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INFLUENCE OF TEMPERATURE AND OF PHYSISORBED Xe/Kr ON THE SPIN RESOLVED PHOTOEMISSION FROM Pt(111)

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Spin polarized photoemission from Pt(111) has been studied under normal incidence and normal emission as function of the temperature between 30 and 550 K using circularly polarized synchrotron radiation of BESSY. The photoelectron intensities and the electron spin polarizations are reduced with increasing temperature and also by increasing coverage of physisorbed rare gas atoms.

1. Introduction

Photoelectrons ejected from unpolarized targets by circularly polarized light are generally spin polarized due to the existence of the spin–orbit interaction and the corresponding dipole-selection rules [1–4]. In non-magnetic solids the electron spin polarization (ESP) depends on the symmetry properties of the electron bands [3,5]. Therefore measurements of this type allowed a symmetry resolved band mapping of Pt(111) [3].

In this paper we report on angle- and spin-resolved photoemission spectroscopy of Pt(111) in normal incidence and normal emission, which has been studied as function of the target temperature between 30 and 550 K and as function of rare-gas coverage using circularly polarized synchrotron radiation at the electron storage ring BESSY. Temperature effects in angle-resolved photoemission processes have been discussed in terms of thermal and other disorders by Williams et al. and Shevchik [6]. Heimann and Neddermeyer [7] observed a pronounced broadening of the photoemission structures for direct transitions at Au(111) with increasing temperature. For metal halides an appreciable broadening of the energy-distribution curves of the photoelectrons with increasing temperature was observed by Bauer et al. [8].

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2. Experimental

The measurements have been performed using the synchrotron radiation emitted above or below the storage-ring plane and monochromatized by a 6.5 m NI monochromator of the Monk–Gillieson type [9] and found to be elliptically polarized with a high degree of circular polarization [2]. The photoelectrons emitted are analyzed with respect to their kinetic energy and their spin polarization by a rotatable simulated hemispherical spectrometer system and by an UHV Mott detector, respectively [3]. The adsorbate was introduced via a doser nozzle in front of a liquid He-cooled target manipulator. The Pt(111) crystal was cleaned by a combination of ion bombardment, heating in oxygen and flashing and was characterized by AES and LEED.

3. Experimental results and discussion

3.1. Influence of the target temperature

One example of a spin-resolved photoelectron spectrum of Pt(111) at 300 K is presented in fig. 1. The spin-polarization values shown are normalized to a complete circular polarization with positive helicity; each error bar contains

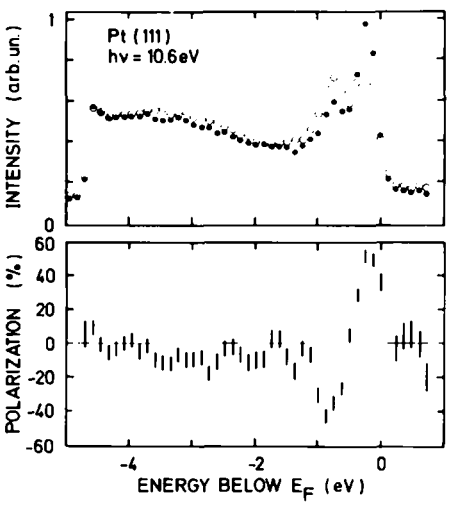

Fig. 1. Spin-resolved photoelectron spectrum of Pt(111) for normal incidence and normal emission at 300 K. Upper part: Intensities measured with the two counters in the Mott detector, solid and open circles. Lower part: Corresponding electron-spin polarization obtained from the data in the upper part and normalized to a complete circular polarization of the light. The experimental energy resolution ΔE is 150 meV FWHM (improved with respect to ref. [3]).

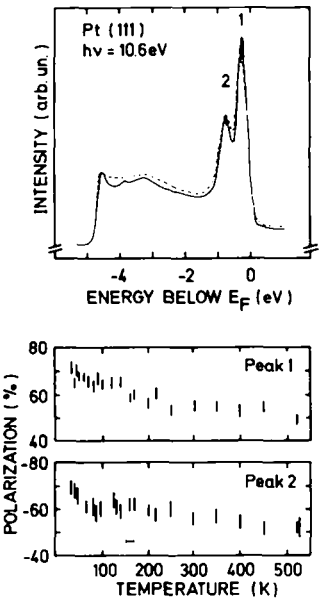

Fig. 2. Upper part: Highly resolved photoelectron intensity spectra for normal incidence and normal emission at a temperature of 300 K (dashed line) and 40 K (solid line). Lower part: The corresponding spin polarization of peaks 1 and 2 (upper part) at $h\nu = 10.6$ eV (close to the theoretical calculation [11] as a function of the temperature. ΔE as in fig. 1.

the uncertainty of photon and electron polarization analysis. For normal emission the ESP has been found to be aligned along the surface normal, which defines the z-axis. The experimental spectrum at a photon energy of 10.6 eV clearly shows two peaks with positive and negative ESP, which arises due to direct interband transitions of the symmetry type $\Lambda_{4,5} \rightarrow \Lambda_6$ (positive ESP) and $\Lambda_6 \rightarrow \Lambda_6$ (negative ESP) [3].

The measured ESP, which never exceeded $\pm 55\%$ at room temperature is, however, lower than the values of $\pm 100\%$ predicted by group theory for transitions between non hybridized bands [5]. Fig. 2 shows the ESP measured of the first two peaks in the intensity spectrum at $h\nu = 10.6$ eV as function of the temperature between 30 and 550 K. With decreasing temperature the ESP increases from $\pm 50\%$ to more than $\pm 70\%$. Opposite to ferromagnetic materials, where the depolarization of 4f photoelectrons increases on approaching the Curie point T_c [10], this effect might be explained by a decreased emission of unpolarized electrons from non-$k_\perp$-conserving transitions and other phonon assisted non-direct transitions which enhance the inelastic contributions to the direct transitions. With increasing temperature the non-direct unpolarized transitions become stronger. This effect may reduce the ESP measured in the peaks of the photoelectron spectrum at 10.6 eV. In addition, going from 300 to

40 K, the peak widths become smaller by about 50 meV and hence a deeper minimum between the intensity peaks is observed. It is worth noting that the ESP of peak 2 in fig. 2 at room temperature is a little bit higher than shown in fig. 1, due to the overall smaller contribution of the inelastic background compared with the peak height. Taking into account that electrons in the inelastic background are unpolarized the ESP analysis of both direct peaks alone yields data close to $\pm 80\%$ for a temperature of 30 K. Each value shown in fig. 2 has been obtained just after the crystal has been cooled down to the corresponding temperature. This procedure has been done to work with a clean crystal, because we observe a depolarization (of about 10%) as function of the time (about 1 h) due to the rest gas adsorption on the crystal. This high positive polarization measured in the first peak is in rather good agreement with a new relativistic one-step photoemission calculation for Pt(111) by Ackermann and Feder [11], who predicted an ESP of about 90% for the first peak at a photon energy of 11 eV.

3.2. Influence of rare-gas adsorption

The photoelectron intensities of the direct transitions of Pt(111) are strongly reduced with increasing coverage of Xe or Kr, as shown for Xe at two different photon energies in fig. 3. A similar decay of d-band intensities depending on coverage of different adatoms was observed also for Ni(110) at 21.2 eV by Jacobi and Rotermund [12]. The absolute photoelectron intensity and the ESP of the peaks of the adatoms are very high near threshold and vary strongly with the photon energy, as discussed in ref. [4], while at $h\nu = 15.5$ eV, however, the intensities from the physisorbed Xe atoms are already strongly reduced. Fig. 4 shows the ESP in dependence of the photon energy for clean Pt and for Pt covered by a complete $\sqrt{3}$ layer of Xe atoms. The ESP in the first two peaks of Pt(111) is more reduced in the threshold region of the rare-gas photoemission than towards higher photon energies. This effect can be explained by a stronger interaction between the outgoing electrons and the physisorbed atoms for electrons of smaller kinetic energies. The adsorption induced depolarization effect is more pronounced in the reality than shown in fig. 4, because it is partly masked by the polarization enhancement due to the decrease of the temperature as discussed in section 3.1. Such depolarization effects for the bulk electrons, which have also been observed for different surface layers of Ni, Gd, Ce, Au and Cs at Ge and GaAs [13], may be due to spin-flip scattering at the Xe overlayer. In accordance with this, the ESP is reduced with increasing coverage and for a complete Xe monolayer we only found an ESP less than $\pm 15\%$.

Another effect of the increasing coverage of Xe or Kr atoms is a new peak at 0.25 eV below E_F (fig. 3), which does not show any dispersion for different coverages of Xe and Kr atoms. This is demonstrated in fig. 5 (peak marked by

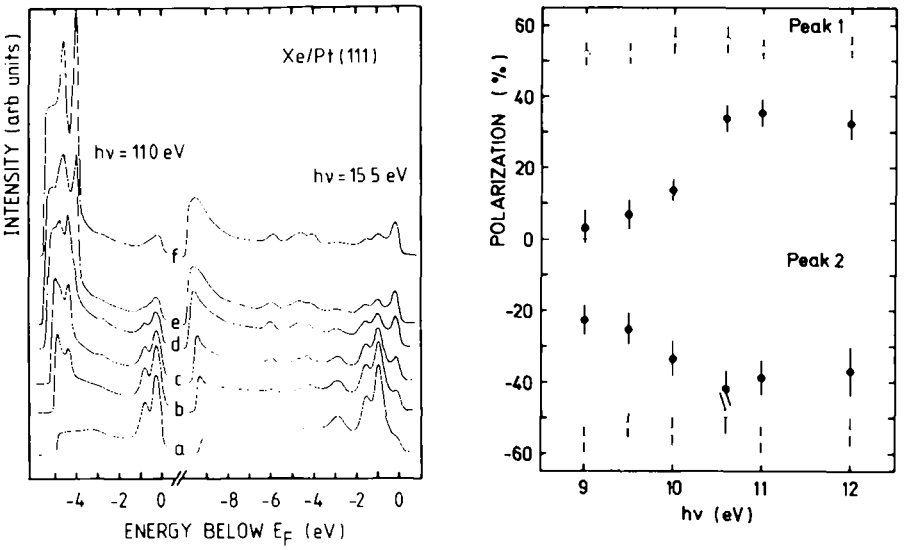

Fig. 3. Photoelectron spectra of Pt(111) for normal incidence and normal emission taken at various coverages of xenon: (a) clean substrate, (b)–(d) growth of commensurate $\sqrt{3} \times \sqrt{3}$ (R30°) islands of Xe, (d) complete $\sqrt{3}$ layer, (e) compression phase, (f) complete incommensurate hcp monolayer.

Fig. 4. Photoelectron-spin polarization of the peaks 1 and 2 of Pt(111) (see fig. 2) as function of the photon energy for clean Pt ($T = 300$ K, open circles) and for Pt covered by a complete $\sqrt{3} \times \sqrt{3}$ (R30°) layer of Xe ($T = 50$ K, full circles).

an arrow) for photon energies between 12.0 and 16.5 eV. At $h\nu \leqq 12.0$ eV it is overlapped by the first peak corresponding to the direct transition of Pt(111), which may be partly responsible for the depolarization (fig 4): With a $\sqrt{3}$ layer of Xe and a monolayer Kr we measured an ESP of $2.7 \pm 3.7\%$ and $7.8 \pm 3.7\%$, respectively, in this peak at a photon energy of 15.5 eV. This new peak which is clearly enhanced by adsorbate coverage (cf. fig. 3) might be already present for clean Pt, as indicated in a recent calculation [11].

4. Conclusion

Spin polarized photoelectrons corresponding to direct interband transitions of Pt in the Λ direction have been measured as function of the target temperature and of the rare gas coverage using spin- and angle-resolved photoelectron spectroscopy. At low temperatures (30 K) spin polarizations of close to $\pm 80\%$ have been observed in the direct transitions, much higher than at room temperature. Furthermore, it has been seen that only a coverage of less

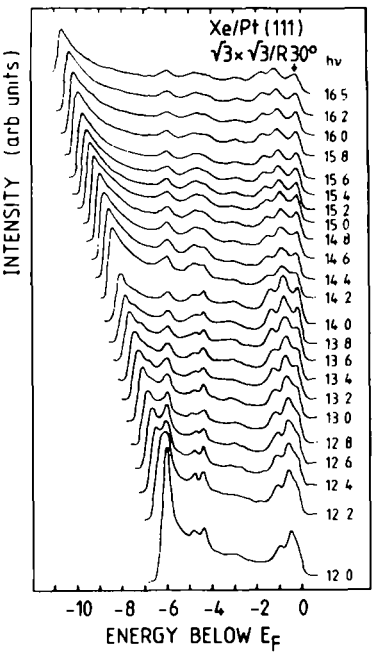

Fig. 5. Photoelectron spectra of Pt(111) with a complete Xe $\sqrt{3}$ layer for various photon energies (normal incidence and normal emission).

than a monolayer of physisorbed rare gas atoms strongly reduced the ESP of photoelectrons from Pt(111).

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