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Influences of the incident He* velocity on metastable de-excitation processes at a Cs-covered Si(100) surface

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Abstract

A Si(100) surface covered with cesium at saturation coverage were exposed to helium metastable-atom beams. The spectra of the electrons induced by metastable-atom de-excitation were detected as a function of the velocity of the incident He* in the velocity range 1–5 km/s. We discuss the influence of the incident He* velocity on the metastable de-excitation processes that take place at the Cs/Si(100) surface of very low work function.

With increasing He* velocity, the relative weight of the peak from the decay of $He^{*-}(1s2s^2)$ in the spectrum was decreased, which means the auto-detachment process becomes more important than the Auger de-excitation process. The low-energy threshold of the spectrum shifted to higher energies with higher He* velocities. This implies that the surface electronic states are distorted by incident atoms, and, consequently, the surface potential barrier is increased.

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1. Introduction

The metastable-induced electron spectroscopy (MIES) utilizes usually beams of excited He atoms (He*) to extract the electronic structure of surface topmost-layers. There are several possible paths of de-excitation of He* atoms at surfaces in the MIES [1]. The probability of each de-excitation process depends on the distance between the He* atom and the surface. Theoretically their integrated probabilities along the trajectory of incident particles determine what process actually occurs.

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When a He atom enters into a surface region with the translation energy of 100 eV, it takes approximately 10^{-15} s for a 1 Å distance near the surface, whereas with 0.1 eV about 10^{-13} s. These time intervals may roughly correspond to characteristic time scales for electronic processes that occur in the He*-surface system [2], e.g. resonance tunneling, Auger transition, or plasmon excitation and its decay. Dominant de-excitation processes will be replaced by others as the mean velocity of incident atoms changes.

Kato et al. studied the de-excitation process for the metastable atoms using a high energy (~500 eV) beam [3]. On the other hand, usual experiments of MIES are performed with He* beams of thermal velocity distribution. However, any influences of the incident particle velocity on MIES spectra have not mentioned so far.

We explored the dependence of the MIES spectra on the projectile velocity by using a Cs adsorbed Si(1 0 0) surface that shows very low work function. From observed differences in the spectra for different He* velocities, we discuss the competition between the two mechanisms, Auger de-excitation and auto-detachment, for the chosen surface conditions.

2. Experimental

In a hot-cathode, low-voltage discharge Helium atoms are excited mainly to the He2^3S state. Metastable atoms, produced by the pulsed discharge, are discriminated from fast ground-state atoms or photons by their time-of-flight (ToF) differences. The length of a tube for the metastable-atom flight is 60 cm. The analysis chamber is equipped with the He* source, the low-energy electron diffraction (LEED) optics, Ar^+ ion bombardment facilities, and a retarding-field energy analyzer. The base pressure was around 1.0×10^{-8} Pa. The sample is a Si(1 0 0) substrate of B-doped p-type, cleaned in a vacuum by direct-current Joule heating. Cesium was deposited by a well-degassed dispenser of SAES Getters. The integrated spectra which are the raw date obtained from the analyzer are differentiated numerically to yield MIES spectra.

Metastable atoms are de-excited at surfaces through several channels [1,2]. If the surface work function is decreased below about 3.5 eV, incident metastable atoms are de-excited through the Auger de-excitation (AD) process [4]. In this case, a He*2s electron is excited to the continuum when a He*1s hole is filled by an electron coming from the surface. The MIES spectrum reflects the local density of states at positions where He* atoms are de-excited. Another de-excitation process, called auto-detachment (AU), occurs with large probability at surfaces with a very low work function (lower than about 2.2 eV), competing against the AD process [4–6]. As the affinity level of the He* atom is lowered near or even below the Fermi level (E_F), the electron tunneling from the surface to that level becomes allowed. As a consequence, the negative ion $He^{*-}(1s2s^2)$ is formed, which is de-excited by auto-detachment. MIES spectra due to this process do not reflect surface local density of states, but rather represent broadened He-2s states.

3. Results and discussion

The relative contribution from each de-excitation process for He* atoms to the spectra implicitly depends on their velocities. It is, therefore, necessary at first to obtain information on the velocity distribution for the incident He* flux in order to correctly interpret measured MIES spectra. We measured emission-time distribution of electrons induced by He* atoms which were produced by a pulsed discharge. The result is shown in Fig. 1, where the amount of emitted electrons is regarded as proportional to the incident He* flux, and the delayed emission times correspond to the times of flight of He* atoms. The former relationship is justified because, at clean Si surfaces, He* atoms are de-excited always through a single channel, i.e. via the process of resonance ionization, followed by Auger neutralization [7], at least in the velocity region used in the present study. Relatively fast He* particles had velocities in the range 4–5 km/s, whereas slower ones around 1 km/s. The majority of He* particles in the beam had velocities of 2–3 km/s.