Project HE 1796 (ID16 beamline) **Experimental report**

Probing depth of high energy photoemission in solid materials with different electronic and magnetic properties

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The objective of the project VOLPE (VOLume PhotoEmission from solids) is to measure the volume electronic properties of solids via photoelectron emission (PE) spectroscopy. The instrumental set-up was first assembled and tested at ESRF (beamline ID-16) in February 2004. The results are very promising (see reports MI-667 and HE-1682), with an analyzer resolution of 50 meV at 6 keV and PE spectra taken up to 8 keV with good statistics [1-3].
Our project **HE-1796**, performed in October 2004 on ID-16, aimed to **quantifying the probing depth of high energy PE spectroscopy**. Samples were wedge shaped overlayers grown on Si substrates. We measured the intensity of core level peaks from the overlayer and from the substrate as a function of the overlayer thickness. Measurements were carried out for kinetic energies E_k in the range 4-6 keV and for different classes of materials, namely noble metals (Cu), 3d transition metals (Co), semiconductors (Ge) and strongly correlated oxides (Gd_2O_3).
Fig. 1 shows an example for the Co overlayer: each Si-1s peak has been measured at a different position along the wedge, corresponding to the given Co thickness. Setting the intensity of the bare substrate to 1, one can fit the peak areas with an exponential decaying function $e^{-x/\lambda}$, where x is the overlayer thickness and λ the effective attenuation length (EAL) in the overlayer material [4]. An example is given in Fig. 2 for Gd_2O_3 at three different kinetic energies of the Si-1s photoelectron. Similarly, the intensity of a peak belonging to the overlayer material can be fitted by a $(1- e^{-x/\lambda})$ function.
Our experimental results for $\lambda(E_k)$ are summarized in Fig. 3. Open diamonds refer to Co, Cu and Ge, filled circles to Gd_2O_3. The full line is a calculation of the inelastic mean free path for Cu [4]. The two dashed lines and the encompassed gray area correspond to calculated values for Gd_2O_3, allowing for maximum variation of parameters.
Our values for Co, Cu and Ge (λ of the order of 45 Å at 4 keV and 60 Å at 6 keV) are very similar. They compare fairly well with existing calculations [4] and experiments [5]. In the case of Gd_2O_3, we find smaller values (30-50 Å), at variance with predictions.
Our results have two important implications:
i) **High energy photoemission can probe bulk properties**. For instance, the top 5 Å of solid Cu contribute about 5% at 6 keV, compared to 45 % at 600 eV. The information depth (thickness contributing 95% of the total signal) is 200 Å at 6 keV compared to 24 Å at 600 eV. Being able to put figures on these quantities is very important to support the idea that high energy photoemission is a bulk probe of the electronic properties of solids.
ii) **High energy photoemission can probe buried layers and interfaces**. Typical protective capping layers are 20 to 40 Å thick, and they will only reduce the signal from an underlying layer by less than a factor of two. Also, a film 10 Å thick buried under a 100 Å overlayer will still contribute a measurable fraction (~3%) of its bulk intensity.

The results of this experiment have been summarized in a manuscript, now accepted for publication in Physical Review B [6].

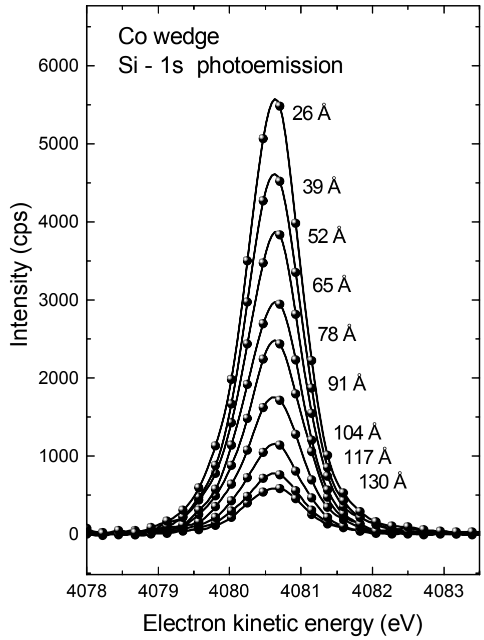

Fig. 1. Si-1s photoemission spectra as a function of the Co overlayer thickness

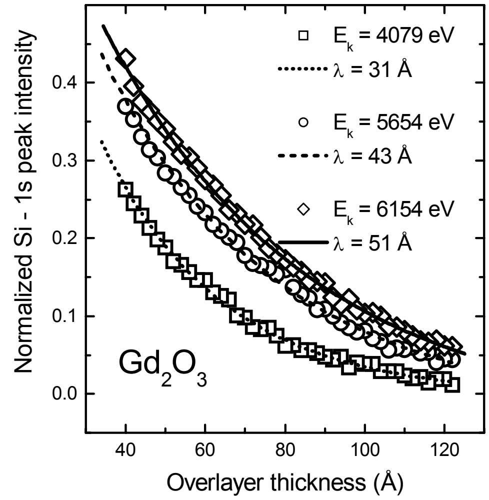

Fig 2: Normalized Si-1s peak intensity *vs.* Gd_2O_3 overlayer thickness at three different kinetic energies. Lines are exponential decay fits with the indicated λ values.

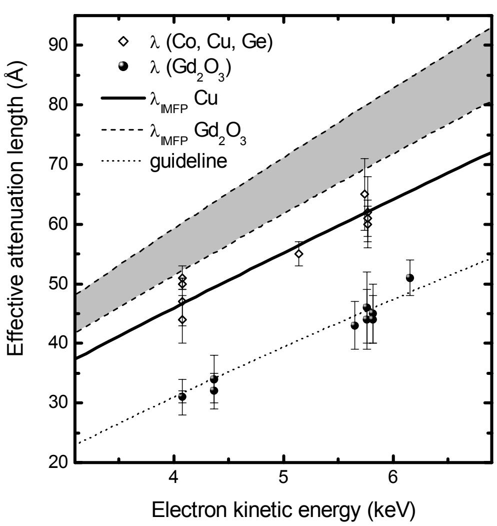

Fig. 3. Summary of our $\lambda(E_k)$ results. Open diamonds refer to Co, Cu and Ge, filled circles to Gd_2O_3. The full line is a calculation of $\lambda(E_k)$ for Cu [http://www.nist.gov/srd/nist71.htm]. The two dashed lines and the encompassed gray area correspond to calculated values for Gd_2O_3, allowing for maximum variation of parameters [S. Tanuma et al., Surf. Interface Anal. 35, 268 (2003)]. The thin dotted line is a guide for the eye.

[1] P. Torelli, M. Sacchi, G. Cautero, M. Cautero, B. Krastanov, P. Lacovig, P. Pittana, R. Sergo, R. Tommasini, A. Fondacaro, F. Offi, G. Paolicelli, G. Stefani, M. Grioni, R. Verbeni, G. Monaco and G. Panaccione, Rev. Sci. Instrum. 76 (2005) 023909.

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[3] G. Panaccione et al., Phys. Rev. B, *submitted*

[4] A. Jablonski and C.J. Powell, Surface Sci. Rep. 47, 33 (2002); see also.NIST Electron Elastic Scattering Cross-Section Database, by A. Jablonski, F. Salvat and C.J. Powell (2002); http://www.nist.gov/srd/nist71.htm

[5] C. Dallera et al., Appl. Phys. Lett. 85, 4532 (2004).

[6] M. Sacchi, F. Offi, P. Torelli, A. Fondacaro, C. Spezzani, M. Cautero, G. Cautero, S. Huotari, M. Grioni, R. Delaunay, M. Fabrizioli, G. Vankó, G. Monaco, G. Paolicelli, G. Stefani, and G. Panaccione *Quantifying the effective attenuation length in high energy photoemission experiments* Phys. Rev. B, accepted for publication