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Electrical and magnetotransport properties of Ag-In-Yb quasicrystals

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ABSTRACT

\((\text{AgIn})_{100-x}\text{Yb}_x (15 \leq x \leq 16)\) quasicrystals (QCs) were prepared and their electrical and magnetotransport properties were investigated between 1.5 K and 300 K under a magnetic field of 0–6 T. For high-quality Ag-In-Yb QCs with a resistivity ratio, \(\rho(4.2 \text{ K})/\rho(300 \text{ K})\), larger than 1, the magnetoresistivity (MR), \(\Delta\rho(H)/\rho(0)\), is quite small (\(\Delta\rho(H)/\rho(0) \approx 10^{-3}-10^{-4}\) at 4.2 K and 6 T) and the temperature-dependent MR follows well with the predications of the effects of weak localization and electron and electron interaction. The observed positive temperature coefficient of the resistivity and large MR (\(\Delta\rho(H)/\rho(0) \approx 60\%\) at 4.2 K and 6 T) can only be found in the Ag-In-Yb QCs with a significant amount of parasitic phases. Among the studied Ag-In-Yb QCs, only the electrical resistivity of the \((\text{AgIn})_{42.25}\text{Yb}_{15.5}\) QC is unaffected by ageing for more than one year. The reported anomalous transport behavior in CdYb QCs was briefly discussed. We find that the electrical magnetotransport properties of the \(\text{Cd}_{84.5}\text{Yb}_{15.5}\) QC are quite similar to those for the \((\text{AgIn})_{42.25}\text{Yb}_{15.5}\) QC if CdYb samples of high quality can be prepared.

I. INTRODUCTION

Until now most of the studies of the structure and physical properties of icosahedral quasicrystals (QCs) are focused on F-type ternary QCs such as Al-Pd-(Fe,Mn,Ru,Re) and Al-Cu-(Fe,Ru,Qs) QCs because the single phase of these samples with good thermal stability and high-perfection quasilattice can be easily prepared through appropriate
Recently discovered binary CdYb and CdCa QCs\textsuperscript{1} may gradually change the research trend since these P-type and thermally stable QCs with less chemical disorder enable us more effectively to study the effects of the quasiperiodicity on the intrinsically physical properties experimentally and theoretically; and a large group of icosahedral Cd-Mg-RE alloys (where RE is a rare earth element) can also be formed, providing us a good opportunity to study the effects of rare earth elements on the electronic properties of QCs more systematically.\textsuperscript{2}

The electronic and thermoelectric properties of binary CdYb QCs have been studied by several authors.\textsuperscript{3-8} The specific heat measurements show that the $\gamma$ values for Cd\textsubscript{100-x}Ybx (15 $<$ x $<$ 16) are in the range of 2-5.1 mJ/(mole . K$^2$), which are unusually larger than those for sp-M (metal) and Al-TM (transition metal) QCs.\textsuperscript{9} The extracted Debye temperature is around 140 K. Photoemission (PE) studies\textsuperscript{5} show that there is a dip at either the Cd\textsubscript{5.7}Yb QC or 1/1 Cd\textsubscript{6}Yb approximant, but the dip is much deeper in Cd\textsubscript{5.7}Yb QC than in 1/1 Cd\textsubscript{6}Yb. This indicates the strong influence of the quasiperiodicity on the electronic structure because their compositions are quite close. The electrical and magnetic transport properties studied by Tamura et al.\textsuperscript{3} show that the resistivity for all the studied Cd\textsubscript{100-x}Ybx (15.4 $<$ x $<$ 16.1) decreases rapidly below~100 K with decreasing temperature down to 10 K so that the resistivity ratio $r = \rho(4.2\;\text{K})/\rho(300\;\text{K})$ for all the studied samples is less than 1. And the giant magnetoresistivity, $\Delta\rho(H)/\rho(0)$, as high as 200\% was observed at low temperatures. However, some authors\textsuperscript{6,8} found that the resistivity ratio $r$ for CdYb QCs can be larger than 1, although their resistivity decreases as the temperature is reduced at low temperature, and the reported MR ($\Delta\rho/\rho$~0.8\% at 0.65 K and 12 T) for the Cd\textsubscript{5.7}Yb QC\textsuperscript{6} is much smaller than those obtained by Tamura et al.\textsuperscript{3} These apparently contradictory results suggest that the intrinsic transport behavior of CdYb QCs has not unraveled yet,
and deserves further investigation to see if new transport mechanisms are needed to understand the electronic properties of these P-type binary icosahedral QCs.

In this work, we will use equal amount of Ag and In to substitute for Cd because in our experience, single-phase stable CdYb QCs are still difficult to be prepared at present.

Since Ag and In locate at both sides of Cd in the periodical table and the average value of their valances is 2 equal to the valance of Cd, thus we believe the electronic properties of (AgIn)\textsubscript{100-x}Yb\textsubscript{x} should be close to those of Cd\textsubscript{100-x}Yb\textsubscript{x} QCs. In addition, the prepared ternary QCs should also be more stabilized than binary QCs due to the increase of configuration entropy. Therefore, it is hoped that we can gain more insight into the intrinsic transport behavior of binary CdYb QCs through the studies of Ag-In-Yb QCs.

II. EXPERIMENT

Ag-In-Yb QCs were first synthesized successfully in 2002 by Guo and Tsai.\textsuperscript{10} Ingots of (AgIn)\textsubscript{100-x}Yb\textsubscript{x} (15 \textless x \textless 6) QCs were prepared by arc-melting a mixture of high-purity constituent elements, Ag (99.99\%), In (99.99\%), and Yb (99.99\%) in purified argon atmosphere, and then the ingots were subsequently annealed at 400~450\(^{\circ}\)C for 50-100 h. For comparison, Cd\textsubscript{84.5}Yb\textsubscript{15.5} QCs were also prepared in an induction furnace. To inhibit the vaporization of Cd with a low boiling point of 765 \(^{\circ}\)C, flakes of Cd (99.9\%) and Yb were sealed in a quartz tube filled with purified argon gas and electrical power was controlled so that the constituent element Yb could be melted slowly at a lower temperature.

X-ray diffraction spectra were recorded using a rotating-anode x-ray generator (Cu K\(\alpha\), 50 KV, 120 mA) with a graphite (002) monochromator. The resistance measurements were preformed from 1.5 K to 300 K under a magnetic field of 0-6 T using a Linear Research LR 700-AC resistance bridge (\~15.9 Hz). And the magnetic susceptibility was
measured using SQUID. The samples used for resistance and magnetic susceptibility measurements are in bar shape with dimensions around $1.5 \times 1.5 \times 5 \text{ mm}^3$.

### III. RESULTS

Prepared (AgIn)$_{85}$Yb$_{15}$, (AgIn)$_{84.5}$Yb$_{15.5}$, and three (AgIn)$_{84}$Yb$_{16}$ QCs will be denoted by Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^a$, Yb$_{16}^b$ and Yb$_{16}^c$, respectively. Typical x-ray diffraction patterns for Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^b$ and Yb$_{16}^c$ samples are shown in Fig. 1. The diffraction peaks can be indexed by Elser’s method. The quasilattice constants calculated using (211111) peak are 5.6042, 5.5962, 5.5962 and 5.5725 Å, respectively for Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^b$ and Yb$_{16}^c$ QCs.

#### A. Resistance measurements

Fig. 2 shows the normalized resistivity, $\rho(T)/\rho(300 \text{ K})$, as a function of temperature between 4.2 K and 300 K for samples Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^a$, Yb$_{16}^b$ and Yb$_{16}^c$. Their resistivity at 4.2 K, $\rho(4.2 \text{ K})$, is 254, 217, 246, 248 and 70 $\mu\Omega\cdot\text{cm}$, respectively. All the resistance is seen to increase with decreasing temperature except the Yb$_{16}^c$ sample in which the resistance decreases as the temperature is lowered. The low-temperature resistance versus temperature for typical samples Yb$_{16}^b$ and Yb$_{16}^c$ is displayed in Fig. 3.

We can see that in the Yb$_{16}^b$ sample, the resistance drops rapidly at around 2.17 K, but it does not reach zero as temperature is down to 0.4 K. Similar resistance behavior is also observed in samples Yb$_{15}$, Yb$_{15.5}$ and Yb$_{16}^a$. But in the Yb$_{16}^c$ sample, the resistance drops at a higher temperature of 3.52 K and goes to zero as temperature is lowered further. This suggests the Ag-In-Yb QCs exhibit the superconducting behavior.
**B. Magnetic susceptibility measurements**

Al-based QCs of high perfection such as Al-Cu-Fe\textsuperscript{12} and Al-Pd-Re\textsuperscript{13} are diamagnetic; only the QCs containing Mn like Al-Mn, Al-Cu-Mn and Al-Pd-Mn exhibit paramagnetic behavior\textsuperscript{14} because in these samples a fraction of Mn atoms carry a magnetic moment. Series of Mg-RE-Zn QCs\textsuperscript{15,16} (RE = Y, Tb, Dy, Ho, and Er), no matter whether they are P-type or F-type lattice, are also paramagnets; their magnetic properties result from the magnetic moment of the RE\textsuperscript{3+} ions. Our magnetic susceptibility measurements on Cd-Yb QCs show that they are weak paramagnets since their magnetic susceptibility $\chi$ at 1.8 K is only about $1-3 \times 10^{-6}$ emu/ gauss-g.\textsuperscript{17} Assuming that their magnetic properties are due to the contribution of Yb\textsuperscript{3+} ions, we find the percentage of Yb\textsuperscript{3+} ions in all the studied Cd-Yb QCs is around 1.2-1.9 %. We believe the magnetic behavior in Ag-In-Yb QCs should be similar to that in Cd-Yb QCs.

In order to ascertain the superconductivity of Ag-In-Yb QCs, we measured the low-temperature magnetic susceptibility $\chi$ of the studied samples. Figs. 4 (a) and (b) typically show the $\chi$ value against temperature for samples Yb\textsubscript{15} and Yb\textsubscript{15.5} under an magnetic field of 10 gauss. As seen in the figure, the value of the field-cooled $\chi$ is negative below 2.5 K and 3.5 K, respectively, for both Yb\textsubscript{15} and Yb\textsubscript{15.5} samples, clearly exhibiting the Meissner effect.

Based on resistance measurements, the determined superconducting transition temperature is around 2.2 K and 3.5 K, respectively, for samples Yb\textsubscript{15} and Yb\textsubscript{15.5}. The $\chi$ values for Yb\textsubscript{15}, Yb\textsubscript{15.5} and Yb\textsubscript{16} also drop at around 2.0 K, but their field-cooled $\chi$ values are all positive as the temperature is lowered down to 1.8 K. For a bulk superconductor with a complete Meissner effect, the magnetic induction $B$ inside the sample is: $B = H +$
$4\pi M = 0$, where $H$ is an applied field and $M$ is the magnetization. With the field-cooled $\chi$ values obtained, we can estimate the volumetric proportion of superconductor, $V_p$, by taking the ratio of the sample magnetization at 1.8 K and 10 gauss to $H/4\pi$ ($H = 10$ gauss). The obtained $V_p$ for samples $\text{Yb}_1^b$ and $\text{Yb}_1^c$ to be $2 \times 10^{-4}$ and $3 \times 10^{-2}$, respectively. Small values of $V_p$ indicate that the Ag-In-Yb QCs are not bulk superconductors and imply that superconductivity should result from parasitic phases.

Since the $T_c$ values of Ag-In-Yb QCs are found to be in the range of 2.17-3.5 K, which are close to the $T_c$ value of 3.4 K for In, thus those parasitic phases might contain free In and/or In-containing alloys.

C. Magnetoresistance

Fig. 5 shows the magnetoresistivity $\Delta \rho(H)/\rho(0) = \rho(T, H) - \rho(T, 0)/\rho(T, 0)$ versus magnetic field $H$ at 4.2 K for samples Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^a$ and Yb$_{16}^c$. All the values of $\Delta \rho(H)/\rho(0)$ are found to be positive. The $\Delta \rho(H)/\rho(0)$ values at $T = 4.2$ K and $B = 6$ T extracted from the MR data are $1.4 \times 10^{-3}$, $1.35 \times 10^{-3}$, $0.2 \times 10^{-3}$ and $6 \times 10^{-1}$, respectively. The values of $\Delta \rho(H)/\rho(0)$ for samples Yb$_{15}$, Yb$_{15.5}$ and Yb$_{16}^a$ are much smaller than those obtained for CdYb QCs but the value of $\Delta \rho(H)/\rho(0)$ (~60% at 4.2K and 6 T) for sample Yb$_{16}^c$ is as large as that for CdYb. Rapp collected the MR data for amorphous metals and a large number of QCs and plotted their $\Delta \rho(H)/\rho(0)$ versus $\rho(4K)$, finding that there is a correlation between $\Delta \rho(H)/\rho(0)$ and $\rho(4K)$ up to $10^5 \mu\Omega\cdot\text{cm}$, i.e., $\Delta \rho(H)/\rho(0) \sim \rho^{1.3}$. Here the value of $\Delta \rho(H)/\rho(0)$ is measured at 4 K and the highest field performed in each experiment. The values of $\Delta \rho(H)/\rho(0)$ measured for Ag-In-Yb QCs excluding the Yb$_{16}^c$ sample are reasonably consistent with that (~$10^{-3}$) extracted from
the derived correlation relation. These values are larger than those (a few times $10^{-4}$) for Al-Mn-(CuZn) QCs\textsuperscript{18,19} with a resistivity ranging from 60 to 110 $\mu\Omega$-cm, but much smaller than order of several percent for Al-Cu-Fe\textsuperscript{20} and Al-Cu-Ru QCs\textsuperscript{21} because the resistivity ($10^3$-$10^4$ $\mu\Omega$-cm) of these Al-TM\textsubscript{1}-TM\textsubscript{2} QCs is much higher.\textsuperscript{9} The $\Delta\rho(H)/\rho(0)$ as a function of magnetic field $H$ at various temperatures is shown in Fig. 6. The MR is seen to increase with increasing magnetic field and to decrease with increasing temperature. This indicates that the temperature and field dependence of the MR follow the trend predicated by the theory of weak localization including spin-orbit (SO) scattering.

According to the quantum interference (QI) theory, the change in magnetoconductivity $\Delta\sigma(H) = \sigma(H,T) - \sigma(H,0)$ can be written as

$$\Delta\sigma(H) = -\Delta\rho(H)/\rho(0)^2 = \Delta\sigma_{WL}(H, \tau_i(T), \tau_{so}, D, g^*) + \Delta\sigma_{EEI}(H, D, F_\sigma, g^*)$$  \hspace{1cm} (1)

where $\Delta\sigma_{WL}$ and $\Delta\sigma_{EEI}$ are the contribution of weak localization and electron-electron interactions (EEI), respectively. The term due to the contribution of the superconducting fluctuation is supposed to be negligibly small in the Yb\textsubscript{15.5} sample for $T > 4.2$ K.

For $\Delta\sigma_{WL}$, we use Fukuyama-Hoshino’s results,\textsuperscript{22} which include the effects of SO scattering and Zeeman splitting of the spin subbands. For $\sigma_{EEI}$, we consider only the diffusion channel term by Lee and Ramakrishnan.\textsuperscript{23} In Eq. (1), $D$ is the electron diffusion constant, $F_\sigma$ an electron screening parameter, $g^*$ the effective Lande factor, $\tau_i(T)$ and $\tau_{so}$ the inelastic and SO scattering times of the electrons. Then we attempt to fit the MR data of the Yb\textsubscript{15.5} QC using Eq. (1).

In the fitting procedures, $g^*$ is taken to be 2. $D$ is estimated from the specific heat measurements (taking the $\gamma$ value of 2.9 mJ/(mole $\cdot$ K$^2$) for Cd\textsubscript{84}Yb\textsubscript{16} measured by us) using Einstein relation and is allowed to vary with temperature. It can be seen the MR data can be interpreted well with the QI theory, as seen in Fig. 6. For $T < 16$ K, the
extracted value of D varies from 0.4 to 0.5 cm$^2$/s; but at $T = 64$ K, the MR data can be fitted well only with a D value as large as 35.9 cm$^2$/s and $\tau_i = 1.4 \times 10^{-12}$ s. In view of the resistivity ratio $r$ being only 1.1, the value of D = 35.9 cm$^2$/s is too large to be accepted. However, keeping the D value close to 0.5 cm$^2$/s, we are unable to interpret the negative MR data at 64 K by further decreasing the value of $\tau_i$; this implies that the WL theory formulated with the perturbation theory may break down at this temperature. Nevertheless, the fact that the MR data at 64 K can be fitted with a D value as large as 35.9 cm$^2$/s remains to be understood. The obtained value of $F_\sigma$ is between 0.8 to 0.9; the value of $\tau_{so} \sim 0.54 \times 10^{-12}$ sec is about the same order of $\tau_{so}$ observed in most of Al-Cu-Fe QCs which have a positive MR$^{24}$ and an order of magnitude smaller than that obtained in Al-Mg-Cu QCs having a negative MR.$^{18}$

Logarithmic plot of the extracted value of $\tau_i$ vs T is shown in Fig. 7. The straight line shown in the figure is obtained by fitting the MR data to the relation: $\tau = \tau_0 T^{-p}$, with $\tau_0 = 1.4 \times 10^{-9}$ s and $p = 1.6$. The value $p \approx 1.6$ suggests that the low-temperature electron scattering process like in Al-Cu-Fe QCs$^{24}$ with a p value in the range 1~1.5 is dominated by electron-electron scattering.$^{25,26}$ This is in contrast with lower-resistivity QCs such as Al-Mg-(CuZn) where the p value is 2 or higher and the inelastic scattering process is attributed to electron-phonon scattering.$^{18,19}$

### D. Effects of ageing on the resistivity of the samples

After finishing our transport studies, we found that except the Yb$_{15.5}$ sample, all the resistivity of the studied samples varies with ageing. Fig. 8 shows the normalized resistivity ratio, $\rho(T)/\rho(300$ K), as a function of temperature measured at different dates for samples Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^a$ and Yb$_{16}^b$. It is seen that ageing can cause the reduction of the resistivity especially at low temperature in Yb$_{15}$, Yb$_{16}^a$ and Yb$_{16}^b$ samples such that
in the low-T regime the negative temperature coefficient of the resistivity (TCR)
becomes positive; but surprisingly, ageing almost cannot change the resistivity of the
Yb$_{15.5}$ samples. Additionally, we also found that the decrease of the low-T resistivity due
to ageing can lead to the increase of the MR, as shown in Fig. 9. It is found that the MR,
$\Delta \rho(H)/\rho(0)$, at 4.2 K and 6T for sample Yb$_{16}^a$ is seen to increase from $2 \times 10^{-3}$ to $15 \times 10^{-3}$
after ageing for about 8 months.

IV. DISCUSSION

All the studied Ag-In-Yb QCs have a negative TCR except the Yb$_{16}^c$ sample which
contains a significant amount of parasitic phases (possibly containing free In as
mentioned in section III-B). The room-temperature resistivity, $\rho(300K)$, for samples Yb$_{15}$,
Yb$_{15.5}$, Yb$_{16}^a$ and Yb$_{16}^b$ is above 150 $\mu \Omega$-cm, obeying the Mooij criterion which states that
in metallic alloys of transition metals, the TCR becomes negative as $\rho(300 K)$ is above
150 $\mu \Omega$-cm. The large $\rho(300 K)$ in these QCs can be ascribed to the low-density of
states (DOS) at the Fermi level ($E_F$) as observed in PE studies on Cd$_{5.7}$Yb QC and Cd$_6$Yb
approximant$^5$ and the decrease of the diffusion constant $D$ due to the reduced Fermi
velocity resulting from the dispersionless bands as found in electronic band calculations
for approximant crystals.$^{28}$ The $\rho(300K)$ for Yb$_{16}^c$, in fact, is also above 150 $\mu \Omega$-cm. The
fact that its TCR is positive is possibly caused by free In because the resistivity of the
metallic In being much smaller than that of the quasicrystalline matrix should dominate
the contribution of the resistivity of Yb$_{16}^c$ especially at low temperatures and therefore
leads to a positive TCR.

In Ag-In-Yb QCs, the parasitic phases are hardly detected by x-ray diffraction (see
Fig. 1), and are inferred from the appearance of the superconductivity and magnetic
susceptibility measurements. On the contrary, free Cd can be easily observed from the x-ray diffraction patterns of quasicrystalline CdYb samples.\textsuperscript{8} Therefore, we believe that the positive TCR observed in all studied CdYb QCs with $\rho(300\text{K})$ greater than 150$\mu\Omega\text{-cm}^{3,8}$ should be also due to free Cd. To confirm this, the resistivity and MR of the newly prepared Cd$_{84.5}$Yb$_{15.5}$ QC (denoted by Cd$_{84.5}$) were measured. The x-ray diffraction pattern of this sample shows that a small free Cd peak still appears at the diffraction angle of 38.3$^0$, but the intensity of this peak is much weaker than that observed in our previous report.\textsuperscript{8} The temperature dependence of $\rho(T)/\rho(300\text{ K})$ for the Cd$_{84.5}$ sample is shown in Fig. 2. It is seen that the resistivity increases with decreasing temperature. This clearly indicates that the negative TCR can be indeed observed in the range of the measured temperature, as expected if the amount of free Cd can be greatly reduced. Tamura et al.\textsuperscript{29} reported that incorporating small amount of Mg atoms (0.1 at %) could result in a negative TCR in CdYb QCs and emphasized that a negative TCR in the ternary systems is mainly due to chemical disorder, not a consequence of quasiperiodicity. However, their results disagree with the findings,\textsuperscript{6,8} and the above results in which CdYb QCs without any dopants can have a negative TCR. For Ag-In-Yb QCs with the value of $r$ greater than 1, their MRs, $\Delta\rho(H)/\rho(0)$, at 4.2 K are quite small (only $10^{-3}-10^{-4}$ at 6 T) and their MR data can be fitted well with the QI theory (see section $\square$-C). This means that the QI theory can be applied to describe the electrical and magnetotransport behavior of Ag-In-Yb QCs as applied to that of the other ternary QCs. Similarly, we believe that the anomalously large value of low-T $\Delta\rho(H)/\rho(0)$ observed in both Yb$_{16}^7$ and CdYb QCs is also caused by free In and Cd, respectively, because the giant value of low-T $\Delta\rho(H)/\rho(0)$ in both free In$^{30}$ and Cd$^{31}$ was reported. This can also be confirmed in Fig. 5, where the $\Delta\rho(H)/\rho(0)$ for the Cd$_{84.5}$ QC at 4.2 K and 6 T is seen to be about $1.22\times10^{-3}$, which is much smaller than that ($12 \times10^{-2}$) measured
by Tamura et al.,\textsuperscript{3} although it is still larger than $6 \times 10^{-4}$ expected from the correlation relation: $\Delta \rho(H)/\rho(0) \sim \rho^{1.3}$. And we found the MR data for Cd$_{84.5}$ QC at 4.2 K could also be described fairly well by the QI theory (see Fig. 5).

The reduction in the resistivity of Yb$_{16}^n$ subject to ageing might result from precipitation of parasitic phases, thereby resulting in the increase of MR. This needs to be confirmed further. The fact that only the electrical resistivity of the Yb$_{15.5}$ sample is unaffected by ageing may suggest the composition of the Yb$_{15.5}$ sample close to stoichiometric composition.

\section{V. CONCLUSION}

For high-quality Ag-In-Yb QCs, the TCR is negative and their MR is small, and the variation of the MR with magnetic field and temperature can be well described by the QI theory. The observed positive TCR and large MR were attributed to the sample including parasitic phases containing free In and/or In-containing alloys. Among the studied (AgIn)$_{100-x}$Ybx QCs with $15 \leq x \leq 16$, the (AgIn)$_{42.25}$Yb$_{15.5}$ sample is found to be the most stable one; and its composition may be close to stoichiometric composition.

The temperature and field dependence of the resistivity for the Cd$_{84.5}$Yb$_{15.5}$ QC behave quite similarly to those for the Yb$_{15.5}$ QC. Thus, the intrinsically electrical and magnetotransport properties of P-type stable QCs can be revealed by focusing on studying (AgIn)$_{42.25}$Yb$_{15.5}$ QCs because binary CdYb QCs of high quality are much more difficult to be prepared at present.

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FIGURE CAPTIONS

Fig. 1. X-ray diffraction patterns for Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^{a}$, Yb$_{16}^{b}$, and Cd$_{84.5}$ quasicrystals.

Fig. 2. The normalized resistivity $\rho(t)/\rho(300K)$ as a function of temperature for

Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^{a}$, Yb$_{16}^{b}$, Yb$_{16}^{c}$, and Cd$_{84.5}$ quasicrystals. The resistivity at 4.2 K,
$\rho(4.2\ K)$, is 254, 217, 246, 248, 70, and 168 $\mu\Omega\cdot$cm, respectively.

Fig. 3. The low-temperature resistance as a function of temperature for samples Yb$_{16}^{b}$
and Yb$_{16}^{c}$ plotted in an expanded scale.

Fig. 4. The temperature dependence of both the field-cooled and zero field-cooled
magnetic susceptibility $\chi$ for Yb$_{16}^{b}$ and Yb$_{16}^{c}$ quasicrystals. The applied field is 10
gauss.

Fig. 5. The magnetoresistivity, $\Delta\rho(H)/\rho(0)$, as a function of magnetic
field B measured at 4.2K for Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^{a}$, Yb$_{16}^{c}$, and Cd$_{84.5}$ quasicrystals.

The solid curve is theoretical calculations using Eq. (1) with D = 0.1 cm$^2$/s, $F_{o}$=
0.6, $\tau_{i}(4.2\ K) = 69 \times 10^{-10}\ s$, and $\tau_{so} = 0.64 \times 10^{-12}\ s$.

Fig. 6. The magnetoresistivity, $\Delta\rho(H)/\rho(0)$, as a function of magnetic field B at various
temperatures for Yb$_{15.5}$ quasicrystals. Solid curves are theoretical fits.

Fig. 7. Logarithmic plot of the inelastic scattering time $\tau_{i}$ vs temperature for Yb$_{15.5}$
quasicrystal.

Fig. 8. The normalized resistivity, $\rho(T)/\rho(300K)$, as a function of temperature for

Yb$_{15}$, Yb$_{15.5}$, Yb$_{16}^{a}$ and Yb$_{16}^{b}$ quasicrystals subject to ageing. The dates on
which the resistivity was measured are also shown in the figure.
Fig. 9. The magnetoresistivity, $\Delta \rho (H)/\rho (0)$, as a function of temperature for quasicrystal Yb$_{16}^a$. The black symbols are the data for the samples subject to ageing; the blank symbols are the data for the fresh sample.
Fig. 1
Fig. 2
Fig. 3

(a) $Yb_{16}^b$

2.17 K

(b) $Yb_{16}^c$

3.52 K

T (K)

resistance (mΩ)

T (K)
Fig. 4

(a) Yb$_n^b$
- FC
- ZFC

(b) Yb$_n^c$
- FC
- ZFC

\[ \chi \text{ (emu/ gauss-g) } \times 10^{-6} \]

\[ \chi \text{ (emu/ gauss-g) } \times 10^3 \]

T (K)

Fig. 4
Fig. 5

$\Delta \rho(H)/\rho(0) \times 10^3$

$T = 4.2$ K

- $Yb^c$
- $Yb^{16}_{15}$
- $Yb^{15.5}$
- $Yb^a$
- $Cd^{16}_{84.5}$

$H$ (T)
Fig. 6

\[ \Delta \rho(H)/\rho(0) \times 10^{-3} \]

- Yb\textsubscript{15.5}
- \( \diamond \) 4.2k
- \( \blacktriangle \) 8k
- \( \circ \) 16k
- \( \triangledown \) 64k

H (T)

\[ \Delta \rho(H)/\rho(0) \times 10^{-3} \]

0 1 2 3 4 5 6

0.0

0.5

1.0

1.5

-0.5

-1.0

Fig. 6
Fig. 7
Fig. 9

\[ \Delta \rho(H)/\rho(0) \times 10^{-3} \]

- Yb\textsubscript{i}\textsuperscript{16}
  - \( \triangle \) 16 K
  - \( \bullet \) 4.2 K
  - \( \square \) 8 K
  - \( \diamond \) 12 K

\[ H (T) \]