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Spin-polarised metastable atom de-excitation at alkali-covered magnetic surfaces: Na on Fe/Ag(001)

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Abstract

Sodium adsorption on Fe/Ag(001) has been investigated by means of spin-polarised metastable de-excitation spectroscopy (SPMDS). Upon Na deposition, a strong difference in the high-kinetic-energy region of the energy distribution curves collected for the two opposite spin polarisations of the metastable atom has been observed. Above monolayer coverage, the difference changes sign indicating profound modifications of the surface magnetic properties. At higher Na coverage, a difference in the maximum kinetic energy of emitted electrons for the two polarisation directions of the metastable atom has been detected.

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Magnetic phenomena at the surface of ultrathin films have attracted a great deal of interest in the scientific community. Such interest was motivated by the enormous influence that surface phenomena may have on the overall properties of magnetic ultrathin films. In this respect, the role of surface defects [1–5] and of adsorbates [6–8] in determining the magnetic anisotropy of the whole film can be mentioned. The possibility of tailoring the magnetic behaviour of ultrathin films by operating on their surface is of foremost importance in view of application.

Even if many experimental studies were carried out to evaluate the influence of adsorbates onto the surface magnetic properties of ultrathin films, they mainly concerned the adsorption of oxidising species and less is known about the effect of electron-donor species, as alkali and alkaline-earth metals. One of the factors responsible for the dearth of the latter experiments is the almost complete insensitivity of standard photoemission spectroscopies to the s states of the alkali and alkaline-earth adlayers, which are expected to play the major role in the modification of the surface electronic and magnetic properties. The sensitivity to such states can be achieved by using metastable de-excitation spectroscopy (MDS) [9–11] and its spin-polarised version (SPMDS) [12,13]. MDS exploits the electron emission induced by the de-excitation at surface of He atoms in the metastable 2^3S excited state [14]. It is sensitive to the electronic states which spill out into vacuum and is therefore characterised by an extreme sensitivity to the s states of alkali and alkaline-earth adlayers. In SPMDS, spin-polarised metastable He atoms are used and information about the spin-selected surface density of states is thus obtained. The drawback of these two techniques is the difficulty in the interpretation of the data which is complicated by the existence of different de-excitation channels and by the interaction of the metastable atoms with the sample surface [14].

In this paper, we report the result of a SPMDS investigation of ultrathin Na adlayers on Fe/Ag(001). Following Na adsorption, the work function reduces and the de-excitation process moves from RI + AN to AD. Already in the

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low-coverage regime, a strong difference in the high-kinetic-energy region of the energy distribution curves (EDCs) collected for the two opposite spin polarisations of the metastable atom has been observed. Above monolayer coverage, the difference changes sign indicating profound modifications of the surface magnetic properties. At higher Na coverage, a difference in the maximum kinetic energy of emitted electrons for the two polarisation directions of the metastable atom has been observed.

The experimental apparatus has been described elsewhere [15,16]. It consists of a UHV system with base pressure lower than 1×10^{-10} mbar. The Ag(001) substrate was prepared by means of cycles of sputtering with Ne$^+$ ions at 1 keV followed by annealing at 850 K. The growth of Fe on Ag(001) is epitaxial [17], with crystallographic orientations $[100]_{\mathrm{Fe}} \| [110]_{\mathrm{Ag}}$ and $[001]_{\mathrm{Fe}} \| [001]_{\mathrm{Ag}}$. Iron was deposited from a Knudsen cell onto the Ag(001) substrate held at 180 K at a deposition rate of 3×10^{-2} ML/s. The deposition rate has been calibrated by the observation of the characteristic oscillations of the He reflectivity during the deposition of Fe on O(1 × 1)–Fe/Ag(001) [18]. Under the above-mentioned conditions, Fe growth proceeds in 3D mode with the formation of square hillocks [19]. Iron deposition was operated at low-temperature in order to hinder the segregation of Ag atoms at the film surface [20], whose presence may influence the evolution of surface electronic and magnetic properties upon Na deposition. Sodium was deposited from a thoroughly outgassed SAES Getters dispenser on a 17 ML-thick Fe/Ag(001) film at 180 K. The deposition rate was calibrated by monitoring He reflectivity during trial depositions onto the Ag substrate at 180 K [21].

As mentioned above, Na deposition induces the lowering of the work function as expected for the adsorption of alkali metals on transition-metal surfaces. Work-function changes ($\Delta\phi$), deduced by the low-energy cutoff of the SPMDS spectra, have been monitored during Na deposition (Fig. 1). Work function reaches a minimum after the deposition of about 1 ML of Na on Fe/Ag(001) which, assuming the work function of the Ag(001) substrate to be approximately 4.5 eV, corresponds to about 2.5 eV. The decrease of the work function is larger than the one induced by Mg adsorption on Fe/Ag(001) [12], indicating a more important charge transfer from the adsorbate to the substrate in the present case.

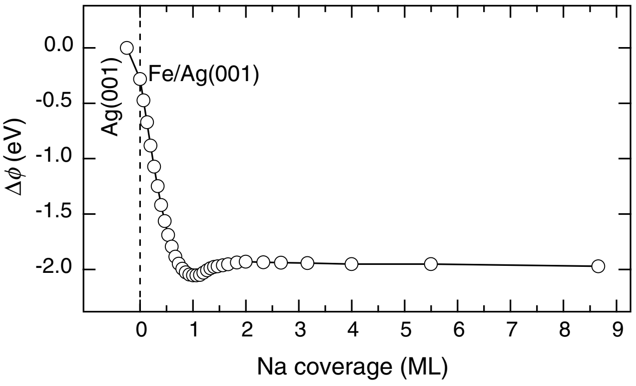

Fig. 1. Work-function changes as a function of Na coverage on Fe/Ag(001).

The reduction of the work function hampers the RI process and favours the AD process as the prevailing de-excitation mechanism. In Fig. 2, the unpolarised EDCs [$I(E)$, left panel] and the differences of the EDCs collected for the two opposite polarisation directions of the metastable atom [$D(E)$, right panel] are shown for the Fe/Ag(001) substrate and for increasing Na coverage. The SPMDS spectra for the substrate are equivalent to the ones previously reported [16]. Following the deposition of Na, the SPMDS spectra change. A part from the shift of the low-energy cutoff toward lower kinetic energies (not shown in Fig. 2) which, in the present experimental conditions, equals $\Delta\phi$, an intense peak at high kinetic energy develops. According to previous works [9–11], this peak results from metastable de-excitation processes in which Na$_{3s}$ electrons are involved.

As shown in Fig. 2, the crossing from RI + AN to AD is already evident after the deposition of 0.6 ML of Na where

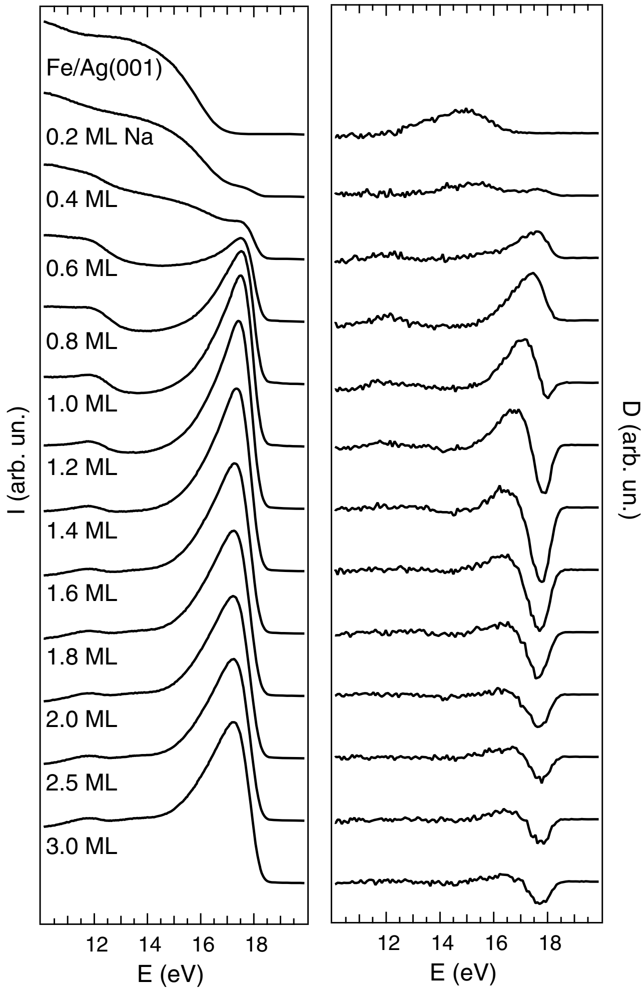

Fig. 2. Unpolarised EDCs (left panel) and the differences of the EDCs collected for the two opposite polarisations of the metastable atom (right panel) as a function of Na coverage.