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Work function of a quasicrystal surface: Icosahedral Al–Pd–Mn

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Abstract

The work function of a surface is one of its most basic and influential features. It has long been recognized that work function controls thermionic and field emission. The work function of a solid surface affects charge transfer to or from an adsorbate. It influences the electron tunneling probability between surfaces. It plays a role in quantization of electron states parallel to the surface in metal-supported metallic nanoislands. There is also evidence linking the work function of a metal surface to its friction coefficient.

Keywords

Ames Laboratory, Materials Science and Engineering, aluminium alloys, manganese alloys, palladium alloys, quasicrystals, work function, i-Al-Pd-Mn quasicrystal, NiAl(110), Ir(111)

Disciplines

Materials Science and Engineering | Physical Chemistry

Comments

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BRIEF REPORTS AND COMMENTS

This section is intended for the publication of (1) brief reports which do not require the formal structure of regular journal articles, and (2) comments on items previously published in the journal.

Work function of a quasicrystal surface: Icosahedral Al–Pd–Mn

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The work function Φ of a surface is one of its most basic and influential features. It has long been recognized that work function controls thermionic and field emission.[1] The work function of a solid surface affects charge transfer to or from an adsorbate.[1] It influences the electron tunneling probability between surfaces.[1] It plays a role in quantization of electron states parallel to the surface in metal-supported metallic nanoislands.[2] There is also evidence linking the work function of a metal surface to its friction coefficient.[3–5]

Quasicrystals are metallic alloys having aperiodic atomic order.[6,7] Most quasicrystals exhibit forbidden rotational symmetries.[8] Their unusual atomic structure engenders unusual physical properties, including low friction.[7] Hence, one might ask whether the work function of a quasicrystalline surface is also unusual.

In this note, we report a value for the work function of a five fold surface of the icosahedral (*i*-) quasicrystal, $Al_{70.2}Pd_{20.7}Mn_{9.1}$ (Ref. 9) and for comparison, we also report a value for an other intermetallics, NiAl(110). The value was measured at room temperature with the retarding field method, using a low-energy electron microscope[10] (LEEM) in mirror electron mode (MEM).[11,12] The LEEM approach uses images to measure reflectivity. The advantage is that the analysis is done on a region known to be stepped and terraced, as shown in Fig. 1(a) for the *i*-Al–Pd–Mn quasicrystal and in Fig. 1(b) for NiAl(110).

In MEM,[13] the electron reflectance is measured as a function of electron kinetic energy. As shown in Fig. 2, when the electrons overcome the work function of the surface, they start to interact with the sample, so the total reflected electron intensity or relative reflectivity R decreases. Typically, the energy at approximately 10% decrease in the plateau value (i.e., $R=1$) of the relative reflectance is equivalent to the work function of the sample.[11,12]

In our experiments, the quasicrystal sample was prepared in a UHV chamber by sputtering and annealing to a final temperature of 924 K (measured by a two-color pyrometer), following previously published procedures.[14] In addition, Fig. 2 also shows the reflectivity versus electron energy for clean Ir(111), Ru(0001), and NiAl(110) at 1115, 973, and 330 K, respectively. From the literature values of $\Phi = 5.70–5.76$ V for Ir(111) (Refs. 15 and 16) and 5.45 V for Ru(0001),[17] the work function of the LEEM instrument (i.e., Φ of the electron emitter cathode) is determined.

Using this calibration procedure, we find $\Phi = 4.75–4.91$ V for the quasicrystal surface, where the range of values is due to the range of literature values for the clean elemental surfaces that served as benchmarks and also partially due to the consistency in the work function determination of the LEEM instrument. The literature work functions of the constituent elements of the quasicrystal are Φ_{Al}

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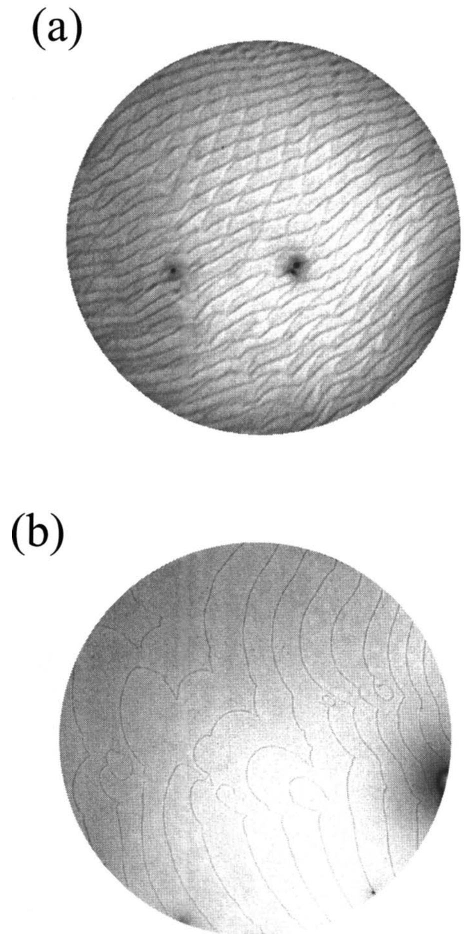

FIG. 1. Bright-field LEEM images for (a) the quasicrystal surface at 300 K. The electron energy is 4.7 eV. The image size, field of view (FOV) is 7 μm. (b) NiAl(110) at 330 K. The electron energy is 4.0 eV and the FOV is 14.5 7 μm. In the images, the dark lines mark the location of the steps on the surface. Note that the dark features in the middle of the image in (a) are the artifacts due to the defects in the multichannel plates.

$=4.2$–4.3 V, $\Phi_{Pd}=5.1$–5.6 V, and $\Phi_{Mn}=4.1$ V.[18,19] From these values, the atomic-composition-weighted average Φ of *i*-5*f*-Al–Pd–Mn is calculated to be 4.38–4.55 V. This value is only about 10% lower than the measured value of the quasicrystal, 4.75–4.91 V, which suggests that the work function is dominated by composition, not structure. For comparison, the atomic-composition-weighted average work function of $Ni_{0.57}Al_{0.43}(110)$ is found to be 4.86–4.90 V from the work functions of its constituent elements, which are $\Phi_{Al}=4.2$–4.3 V and $\Phi_{Ni}=5.35$ V.[18,19] This value is 6%–10% lower than our measured value for $Ni_{0.57}Al_{0.43}(110)$, 5.23–5.39 V, which again suggests that work function scales with composition. Our measured work function value is also consistent with the reported value of NiAl(110), 5.1–5.6 V.[20] In addition, for NiCu and PtRh alloys, composition dependent work function values have been reported.[21] In the former case, the scaling relationship was linear but in the latter the relation was nonlinear.[21]

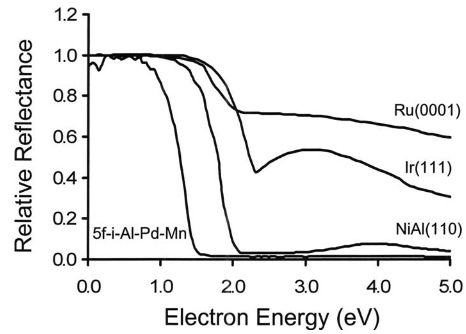

FIG. 2. The electron energy where the relative reflectance R decreases by 10% from $R=1$ is taken as the work function, relative to the LEEM instrument's work function. The latter is determined from the measured curves for Ru(0001) and Ir(111) using the literature values of their work function.

If the work function indeed scales with composition, then it may be a useful measure of the composition of quasicrystal surfaces. More generally, work function measurements may be useful for predicting or understanding other surface properties of quasicrystalline materials.

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