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Electron screening and electron–electron scattering mechanisms

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ABSTRACT

The roles of binary and multiple scattering are considered in the context of electron scattering and diffraction on the W(1 1 0) and W(1 1 0)+O(1 × 1) surfaces for energies from 10 to 40 eV. We define a binary scattering mechanism as the incident electron interacting with the field of a valence electron with conservation of the total momentum of the incident and valence electrons. Multi-particle scattering is defined as an interaction of the incoming electron with superposed valence electron fields where determination of the total momentum is not well described. The scattering mechanisms all depend on the electron energy, the density of the scattering electrons and the screening parameter of the Coulomb field in the solid. A model is suggested for the formation of the potential of the scattering field as a superposition of the fields of the screened valence electrons uniformly situated over the first coordination sphere. A quantitative criterion is developed for the binary scattering in which the radial distribution of the scattering potential is normalized to a single charge potential distribution. The model predicts an electron binary scattering mechanism from clean W(1 1 0) and a multi-particle scattering mechanism from W(1 1 0)+O(1 × 1). The results agree with experimental results and imply the validity of the modeled assumptions. The model also shows for electron-pair (e,2e) spectroscopy on metals that the electron–electron interaction occurs predominantly in the vicinity of an atom associated with the diffraction of the incident electron.

1. Introduction

It is generally recognized that the electron subsystem of normal metals can be described by the Fermi-liquid model [1]. Also the approximation of a weak interacting Fermi gas can describe the heat capacity and electro conductivity of metals [2]. The electron–electron scattering allows us to have a look inside the electron structure of solids. We use e2e electron spectroscopy to analyze the individual scattering of the particular primary electron on a valence electron of the solid. A simple phenomenological model of the primary electron interaction with the superposition of fields of valence electrons is considered.

We start by considering the electrons in a metal as quasiparticles such that in a weak interacting electron gas the electron–electron scattering may be described in the binary approximation. The total momentum of the two interacting particles is conserved. By binary scattering we understand that the incident particle interaction is predominantly with the field of an individual quasiparticle. The limiting alternative is the incident electron interaction with the total field of many quasiparticles. A strong interaction between the electrons may occur in the region of a superposition of fields of several valence electrons. The binary approximation is not valid, the momentum of the "test" electron is lost in a "sea" of the interacting particles but to what extent the interaction can be regarded as binary? It has been shown that the electron–electron scattering at electron energies in the region from 10 to 50 eV near the surface of a metal can be described generally by binary particle scattering with conservation of the total energy and momentum, however similar scattering on the surfaces of the semiconductor (n-Si) and dielectric (MgO) is described better by multi-particle interactions [3].

Electron-pair, alternatively termed (e,2e), spectroscopy has been well interpreted as an incident electron scattering by a valence electron. For the case of measurements using "reflection geometry", inelastic electron scattering must be accompanied by elastic scattering on the potential field of the atom. In the case of a crystal surface elastic scattering is synonymous with diffraction. Then the normal to the surface component of the incident momentum vector reverses sign, and the tangential to the surface component of the momentum is conserved up to a reciprocal lattice vector. An (e,2e) experiment allows us to see if the total momentum of the scattered electrons is changed with the change of the incident electron incidence angle. That is why an (e,2e) experiment on a single crystal surface allows us to judge if the total momentum of the pair of interacting particles is conserved during electron–electron scattering.

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The dynamical low energy electron diffraction (LEED) and very-low-energy diffraction (VLEED) allow us to investigate the atomic structure of crystalline surfaces [4–6]. The theory of dynamical scattering takes into account the multiple elastic scattering of electrons on the ion cores of solids. The multiple elastic scattering is essentially important in the low energy region of scattering electrons. Electron energy loss spectroscopy (EELS) deals with the inelastic electron scattering [7]. In the typical for LEED and VLEED energy region EELS considers the excitation of valence electrons and plasmons in solids. The inelastic low energy electron diffraction (ILEED) considers the electron–electron and electron plasmon interaction on the crystalline surface [8,9]. e2e electron spectroscopy in the low energy region from the formal point of view may be considered as an extension of EELS and ILEED. The main difference of e2e electron spectroscopy is the possibility to detect both scattered electrons at the same time. In a conventional ILEED and EELS one detects only one of the scattered electrons and the second electron is not detected and it can be scattered in any possible final state. The intensity of losses is averaged over all possible states of the second electron and over all valence electrons taking part in the scattering, accordingly. e2e electron spectroscopy unlike the conventional one allows us to detect the state of the valence electron taking part in the scattering reaction and to get all possible information about the unit scattering reaction.

The full quantum mechanical approach to e2e electron spectroscopy of metals was developed in Refs. [10–14]. Its application to experimental results in the region of low energy e2e spectroscopy gives reasonable agreement for various metals which have strong electron screening [15–17]. There is also a successful application of this approach to the e,2e scattering on LiF(1 0 0) [18]. Unfortunately, until now there are no systematic investigations of the application of these methods to different crystalline solids with varying screening and a valence electron density. At the same time, experimental results of low energy e2e spectroscopy on the semiconductor (n-Si), dielectric (MgO) and adsorption system of W(1 1 0) + O(1 × 1) [19] show that the electron scattering mechanism in those materials is different from that in metals. We present here a simple phenomenological model to show that the electron screening and the density of valence electrons taking part in the interaction may influence the electron scattering mechanism. The proposed model allows to estimate how much the superposition of the valence electron fields differs from the field of a point charge and in turn to estimate the probability of the binary scattering. These results can be helpful in the case of any electron spectroscopy when the electron–electron interaction is considered.

We use a model of electron–electron scattering for low energy electrons at the excitation energy of 10–40 eV [3]. It is assumed that the valence electron fields, as well as the incident electron field, in the solid are screened with the screening parameter λ whose value depends on the electron density at the Fermi level. Only when those fields may be neglected, the approximation of the binary scattering can apply, i.e. scattering on a specific valence electron with the total momentum of the interacting particles being conserved, otherwise the incident electron on entering the solid experiences a field corresponding to the superposition of the screened fields of the nearest surrounding valence electrons. This possibility depends both on the incident electron energy and the screening parameter of the Coulomb field of the point charge. In the quasi-particle approximation the low energy electron scattering in metals with strong screening may be described in the binary scattering approximation with the total momentum being conserved. In contrast the electron scattering in semiconductors and dielectrics with weak screening is the multi-particle type as confirmed by experimental results [3].

In the present paper we discuss the quantitative criteria for applicability of the binary or multi-particle mechanism for low energy electron scattering in a solid. The experimental results and theoretical calculations have been obtained for the adsorption system W(1 1 0) + O. On the clean W(1 1 0) face the electron-pair (e,2e) scattering proceeds with the momentum conservation of binary scattering while in the case of the W(1 1 0) + O system with multi-particle scattering and the momentum is not conserved. The theoretical estimations show that there is a correlation between the mechanism of the scattering and the electron screening parameter when determined by the electron density at the Fermi level.

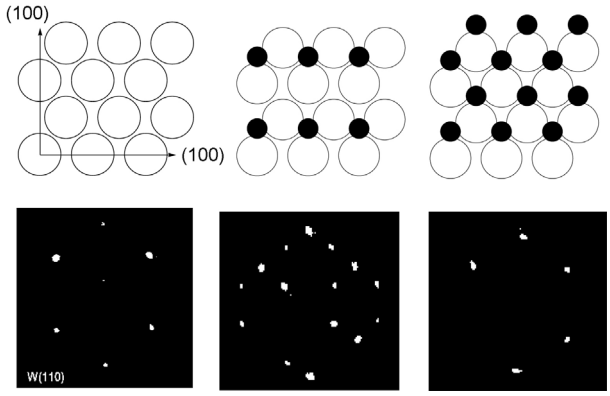

Fig. 1. Diffraction patterns from tungsten and adsorption structures on the surface. Left panes – W(1 1 0), middle panes – W(1 1 0) + O(1 × 2) and right panes – W(1 1 0) + O(1 × 1). The upper panes represent the surface structures projected on the W(1 1 0) surface. The open circle is the atomic sphere of tungsten with the radius of 1.27 Å, the closed circle is the atomic sphere of oxygen with the radius of 0.635 Å.

2. Experimental results

The experiments were performed in 10^{-11} Torr UHV conditions. The residual magnetic field within the vacuum chamber was reduced to less than 5 mG by using a combination of static and dynamic Helmholtz coils. The W(1 1 0) crystal was cleaned by standard procedures including oxygen treatment at 1400 °C followed by high temperature flashes [20]. The cleanliness of the sample was monitored by Auger Electron Spectroscopy and Low Energy Electron Diffraction. An ordered oxygen layer was formed at the sample temperature of 1300 °C with oxygen at 2×10^{-8} Torr while the diffraction pattern was monitored [19].

We examine the influence of a controlled oxygen adsorption on the electron–electron scattering mechanism on the tungsten surface. The atomic structure of the oxygen monolayer on W(1 1 0) is well known [21,22]. We use LEED to control the emergence of the well established oxygen monolayer on the tungsten surface. Fig. 1 shows diffraction patterns illustrating the changes in the surface structure during the oxygen adsorption on tungsten with Fig. 1 left panes, clean W(1 1 0) surface; Fig. 1 middle panes, predominant formation of the W(1 1 0) + O(1 × 2) structure; Fig. 1 right panes, predominant formation of the W(1 1 0) + O(1 × 1) structure. The upper panes represented surface structures projected onto the W(1 1 0) surface. The open circle represents a tungsten atomic sphere with the radius of 1.27 Å and the closed circle represents an oxygen atomic sphere with the radius of 0.635 Å. The distance between the centers of two tungsten atoms is 2.741 Å and the acute angle between tungsten atoms is 70.53°. The position of the diffraction maxima corresponds to the crossing points of the Ewald sphere with the "rods" of the surface reciprocal lattice. The six diffraction maxima, nearest to the center in Fig. 1 left bottom pane, correspond to the W(1 1 0) surface structure. The appearance of additional diffraction maxima in Fig. 1 middle bottom pane is the evidence of formation on the surface of the new spatial O(1 × 2) structure with the double period in one direction (see Fig. 1 middle upper pane). Accordingly, the period of the reciprocal surface lattice