

THE PHOTOEMISSION FROM THE GADOLINIUM SUBMONOLAYERS ON W(112)

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Both relatively unstrained [1-3] and strained gadolinium [3-5] exhibit a pronounced surface state that dominates the electronic structure near the Fermi level, near the surface Brillouin zone center. On many surfaces, notably the refractory metal surfaces of tungsten and molybdenum, the gadolinium overlayer adopts a sequence of ordered structures with increasing coverage, and grows, at least initially layer by layer [5-7]. This provides an experimental system in which the development of the surface state is more easily identified than for many other ferromagnetic overlayers. While the development of the gadolinium surface state, as a function of coverage, has been investigated previously [8], the critical coverage necessary to support the surface state has, surprisingly, not been identified for gadolinium overlayers on any substrate. We identify this critical coverage, herein, for Gd on W(112).

With the highly plane polarized synchrotron light, photoemission experiments were undertaken with polarization varied from p-polarization (65 degrees off normal), with the vector potential oriented more normal than parallel to the surface, to s+p polarization (40-45 degrees measured from normal). A photon energy of 16 eV was used throughout these measurements.

The widely separated chains of gadolinium in the p(1x7) structure on W(112) suggest an electronic interaction between the chains mediated by the W(112) surface electronic structure. Thus the formation of the gadolinium p(1x7) linear structure on the W(112) not only confirms strong hybridization between the gadolinium and the substrate but also indicates the minimum in potential of the indirect interaction between the chains at the distance of 7 periods of the substrate along the furrows [9,10].

The coverage regimes of $\vartheta \leq 0.5$, $0.5 \leq \vartheta < 0.79$ and $\vartheta > 0.79$ ($\vartheta = n_{\text{Gd}}/n_{\text{W}}$ - the ratio of the surface concentration of the Gd adatoms n_{Gd} and surface W atoms on the (112) n_{W}), are characterized by distinct changes in symmetry of bands. Since the light from the synchrotron is highly plane-polarized, the corresponding symmetry assignments can be made from a comparison of light incidence angle

photoemission spectra collected along the surface normal. For $\alpha = 45^\circ$, the incident light is a combination of s polarized, and p-polarized light while at $\alpha = 70^\circ$, the light is strongly p polarized. Since, at Γ , the point group symmetry is C_{2v} the bands observed in photoemission must be a_1 (s, p_z , $d_{3z^2-r^2}$), b_1 (p_x , d_{xz}) or b_2 (p_y , d_{yz}).

At coverages up to the completion of the c(2x2) structure, from the decreased enhancement of this band in p-polarized light, the symmetry a_1 ($d_{3z^2-r^2}$ and s character) of 0.4 eV binding energy W(112) surface state is lost or destroyed while density of states is not suppressed. This again is consistent with strong gadolinium adatom hybridization with the W(112) substrate. The development of a new peak at about of 0.2 eV binding energy (seen Figure 1) at gadolinium coverages in the range of $0.5 \leq \vartheta < 0.79$ is accompanied by an enhancement of this peak in s+p polarized light. This is clearly seen already at $\vartheta = 0.57$ (Figure 1d). Thus in this coverage range, there is the development of interface states or gadolinium states, that still must contain contributions from the W(112) substrate. The enhancement of intensity is characteristic of $d_{xz}d_{yz}$ character, not the $d_{3z^2-r^2}$ and s character observed at higher coverages.

We found that the intensity of peak at 0.2 eV binding energy increases with increasing coverage for $\vartheta > 0.5$, up to 10 monolayers. For coverages $\vartheta \geq 0.79$, or a little above one monolayer, the gadolinium state is also increasing in p-polarized light. This enhancement of this state in p-polarized light is characteristic of the a_1 symmetry ($d_{3z^2-r^2}$ and s character) observed for the gadolinium surface state on many different substrates [1-5]. The surprise is not that it takes more than a monolayer of gadolinium for the surface state of gadolinium to become established. The surprise is that the surface state is established so quickly at coverages above a monolayer.

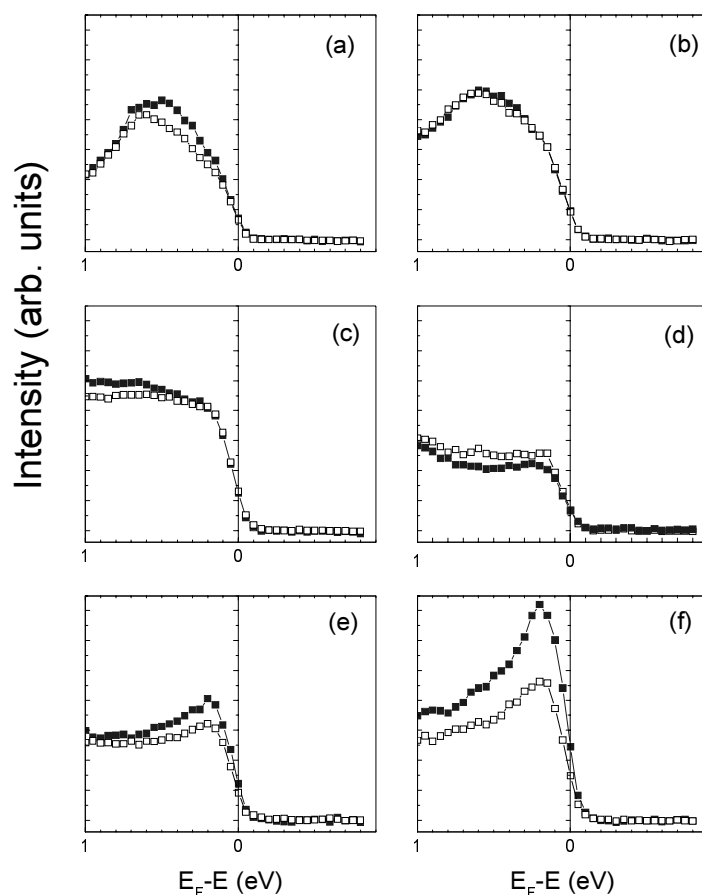


Figure 1. Normal photoemission spectra of Gd on W(112) obtained with p and s+p polarized light. The spectra obtained with s+p polarized light are denoted by open (\square) symbols and the spectra from p polarized incident radiation by filled (\blacksquare) symbols. Gd coverages are 0; 0.14; 0.5; 0.57; 0.79 and 8.8 for panels (a); (b); (c); (d); (e) and (f) respectively.

References

- [1] Li Dongqi, C.W. Hutchings, P.A. Dowben, C. Hwang, Wu Rong-Tzong, M. Onellion, A.B. Andrews, J.L. Erskine. *J. Magn. Magn. Mater.* **99** (1991) 85
- [2] P.A. Dowben, D.N. McIlroy, Li Dongqi, "Surface Magnetism of the Lanthanides", *Handbook on the Physics and Chemistry of Rare Earths*, edited by K.A. Gschneidner, LeRoy Eyring (North Holland Press, 1997) Vol. **24**, chapter 159, pp. 1-46
- [3] C. Waldfried, T. McAvoy, D. Welipitiya, T. Komesu, P.A. Dowben, E. Vescovo. *Phys. Rev. B* **58** (1998) 7434
- [4] I. Yakovkin, T. Komesu, P.A. Dowben, *Phys. Rev. B* **66** (2002) 35406
- [5] C. Waldfried, D.N. McIlroy, P.A. Dowben, *J. Phys.: Condens. Matter.* **9** (1997) 10615
- [6] F.M. Gonchar, V.K. Medvedev, T.P. Smereka, Ya. B. Losovyj, G.V. Babkin, *Sov. Phys.-Solid State* **29** (1987) 1629
- [7] D. Weller, S.F. Alvarado, *J. Appl. Phys.* **59** (1986) 2908-2913
- [8] Li Dongqi, C.W. Hutchings, P.A. Dowben, Wu Ron-Tzong, C. Hwang, M. Onellion, A.B. Andrews, J.L. Erskine, *J. Appl. Phys.* **70** (1991) 6565
- [9] I.N. Yakovkin, *J. Nanosci. Nanotechnol.* **1** (2001) 357-374