference processes to the resistivity (ρ_{int}). In particular, they found that ρ_{int} scales with the residual resistivity ρ_0 of the disordered sample and varies with the square of temperature, i.e., $\rho_{\text{int}} \propto \rho_0 T^2$ at low temperatures of about $T < 0.1\theta_D$. This multichannel interference contribution to resistivity has recently been tested in experiments using thin metals films⁴⁻⁶ and metal-dielectric composite nanowires.⁷ Less extensive studies have been performed on bulk samples.^{8,9} On using bulk samples, one of the advantages is that the phonon spectra would be definitely three dimensional;¹⁰ three dimensionality of phonons is a criterion that was originally assumed in the theoretical calculations of Ref. 2.

Under the conditions that $q_{l,t}l > 1$ and $\rho_{\text{int}} < \rho_0$ (where $q_{l,t}$ is the wave number of the longitudinal and transverse thermal phonons, respectively, and l is the electron mean free path), the correction to the resistivity due to the electron-phonon-impurity interference effect has been explicitly calculated by Reizer and Sergeev. The clean limit criterion of $q_{l,t}l > 1$ is equivalent to $q_{l,t}l \approx k_B T l / (\hbar u_{l,t}) > 1$, where $u_{l,t}$ is the longitudinal and transverse sound velocity, respectively. Therefore, the clean-limit criterion is satisfied when the measuring temperature is higher than a characteristic temperature of $T_{l,t}^* \approx \hbar u_{l,t} / (k_B l)$. The Reizer-Sergeev result for the interference-mechanism-induced resistivity is given by²

$$\rho_{\text{int}}(T) = BT^2 \rho_0 \left(\frac{6}{\pi^2} \right) \int_0^{\theta_D/T} \left[\frac{x^2 e^x}{(e^x - 1)^2} - \frac{x}{e^x - 1} \right] dx, \quad (2)$$

where

$$B = \left[2 \left(\frac{u_l}{u_t} \right) \beta_l + \left(\frac{\pi^2}{16} - 1 \right) \beta_l \right] \frac{2\pi^2 k_B^2}{3E_F \rho_F u_l}. \quad (3)$$

Here $\beta_{l,t}$ is the coupling constant of electrons with longitudinal and transverse phonons, respectively, E_F (p_F) is the Fermi energy (momentum), and k_B is the Boltzmann constant. At low temperatures ($T < 0.1\theta_D$), the integral in Eq. (2) approaches $\pi^2/6$, and thus the temperature dependence of ρ_{int} reduces to a simple power law

$$\rho_{\text{int}}(T) = BT^2 \rho_0. \quad (4)$$

Notice that $d(\rho_{\text{int}}/\rho_0)/dT^2 = B$ is a constant for a given material, being independent of the amount of disorder contained in the sample.

In the jellium model with the Bohm-Staver relation for the sound velocity,^{2,11} $\beta_l = 0.5$ and the two coupling constants are related to each other by $\beta_l/\beta_t = (u_l/u_t)^2$. The electron-phonon coupling constants can be explicitly written as $\beta_{l,t} = (\frac{2}{3}E_F)^2 N(0)/(2\rho_m u_{l,t}^2)$, where ρ_m is the mass density, and $N(0)$ is the electronic density of states (both spins) at the Fermi level. It should be noted that in usual metals, $u_l/u_t \approx 2-3$. Thus, inspection of Eq. (3) indicates that the contribution from the interactions of the electrons with the *longitudinal* phonons (the second term in the square parentheses) is *negligibly small* compared with the interactions of the electrons with the *transverse* phonons (the first term in the square parentheses).

It is worth mentioning that, by the same token, current theories^{12,13} and experiments¹⁴ have also established that the total electron-phonon scattering rate in impure conductors is dominated by the interactions of electrons with *transverse* rather than with longitudinal phonons.

The contribution of the “pure” electron-phonon scattering to the resistivity in a disordered metal has been calculated by Altshuler.¹⁵ His result at temperatures $T > (a/l)\theta_D$ (where a is the lattice spacing) is similar to that given by the Bloch-Grüneisen law^{6,16}

$$\rho_{\text{BG}}(T) = \beta_{\text{BG}} T \left(\frac{T}{\theta_D} \right)^4 \int_0^{\theta_D/T} \frac{x^5 dx}{(e^x - 1)(1 - e^{-x})}, \quad (5)$$

where

$$\beta_{\text{BG}} = \frac{\pi \beta_l \tau k_B^5}{2 \hbar \rho_F^4 u_l^4} \rho_0 \theta_D^4. \quad (6)$$

Here $\tau = l/v_F$ is the electron elastic mean free time, and v_F is the Fermi velocity.

Comparison of the theoretical predictions Eqs. (2) and (5) reveals that the Bloch-Grüneisen term dominates at high temperatures while the electron-phonon-impurity interference effect dominates at low temperatures of about $T < 0.1\theta_D$. Quantitative comparison of these two contributions in our samples is presented in Figs. 2 and 4.

III. EXPERIMENTAL METHOD

Prototypical disordered Au₅₆Pd₄₄ alloy was selected for this study for the following reasons. The substitutional disorder and the structural disorder for the present concentration ratio of the material provide enormous scattering centers and the level of disorder can be “tuned” by adjusting the dc-sputtering deposition rate,¹⁷ resulting in a wide range of residual resistivity ρ_0 [$=\rho(10\text{ K})$] from ≈ 40 to $\approx 280\ \mu\Omega\text{ cm}$ in our case, yet the alloy is still at the Au-rich side where the electronic structure at the Fermi level is not much complicated by the *d*-band.¹⁸ It is well known that Au and Pd form perfect fcc solid solution and it would be safe to treat the alloy as an isotropic material. The details of the sample preparation were described in Ref. 17. To ensure a three-dimensional phonon spectrum as well as to minimize the weak-localization and electron-electron interaction effects at liquid-helium temperatures, we have made our films sufficiently thick ($\geq 0.50\ \mu\text{m}$) in this study.

In a quantitative comparison of the theory with experiment, the Debye temperature θ_D plays an important role in both the ρ_{int} and ρ_{BG} terms. Therefore, instead of treating θ_D as an adjusting parameter in Eqs. (2) and (5), we have experimentally extracted the value of θ_D from specific heat, C , measurements between 0.4 and 40 K. We then evaluated θ_D according to the relation $C/T = \gamma + \alpha T^2$, where γ and α are material dependent parameters.¹⁹ From the value of α , we obtained $\theta_D \approx 240\text{ K}$ for our Au₅₆Pd₄₄ alloy. This value is reasonable, compared with the $\theta_D(\text{Au}) \approx 165\text{ K}$ and $\theta_D(\text{Pd}) \approx 274\text{ K}$.²⁰ Since the Debye temperature determined from resistance measurement and that from specific heat measurement differs only slightly,¹⁶ we have fixed θ_D to this value in Eqs. (2) and (5) in our data analysis. (We have also treated θ_D as a free parameter and found a similar result.)

IV. RESULTS AND DISCUSSION

A. Au₅₆Pd₄₄ thick films

Figure 1 plots the phonon dependent part of the resistivity, $\Delta\rho = \rho - \rho_0$, as a function of temperature for a series of Au₅₆Pd₄₄ thick films with various amounts of disorder as indicated in the caption to Fig. 1. According to Matthiessen’s rule, $\Delta\rho$ should be independent of disorder, and thus a plot of $\Delta\rho$ versus temperature for all samples should collapse on a same curve. Obviously, this is not the case found in Fig. 1. On the contrary, Fig. 1 reveals that the temperature variation of $\Delta\rho$ is strongly sample dependent, being larger in films with higher ρ_0 . This observation clearly implies that disorder must play a crucial role in determining the temperature behavior of the measured resistivity.

To illustrate the importance of the electron-phonon-impurity interference term, we plot in Fig. 2 the variation of $\Delta\rho/\rho_0$ with temperature in double logarithmic scales for three representative samples. The measured data for each film were least-squares-fitted to Eqs. (1), (2), and (5), and the relevant parameters were determined.²¹ It is clearly seen that the theoretical predictions (the solid curves) can well describe the experimental results. We notice that at low temperatures of $T \approx 0.1\theta_D$, the measured resistivity is a factor of

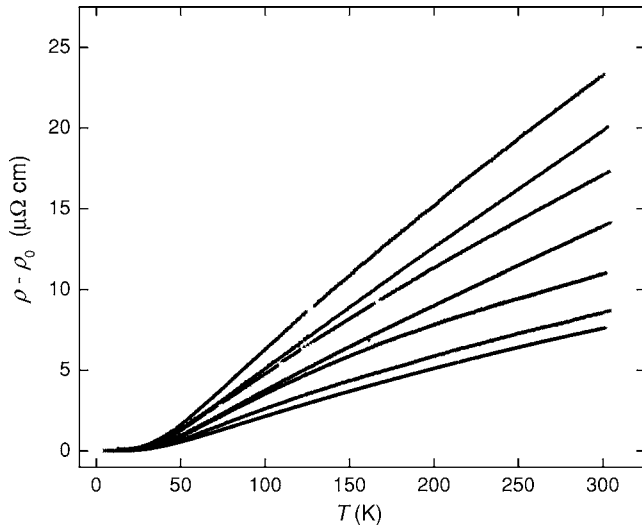


FIG. 1. Variation of $\Delta\rho = \rho - \rho_0$ with temperature for a series of $\text{Au}_{56}\text{Pd}_{44}$ thick films. The values of the residual resistivity for the films are (from bottom to top): 39.3, 66.4, 125, 171, 202, 264, and 275 $\mu\Omega$ cm. Notice that $\Delta\rho(T)$ increases with increasing disorder.

~ 3 (for our cleanest sample) to ~ 5 (for our dirtiest sample) larger than the Bloch-Grüneisen contribution, indicating the dominant role of the electron-phonon-impurity interference mechanism. Thus, the prediction of Eq. (2) is realized in the present material system. As the temperature increases, the

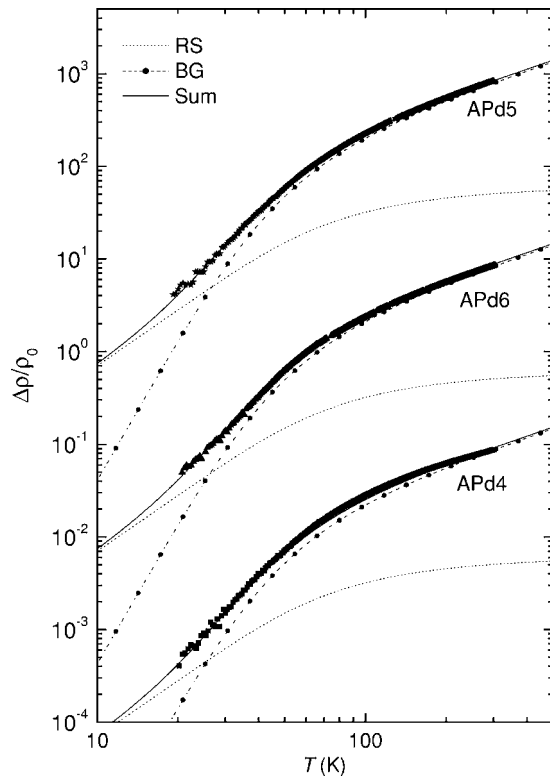


FIG. 2. Variation of $\Delta\rho/\rho_0 = (\rho - \rho_0)/\rho_0$ with temperature for three representative $\text{Au}_{56}\text{Pd}_{44}$ thick films as indicated. The theoretical predictions (solid curves) can well describe the experimental data. For clarity, the data for APd6 and APd5 have been multiplied by 100 and 10 000, respectively.

TABLE I. Values of relevant parameters for seven $\text{Au}_{56}\text{Pd}_{44}$ and two IrO_2 thick films. The $\text{Au}_{56}\text{Pd}_{44}$ films are ≥ 0.50 μm thick, and the IrO_2 films are 0.30 μm thick.

Films	ρ_0 ($\mu\Omega$ cm)	$\rho(300 \text{ K})/\rho_0$	β_{BG} ($\mu\Omega$ cm/K)
APd5	276	1.084	0.30
APd3	265	1.075	0.25
APd6	202	1.086	0.23
APd1	171	1.082	0.18
APd4	125	1.091	0.15
APd2	66.4	1.130	0.12
AP052	39.3	1.194	0.10
Ir300	286	1.208	0.38
Ir100	432	1.085	0.18

Bloch-Grüneisen contribution becomes progressively important. Between 20 and 28 K (depending on disorder), a cross-over happens and the Bloch-Grüneisen term eventually determines the measured resistivity, as expected from the standard electrical-transport theory.

The measured and fitted values for the relevant parameters for our samples are listed in Table I. In performing least-squares fits to Eqs. (1), (2), and (5), we found that a *single* value of $B = 7.0 \times 10^{-7} \text{ K}^{-2}$ could be used for *all* the $\text{Au}_{56}\text{Pd}_{44}$ thick films listed in Table I. Since the residual resistivity of our films varies by a factor as large as 7, this result of a *constant* B provides a strong justification for Eq. (2). This value of B is a factor of ~ 4 and ~ 1.5 smaller than that found in Au and Al thin films, respectively.⁶

For $\text{Au}_{56}\text{Pd}_{44}$, using the free-electron theory, we estimate $E_F \approx 4.1 \text{ eV}$, $N(0) \approx 1.0 \times 10^{47} \text{ states/J m}^3$, $\rho_m \approx 1.65 \times 10^4 \text{ kg/m}^3$, $u_l \approx 3.5 \times 10^3 \text{ m/s}$, $u_t \approx 1.3 \times 10^3 \text{ m/s}$, and $p_F \approx 1.3 \times 10^{-24} \text{ kg m/s}$. Then, we obtain the theoretical values of $\beta_l \approx 0.34$ and, from Eq. (3), $B \approx 7.7 \times 10^{-7} \text{ K}^{-2}$. This theoretical values of B is in excellent agreement with the experimental data. For a typical $\text{Au}_{56}\text{Pd}_{44}$ film with ρ_0 of order 100 $\mu\Omega$ cm, the characteristic temperature T_l^* above which $q_l l > 1$ is 5 K. This criterion is satisfied in our measurements.

Figure 3 shows the variation of the fitted Bloch-Grüneisen prefactor β_{BG} , Eq. (6), with residual resistivity for our $\text{Au}_{56}\text{Pd}_{44}$ thick films. This figure demonstrates that β_{BG} increases with increasing ρ_0 . As ρ_0 varies from 40 to 280 $\mu\Omega$ cm, β_{BG} increases roughly linearly from 0.10 to 0.30 $\mu\Omega$ cm/K. (However, there is no *prior* reason why β_{BG} should vary linearly with disorder.) This result is in sharp contrast to the behavior of the interference mechanism prefactor B . As discussed, the prefactor B for all of our films can be fixed at a single value, being independent of disorder. On the other hand, we stress that, when a wide range of ρ_0 is concerned, Fig. 3 indicates that one can by no means fix β_{BG} at a single value for all samples. The issue of applying the Reizer-Sergeev theory to a *wide* range of disorder for a given material has not been addressed in previous experiments.⁴⁻⁹

We notice that our experimental data of $\Delta\rho(T)/\rho_0$ *cannot* be described by Eq. (1) even by fixing β_{BG} to a constant value while allowing θ_D to vary from sample to sample, as

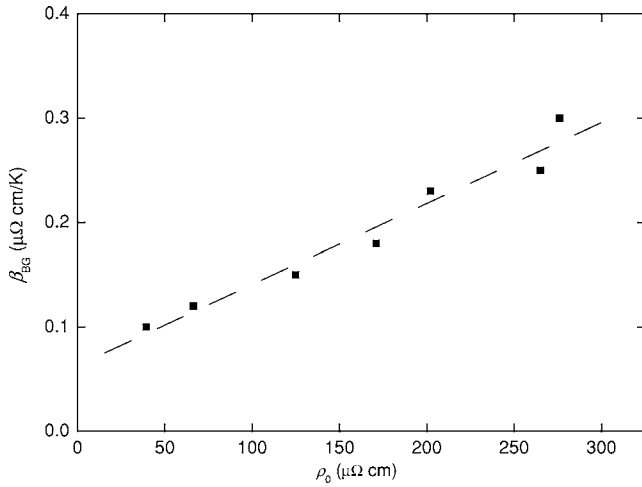


FIG. 3. Variation of the fitted Bloch-Grüneisen prefactor β_{BG} with residual resistivity ρ_0 for $\text{Au}_{56}\text{Pd}_{44}$ thick films. The dashed line is a guide to the eye.

one might conjecture. The functional form of Eq. (5) indicates that the effect of changing the value of θ_D is to significantly alter the temperature behavior of $\Delta\rho/\rho_0$ (especially at several tens K and higher, or $T \gtrsim 0.3\theta_D$), and thus no longer reproduce our experimental results.

At first glance, a prefactor β_{BG} dependent on disorder is unexpected according to the Bloch-Grüneisen law. However, comparison of Eqs. (6) and (3) suggests that β_{BG} possess a much stronger dependence on the electronic properties of the material than B does. Therefore, it may not be unfeasible to find, in our system, a prefactor β_{BG} revealing a variation with disorder while the prefactor B remaining essentially constant. Physically, the noticeable dependence of β_{BG} on ρ_0 found in Fig. 3 is likely to result from significant modifications of the electron (and probably phonon) properties of $\text{Au}_{56}\text{Pd}_{44}$ with increasing disorder. [We should point out that our $\text{Au}_{56}\text{Pd}_{44}$ thick films are so disordered that $\rho(300\text{ K})/\rho_0 \approx 1.1-1.2$.] Indeed, systematic measurements of the electronic-transport properties as a whole, including resistivities, thermoelectric powers, and Hall coefficients, have been undertaken on our films. Our results indicate that lattice disorder renormalize the material parameters, leading to an enhancement in the electron-phonon coupling and a reduction in the Fermi velocity of this material.²² Further theoretical and experimental investigation is definitely necessary to clarify this issue of disorder variation of β_{BG} in $\text{Au}_{56}\text{Pd}_{44}$.

B. IrO_2 thick films

In order to test the validity of Eq. (2) for a wide range of materials, we have also studied the resistivities of two polycrystalline IrO_2 thick films between 15 and 300 K. The films were prepared by rf sputtering on glass substrates as described previously.²³ The electronic band structure and electrical-transport properties of IrO_2 have been established, both theoretically^{24,25} and experimentally.²⁶ It is understood that in this *metallic* material, apart from the usual Bloch-Grüneisen contribution to the resistivity, there is an additional contribution due to the coupling of electrons with

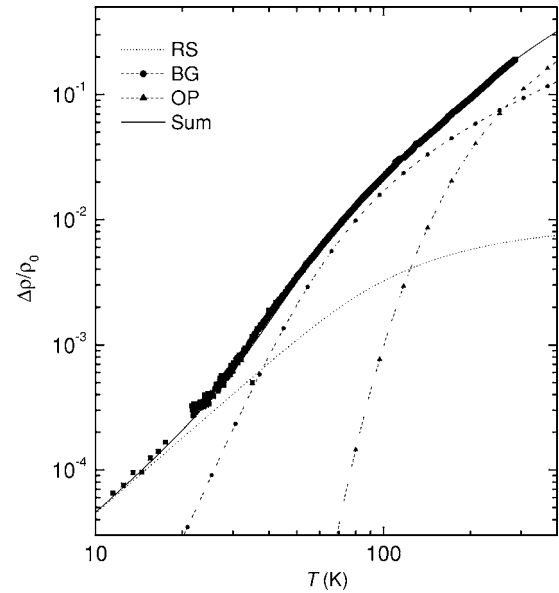


FIG. 4. Variation of $\Delta\rho/\rho_0 = (\rho - \rho_0)/\rho_0$ with temperature for Ir_{300} thick film. The theoretical prediction (the solid curve), Eq. (7), can well describe the experimental data.

optical-mode phonons (this term is important for transition-metal oxides which contain multiatom bases). Therefore, this material can provide a new horizon to test whether the Reizer-Sergeev theory may be applied to *conducting* transition-metal oxides. In the presence of the electron-optical-mode phonon coupling, the total resistivity can be written as:

$$\rho(T) = \rho_0 + \rho_{\text{int}}(T) + \rho_{BG}(T) + \rho_E(T). \quad (7)$$

Here the last term is treated using the Einstein approximation with a single phonon frequency corresponding to the energy $k_B\theta_E$, and can be written as^{25,26}

$$\rho_E(T) = \beta_E T \left[\frac{\theta_E/2T}{\sinh(\theta_E/2T)} \right]^2, \quad (8)$$

where β_E is a prefactor whose value depends on the material properties.

Figure 4 shows the variation of $\Delta\rho/\rho_0$ with temperature in double logarithmic scales for one of our IrO_2 thick films. (For clarity, we show only one film with various contributions in this plot.) The measured data were least-squares-fitted to Eq. (7) and the relevant parameters were determined and listed in Table I.²⁷ It is clearly seen that the theoretical prediction (the solid curve) can well describe the experimental result. In particular, at low temperatures of $T \approx 0.1\theta_D$, the contribution from the interference mechanism is a factor of ~ 10 larger than that from the Bloch-Grüneisen term. Thus, the prediction of Eq. (2) is established, for the first time, in conducting transition-metal oxides. At higher temperatures, the usual Bloch-Grüneisen and the optical-mode contributions become progressively dominant. Eventually, at sufficiently high temperatures (well above θ_D), the

electron-optical-mode phonon coupling term would surpass the Bloch-Grüneisen term which is due to electron-acoustic-mode phonon coupling.

Quantitatively, we obtained the electron-phonon-impurity interference prefactor $B \approx 4.5 \times 10^{-7} \text{ K}^{-2}$ in these two films. This value is close to that ($\approx 7.0 \times 10^{-7} \text{ K}^{-2}$) found in our $\text{Au}_{56}\text{Pd}_{44}$ thick films. This agreement, on one hand, supports the idea that IrO_2 possess usual metallic behavior and, on the other hand, establishes the wide validity of the Reizer-Sergeev theory.

V. CONCLUSION

Using a series of $\text{Au}_{56}\text{Pd}_{44}$ and two IrO_2 thick films with different amounts of disorder for resistivity measurements, we have found that the contribution from the electron-

phonon-impurity interference effect to resistivity ρ_{int} is significant. This interference mechanism dominates over the usual Bloch-Grüneisen term at temperatures below $0.1\theta_D$. Our observation confirms the predicted temperature and disorder behavior of $\rho_{\text{int}} \propto \rho_0 T^2$. Moreover, our results imply that the electron and phonon properties (e.g., the electron-phonon coupling and Fermi velocity) of $\text{Au}_{56}\text{Pd}_{44}$ may be significantly modified in the presence of strong disorder. This last observation deserves further investigation.

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參加國際會議報告

出席第二十四屆國際低溫物理會議 (LT24) 心得報告

94 年 8 月 23 日

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會議期間	94/8/10 – 94/8/17		
會議地點	美國佛羅里達州奧蘭多市 (Orlando, Florida, USA)		
會議名稱	(中文) 第二十四屆國際低溫物理會議 (英文) 24 th International Conference on Low Temperature Physics		
發表論文題目 (壁報論文)	(中文) 單晶氧化銱奈米線之電性量測 (英文) Electrical Measurements on Single-Crystalline Iridium Dioxide Nanorods		
內容摘要	Single-crystalline iridium dioxide (IrO ₂) nanorods have been prepared by metal-organic chemical vapor deposition method. Applying the standard electron-beam lithography technique, a single nanorod with a diameter of 110 nm is contacted by three Cr/Au fingers from above. The resistance measurements on this nanorod have been performed between 10 and 300 K, using different probe configurations. We observe that the resistivity ρ of the nanorod has a value $\leq 120 \mu\Omega \text{ cm}$ at 300 K. On the other hand, the temperature dependence of the contact resistance R obeys the law $\log R \propto T^{-1/2}$ below 100 K. The conduction process through the contact is ascribed to the transport of electrons via hopping in granular metals accidentally formed at the contact region.		

填寫日期： 94 年 8 月 23 日

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會議名稱	(中文)第二十四屆國際低溫物理會議 (英文)24 th International Conference on Low Temperature Physics		
發表論文題目 (請附論文全文)	(中文)透明導電氧化銦摻雜錫薄膜的電子傳輸 (英文)Electrical Transport in Transparent Conducting Tin-doped Indium Oxide Films		
內容摘要	<p>We have studied the temperature behavior of the electrical resistivities $\rho(T)$ in a series of tin-doped indium-oxide films with different residual resistivities ρ_0 varying from 218 to 568 $\mu\Omega$ cm. We found that the temperature dependence of ρ can be well described by the Bloch-Grüneisen law from 300 K down to about 100 K. In particular, we observed that the strength of the electron-phonon coupling, β_{BG}, (which characterizes a prefactor in the Bloch-Grüneisen formula) increases linearly with increasing ρ_0. This result is not understood in terms of current theoretical concept for electron-phonon interaction in metals.</p>		

一 前言

每 3 年舉辦一次的國際低溫物理會議，是一具有相當長久歷史且極負盛名之大型會議，自 1946 年起開始舉辦，今年已是第 24 屆，此次會議由位於美國的佛羅里達大學(University of Florida)所主持，會議地點則選於同州的奧蘭多市，此地不僅具有獨特的沼澤景觀與保護完善的自然生態，更是全球最大的迪士尼樂園所在地。

二 與會經過

由於當地為世界上極負盛名的度假地點，且此時剛好是暑假旅遊旺季，因此我們在行程安排上極為不便，機位可說是一票難求，我們去程轉機時，在洛杉磯等候近八小時，再搭機五小時後始抵達奧蘭多。

今年會議的總與會人數大概在兩千人左右，口頭論文演講有一百九十一場，其中有三十一場為大會的重點演講，安排在每日的上午舉行，其餘的一百六十場則為大會的邀請演講，在每日的重點演講結束後分別於不同的會議廳平行舉行。展示的壁報論文約在一千幅上下，參展的相關儀器廠商則約有數十家，整個會議過程當中，我們不僅可以看到目前世界上頂尖的低溫物理研究，也可以有機會面對面和來自世界各地的研究學者及學生討論、交換各種心得。

由於時差的關係，我們到達奧蘭多的時間為會議註冊日當日。正式會議期間，每日上午至下午排定為口頭論文報告，傍晚則為壁報展示時間。雖然大會要求在展示時間開始之前半小時掛上壁報，但由於展示時間只有一個半小時，在每日展示的兩百五十幅壁報中，僅僅只是觀看與自己研究主題密切相關的壁報，要在這麼短的時間內吸收也不是一件容易的事，若再加上語言的不甚熟練，更遑論要與研究者有深入的討論，所幸大家十分有默契，不約而同地在一早即將壁報張貼完畢，此舉讓我們意外地有一整天相當充裕的時間可以仔細觀看感興趣的主題，以便在正式展示的一個半小時內與研究者有較為充裕的時間討論。

會議內容與進行方面,簡述如下。由於低溫物理涵蓋範圍很廣，此次會議大概分為以下五個領域:

1. 量子氣體，流體，與固體 (Quantum Gases, Fluids and Solids)
2. 超導 (Superconductivity)
3. 固體的磁性與其他性質 (Magnetism and Properties of Solids)
4. 凝聚態物質的導電電子 (Conducting Electrons in Condensed Matter)
5. 材質，技術，與應用 (Materials, Techniques, and Applications)

在會議進行方面，第一天(八月十日)下午為與會人員登記註冊的時間，當天並沒有會議，只是辦理註冊。第二天上午九點會議開幕，並有三位 London Prize 得主演講。分別是 Richard Packard，演講題目為 ” Berkeley Experiments on Macroscopic Quantum Effects”，Sébastien Balibar，演講題目為 ” Rotons, superfluidity and crystallization ”，J. C. Séamus Davis，演講題目為 ” Exploring the Atomic Scale Electronic Structure of High-Tc Cuprates ”。下午，為 Simon Memorial Prize 得主 Grigory E. Volovik 演講，講題為 “Emergent physics on vacuum energy and cosmological constant ”。

其中 Sébastien Balibar 因為他在氦晶體方面的研究與早期在液氦超流量子蒸發方面的研究而獲獎。J. C. Séamus Davis 因為他在氦三超流方面的研究與發明發展 STM 技術而獲獎。Richard Packard 因為他在液氦超流所展現出來的巨觀量子效應的研究而得獎。Grigory E. Volovik 因為他關於超流超導的對稱性方面的研究並把這些觀念推廣到量子場論，宇宙學，量子重力，與粒子物理方面的貢獻而獲得 Simon Memorial Prize。

自第二天開始，會議分成不同的領域平行進行。每天每個領域自早上九點至十點半之間的一個半小時，安排三位相關領域的學者演講報告，每人報告半小時，十點半

到十一點之間為休息時間，會場提供咖啡蛋糕等點心，與會人員在這段時間可互相交談討論。十一點至十二點二十分的八十分鐘時間，安排四位演講者報告。十二點半至下午兩點為午餐時間，會場為每個與會人員安排一些餐點飲料。下午兩點至三點二十分的八十分鐘時間，有四位演講者報告。自下午三點半之後的時間，可到壁報區看壁報，並可與壁報的作者交流討論，對一些實驗細節，可以有更清楚的認識。而壁報的作者，自下午四點半至六點的九十分鐘的時間，會被要求出現在自己所做壁報之前，與參觀壁報者雙向討論。此次葉勝玄等人的壁報”Electrical Transport in Transparent Conducting Tin-doped Indium Oxide Films”於會議第二天下午張貼，林永翰等人的壁報”Electrical Measurements on Single-Crystalline Iridium Dioxide Nanorods”於第六日下午張貼。參觀者皆給了許多不少中肯的建議，整體而言算是不錯。在壁報展示的過程中，感觸最深的應該算是言語的表達了，由於與會者來自世界各國，英文不免具有各國的濃厚特殊口音，加上自己本身英文聽說能力平日即較少磨練，因此常會有雞同鴨講的情形產生，不過所幸都在彼此的諒解下輔以比手劃腳解決，但也由於語言能力的隔閡，而使諸多想討論的問題因無法適切表達而付諸流水。不過，幾天磨練下來英文的聽說能力也有相對的進步，不論是生活上或專業領域上，此應算是這次會議的另一個收穫吧。

我們於八月十七日離開，經亞特蘭大轉機至舊金山，在舊金山九小時後才再搭機返回台灣。

三 與會心得

我們的研究主題與興趣在於電子的傳輸特性，會中有若干壁報的主題與這相關，例如金屬、絕緣、超導相變與金屬顆粒大小的關係；無序系統中電子與聲子的交互作用；二維電子氣中電子與電子間的交互作用等等。透過參加國際會議，除了讓我們有機會與一些學者現場就研究議題討論，激發靈感外，還能讓我們第一手獲悉目前前沿的研究課題，開闊視野。看到許多學者傑出的研究成果，可以激勵我們更上一層樓的士氣，而發表自己的研究成果，看到許多研究者對我們研究課題的興趣與討論，也可增長自己的信心。

八月十四日為星期天，當天沒有會議，我們參加大會安排的美國太空總署甘迺迪太空中心之旅，親眼目睹參與登月任務的火箭殘骸，與登月小艇的主體引擎，感到相當震撼。美國人數十年前就登上了月球，當初的飛行器現在擺在太空中心讓人參觀拍照。登上月球不僅僅具有太空競賽上的意義，而是科學成就與技術發展的一大整合。更重要的，是夢想，與實現夢想的實力與努力。台灣曾有過製造、加工業蓬勃發展的歷史，賺進不少外匯，而現在，雖然台灣的半導體工業發達，但仍以”重複製造相同的東西”為主，高科技公司的資本額、營業額龐大，也設有研發部，但研發的重點，仍是以如何大量便宜製造產品為重點。我們或許在短時間之內賺到了錢，卻喪失了某

些夢想。夢想無法在短時間之內實現，需要長時間的投資與耕耘才能開花結果，就某方面而言，那是一種遠見。

在美國參加會議的這些日子，天天要從住宿的飯店步行至會場，約有十五分鐘的路程，其中要經過數個十字路口，讓人感受深刻的是，他們的車子相當禮讓行人。在沒有紅綠燈的路口，當他們的車子看到路口站有行人想過馬路時，會自動停車，讓路人過了馬路，再繼續開。台灣號稱人情味濃厚，但從車子對待行人的態度上，我們嗅不出一丁點的人情味，這是我們要省思的地方。

四 結論

此次去美國參加國際低溫物理會議，對於當前前沿研究課題的發展，有最新的了解。發表我們的研究成果，可增長自己的信心與提昇台灣在國際上的能見度。透過與其他學者的交流討論，可激發我們的靈感並擴展視野。整體而言，具有正面的意義。