INELASTIC SCATTERING

STRUCTURAL STUDY OF THE SURFACE SOLID LAYERS BY ANOMALOUS SCATTERING OF SOFT X-RAYS TECHNIQUES

S.K. Kozhakhmetov

Institute of Nuclear Physics, National Nuclear Center

1, Ibragimov str., 480082, Almaty, Republic of Kazakstan,

To investigate the electronic and atomic structure of surface solid layers various structural methods have been used [1, 2]. In common to these methods, the measurements of anomalous scattering of soft X-rays (λ=10÷300Å) provide an access to the structure of surface solid layers [3]. In this work the results of extended experimental soft X-ray scattering investigation of the surface solid layers structure is presented.

On the basis of carried study physical regularity of genesis of the scattering indicatrix was established and one relationship with electronic and atomic structure of surface layers was founded. Two model system, such as implanted by phosphor ions crystalline silicon and SiO_2 surface films with different thickness, grown on crystal silicon substrate, have been investigated.

For soft X-ray region, experimentally X-ray anomalous scattering effect (Yoneda effect) has been detected.

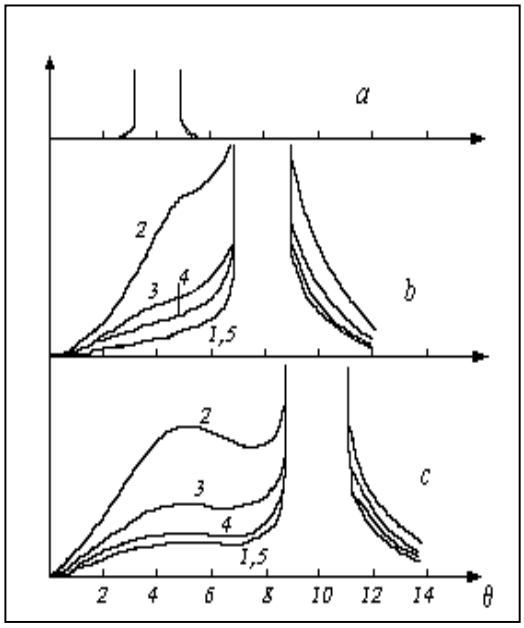

Fig. The indicatrixes of scattering for Si-SiO_2 model system at λ=57Å for SiO_2 surface films with different thickness (*1* - 20, *2* - 85, *3* – 140, *4* – 190, *5* – 630Å): *a* – θ_0=4˚, *b* – θ_0=8˚, *c* – θ_0=10˚.

The typical indicartixes of scattering in soft X-ray region on figure are showed. Their parameters (angular displacement and relative intensity) could make it possible to extract additional structural information about solid surface region.

On the basis study of the number of solid-state objects, used in various technologies (X-ray optics, microelectronics etc.,), the possibility of undestroyed surface structural analysis with nano- and subnano-scale resolution was showed.

Unfortunately we could not obtained the good results for many interesting objects, because in our experiments usual x-ray tube is used. Hence it appears clear the intensity of incident radiation was limited. Beyond doubt using the synchrotron radiation can be avoid above-mentioned problem.

References

[1]. Whitehouse D.J. //J. Phys. E, **8**, 955(1997)

[2]. Tsui Kouchi, Hirocawa Kichikosuke //Surface and Interface Anal. **24**, 286(1996)

[3]. Kozhakhmetov S.K.// J. Exp. and Theor. Phys. **90**, 823 (2000) [Zh. Eksp. Teor. Fiz. **117**, 947 (2000)].

Contact: Kozhakhmetov, Serik K. – 1, Ibragimov str., 480082, Almaty, Republic of Kazakstan, Phone +7 3272 546524; fax +7 3272 546517; e-mail: kserik@inp1.sci.kz

SPIN-FLIP TRANSITIONS in Gd STUDIED by RESONANT INELASTIC SCATTERING of POLARIZED X-RAYS

J.-M. Mariot[1], L. Journel[1], R. Delaunay[1], C. F. Hague[1,2], M. Sacchi[2], A. Mirone[2], S. Turchini[3] and T. Prosperi [3]

1 Laboratoire de Chimie Physique – Matière et Rayonnement (UMR 7614), Université Pierre et Marie Curie, 11 rue P. et M. Curie, 75231 Paris Cedex 05, France
2 LURE, Université Paris-Sud, BP 34, F–91898 Orsay Cedex, France
3 CNR-ICMAT, Area della Ricerca di Roma, CP 10, I–00016 Monterotondo Stazione, Italy

A spin flip in the final state of a $4d\ \gamma\ \ 4f\ \gamma\ \ 4d$ resonant inelastic x-ray scattering (RIXS) experiment was first observed by Gallet *et al.* [1], using a second generation synchrotron radiation source. It concerned Gd which has a $^8S_{7/2}$ ground state (half-filled 4f shell). Later experiments performed under very high resolution conditions at the Advanced Light Source demonstrated that a spin-flip could even be resolved into fine structure [2].

Magnetic circular dichroism experiments and multiplet calculations have demonstrated that polarization effects are present in $4d\ \gamma\ \ 4f$ x-ray absorption spectra performed on magnetized samples [3]. Preliminary calculations performed by A. Mirone (unpublished results) have predicted large variations in the intensity of the multiplets as a function of polarization in the $(4d^{10}4f^{n})\ \gamma\ \ (4d^{9}4f^{n+1})\ \gamma\ \ (4d^{10}4f^{n})^*$ RIXS transitions, where * denotes an excited state.

We report here on RIXS measurements performed in the quasi-elastic energy range after $4d\ \gamma\ \ 4f$ excitation of a magnetized Gd layer. Experiments were performed at Elettra on the Circular Polarization 4.2R beamline. The low energy excitations in the final state, that correspond to low energy losses relative to the elastic peak in the RIXS spectrum, are resolved into three contributions. The intensity of these features shows a marked dependence on the energy of the incident photons, a maximum in intensity being observed in the vicinity of the $4d^{10}4f^{7}\ \gamma\ \ 4d^{9}4f^{8}$ (^{6}D) excitation. There is also a marked helicity dependence of these features, the maximum of this dependence being obtained when the incident photon energy is set 0.5 eV above the $4d^{10}4f^{7}\ \gamma\ \ 4d^{9}4f^{8}$ (^{6}D) excitation.

References

[1] J.-J. Gallet, J.-M. Mariot, C. F. Hague, F. Sirotti, M. Nakazawa, H. Ogazawara, A. Kotani, *Phys. Rev. B* **54**, 14238 (1996).
[2] A. Moewes, T. Eskilden, D. L. Ederer, J. Wang, J. McGuire, T. A. Callcott, *Phys. Rev. B* **57**, 8059 (1998).
[3] K. Starke, E. Navas, E. Arenholz, Z. Hu, L. Baumgarten, G. van der Laan, C. T. Chen, G. Kaindl, *Phys. Rev. B* **55**, 2672 (1997).

Ce 2*p*3*d* RESONANT INELASTIC X-RAY SCATTERING as a PROBE of HYBRIDIZATION EFFECTS in CERIUM COMPOUNDS

J.-M. Mariot[1], J.-J. Gallet[1], L. Journel[1], C. F. Hague[1,2], A. Rogalev[3], G. Krill[2], J.-P. Kappler[4] and G. Schmerber[4]

1 Laboratoire de Chimie Physique – Matière et Rayonnement (UMR 7614), Université P. et M. Curie, 11 rue P. et M. Curie, F–75231 Paris Cedex 05, France
2 LURE, Université Paris-Sud, BP 34, F–91898 Orsay Cedex, France
3 ESRF, 6 rue Jules Horowitz, BP 220, F–38043 Grenoble Cedex, France
4 IPCMS, 23 rue du Loess, F–67037 Strasbourg, France

The fundamental difficulty in describing the electronic structure of mixed-valent Ce compounds lies in the description of localized and itinerant electrons within the same framework. The problem is further aggravated in high energy spectroscopies in the presence of a core-hole excitation introducing further complex exchange interactions.

We report here on Ce 2*p*3*d* resonant inelastic x-ray scattering (RIXS), i.e., a process where a Ce 2*p* electron is resonantly excited into empty states in the vicinity of the Fermi edge and the energy distribution of the scattered photons resulting from decay to a final 3*d* core-hole state is recorded.

Information on the hybridization between the 4*f* and the valence states (v) is obtained. In particular these experiments provide information concerning the $4f^2$-related component of the L_3 absorption spectra not normally available via the first order process.

We will compare the weight of the RIXS features arising from the various $2p^{-1}4f^n\underline{v}$ excitations involved in the intermediate states of the process through a series of compounds. The trends on the degree of 4*f*–v hybridization across the series will be discussed.

WHAT CAN BE LEARNED FROM THE ANGULAR DEPENDENCE IN X-RAY RESONANT RAMAN SCATTERING

A. Tagliaferri[1], L. Braicovich[2], G. Ghiringhelli[2], K. Giarda[2], M. Marcon[2], G. van der Laan[3], N.B. Brookes[1]

1 ESRF – European Synchrotron Radiation Facility, BP 220, 38043 Grenoble, France
2 INFM, Dipartimento di Fisica, Politecnico di Milano, piazza Leonardo da Vinci 32, 20133 Milano, Italy
3 Daresbury Laboratory, Warrington WA4 4AD, United Kingdom

Despite the little experimental investigation ever devoted to it, the angular dependence in x-ray resonant Raman scattering (RRS) has the potentiality of giving information hardly accessible to other spectroscopies. It can be shown that the RRS spectra can be expressed as the linear combination of fundamental spectra, weighted over functions having specific angular dependence, so that each term carries specific information. In particular, if the geometrical arrangement of the experiment is properly chosen, this approach gives direct access to information on the symmetry of the emitting site. We show that this general approach can be conveniently implemented by directly measuring the RRS spectra as integrated along $h\nu_{out}$ over the whole emission peak. In this way we obtain what we call the integrated RRS spectra, which are functions of $h\nu_{in}$ and of the scattering angles. This integration does not wash out the significant angular dependence and gives a substantial signal to be tracked over all directions in space. We describe, for the first time at this conference, the new apparatus built for this kind of spectroscopy. We present measurements on Co-metal, Co in the $CoFe_2O_4$ ferrite and Ni-metal, using circularly polarised light incident perpendicularly to the sample magnetisation direction. In particular, we give the spectral distribution of the RRS dichroism and of the sum signal $I_{dichr}=[I^+(h\nu_{in})-I^-(h\nu_{in})]$ and $I_{sum}=[I^+(h\nu_{in})+I^-(h\nu_{in})]$ where the indices refer to the opposite helicities of the incident x-rays. In this geometry any anisotropy of the I_{sum} signal at constant deflection around the incident beam is related to the charge and magnetic quadrupolar moments of the ground state. It is important to notice that the angular anisotropy in this case cannot be altered or generated by the self-absorption/saturation effects, always very dangerous in the soft x-ray scattering experiments. We find that Ni is fully adapted to the crystal symmetry i.e. that it has no quadrupoles. This is not the case of Co-metal showing a tiny anisotropy and of Co ferrite showing clearly that the Co ion is not fully adapted to the local symmetry and has non-zero charge and magnetic quadrupolar moments. The quantitative analysis is currently in progress. The perspectives offered by this new approach are discussed.

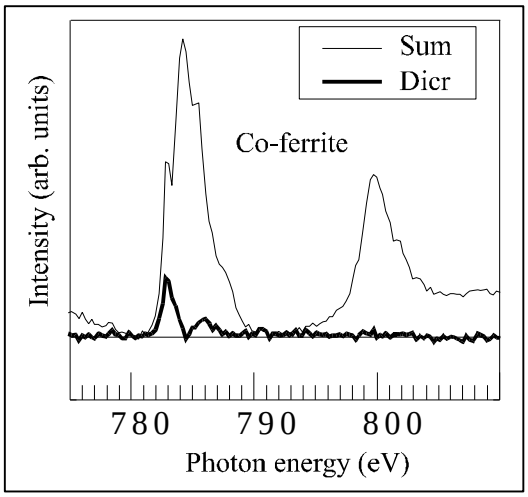

Fig. 1. Integrated RRS spectra of Co in the $L_{2,3}$ region in the Co ferrite. The sum and the difference ("Dicr") of the spectra taken with the opposite photon polarisations are shown. In these measurements the incidence is perpendicular to the magnetisation direction, and the detection of the integrated RRS signal is at the magic backscattering angle ($\arccos(1/\sqrt{3})$). The circular dichroism in absorption is obviously zero while a strong RRS dichroism is measured. This RRS dichroism exists only at the L_3 edge while it is zero at L_2, as predicted by the theory.

POLARIZATION-DEPENDENCE STUDY OF RESONANT SOFT X-RAY EMISSION SPECTRA ON $CeRh_3$

M. Watanabe[1], Y. Harada[1], Y. Ishii[2], Y. Ishiwata[2], R. Eguchi[2], T. Takeuchi[2], and S. Shin[1,2]

1 RIKEN/Spring-8, 1-1-1, Kouto, Mikazukki-cho, Sayo-gun, Hyogo 679-5148, Japan
2 Institute for Solid State Physics, University of Tokyo, Kashiwanoha, Kashiwa, Chiba 277-8581, Japan

4*f* electrons of Ce compounds play an important role to determine electronic properties of the substances due to hybridization between 4*f* states and valence bands. $CeRh_3$ is one of strongly hybridized Ce compounds. The electronic structure of $CeRh_3$ has been investigated using many spectroscopic methods and theoretical efforts. In this presentation, we will present a result of polarization dependence of resonant soft x-ray emission spectroscopy (RXES) of $CeRh_3$.

The RXES is a powerful tool to inspect the hybridization of the electronic structures. Butorin *et. al.* reported results of RXES on some Ce compounds. In the study of CeO_2, the hybridization appears in the spectra as inelastic scattering peaks[1]. On the other hand, Harada *et. al.* tried to detect the polarization dependence of the RXES spectra on TiO_2[2]. They found that some spectral peaks appear or disappear depending on the linear polarization of incident photons. It indicates polarization dependence of the spectra gives information about symmetry concerning the electronic states.

Figure shows the polarization dependence of the RXES spectra on $CeRh_3$. The incident photon energies are set at the satellite peaks of Ce-$M_{4,5}$ absorption spectrum. In both of the spectra, apparent difference due to the polarization dependence exists. The sharp and highest-energy peaks are the elastic scattering peaks. In the depolarized configuration, there is neither elastic scattering peak nor 4.5-eV inelastic peak. The fact says that the 4.5-eV peak is originated from same symmetry as the ground state. In addition, the width of the 4.5-eV peak tells us that the peak is composed by the states with electron-hole pairs near the Fermi level.

In the presentation, the polarization dependence of the resonantly excited XES spectra will be shown.

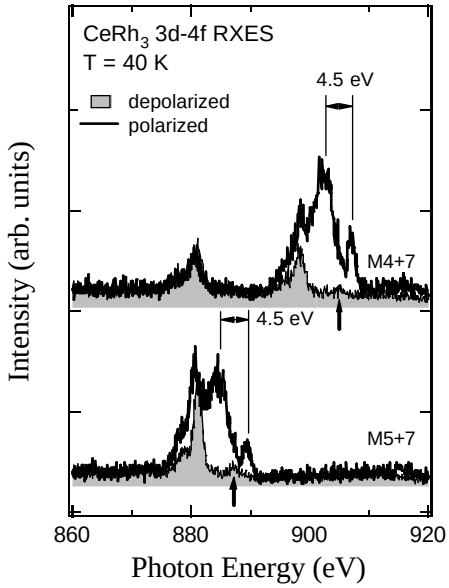

Figure : Polarization dependence of the RXES spectra on $CeRh_3$ with excitation photon energy at satellite peaks of Ce-$M_{4,5}$ absorption spectrum.

References

[1] S. M. Butorin, D.C. Mancini, J.-H. Guo, N. Wassdahl, J. Nordgren, M. Nakazawa, S. Tanaka, T. Uozumi, A. Kotani, Y. Ma, K.E. Myano, B.A. Karlin, D.K.Shuh, Phys. Rev. Lett. **77**, 574 (1996)

[2] Y. Harada, T. Kinugasa, R. Eguchi, M. Matsubara, A. Kotani, M. Watanabe, A. Yagishita, and S. Shin, Phys. Rev. **B61**, 12854(2000)

Soft x-ray magnetic diffraction with coherent beams: towards magnetic speckle spectroscopy

J.F. Peters[1], M.A. de Vries[1], J.Miguel[1], O.Toulemonde[1], E. Brück[1], J.B. Goedkoop[1], S.S. Dhesi[2], N.B. Brookes[2]

1 Van der Waals-Zeeman Institute, Valckenierstraat 65, 1018 XE Amsterdam The Netherlands

2 ESRF BP220, 38043 Grenoble, France

Traditionally, x-ray diffraction was a matter of hard x-rays. Currently, this situation is changing by the growing awareness that the spectroscopic information contained in soft x-ray edges can be exploited in anomalous scattering experiments to obtain electronic or magnetic information on nanometer length scales.

Thus, it has recently become possible to study the magnetic domain structures in thin films and surfaces using polarization dependent soft x-ray magnetic scattering. A unique feature of this technique compared to microscopic techniques is the possibility to obtain 3-dimensional information. In reflection geometry this is achieved by varying the angle of incidence [1]. A number of systems can also be studied in transmission [2].

This will be illustrated for weak-stripe domain structures in amorphous GdFe thin films. We will show results of magnetic field dependent measurements in transmission and reflection geometries and with the field applied both parallel and normal to the film plane. These data allow us to follow the changes in the 3-dimensional magnetic structure of the stripe domain system up to saturation with a resolution of 30 nm.

The next step in this development is the exploitation of the coherence available at third generation sources. In this presentation we will demonstrate the possibility to obtain sufficient coherent flux to obtain magnetic x-ray speckle patterns from static magnetic domain structures in thin films. It will be shown that the speckle pattern yields the correlation function of the magnetization on length scales ranging from ~10 nm to ~50 μm. Possible applications of speckle spectroscopy for the study of magnetic fluctuations will be discussed.

References

[1] H.A. Dürr, E. Dudzik, S.S. Dhesi, J.B. Goedkoop, G. van der Laan, M. Belakhovsky, C. Mocuta, A. Marty and Y. Samson, *Chiral magnetic Domain Structures in Ultrathin FePd Films*, Science **284**, 2166-2168 (1999)

[2] J.F. Peters, M.A. de Vries, J. Miguel, O. Toulemonde and J.B. Goedkoop, *Magnetic Speckles with Soft X-rays*, ESRF Newsletter **34**, 15-16 (2000)

RESONANT INELASTIC SOFT-X-RAY SCATTERING OF MgB_2 BY INCIDENT PHOTON ENERGY DETUNING BELOW B 1s THRESHOLD

S.M.Butorin[1], J.-H. Guo[1], D.K. Shuh[2], and J. Nordgren[1]

1 Department of Physics, Uppsala University, Box 530, S-751 21 Uppsala, Sweden
2 Chemical Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

Resonant inelastic soft-x-ray scattering spectra of MgB_2 were measured at a number of incident photon energies near the B 1s threshold. When the excitation energy is tuned to the first resonance in the B 1s absorption edge, corresponding to unoccupied B 2p states close to the Fermi level, the B K_α fluorescence spectrum shows a distinct inelastic scattering structure at a about 0.5 eV below the elastic peak. This structure is also observed in spectra for a range of incident photon energies from 0.85 eV below to 0.3 eV above the B 1s threshold. Since detuning the excitation energy below the threshold has been proven to suppress effects of electron-phonon interaction and vibrational coupling, the observed inelastic structure is thought to originate from other type of coupling such as electron-electron interaction.

PROBING Mn^{3+} SUBLATTICE IN Ca-DOPED $LaMnO_3$ BY RESONANT INELASTIC SOFT-X-RAY SCATTERING

S.M. Butorin[1], C. Såthe[1], F. Saalem[1], X.-M. Zhu[2], J. Nordgren[1]

1 Department of Physics, Uppsala University, Box 530, S-751 21 Uppsala, Sweden
2 Department of Experimental Physics, University of Umeå, S-901 87 Umeå, Sweden

Resonant inelastic soft x-ray scattering data of $La_{1-x}Ca_xMnO_3$, obtained at different excitation energies throughout the Mn 2p edge, are compared with spectra calculated for the Mn^{3+} system in the D_{4h} crystal field within framework of an single-impurity Anderson model. In the calculation, $3d^4$ and $3d^5\underline{L}$ ($\underline{L}$ stands for a hole in the O 2p band) configurations were taken into account for the ground and final states of the spectroscopic process and $2p^53d^5$ and $2p^53d^6\underline{L}$ configurations for the intermediate state. Good agreement between experiment and theory indicates that in this case the technique probes the sublattice of $La_{1-x}Ca_xMnO_3$ which is based on Mn^{3+} ions. The existance of local magnetic order and orbital d_{3x2-r2}/d_{3y2-r2} ordering manifest themselves in the domination of $\Delta m = \pm 1$ radiative transitions over $\Delta m = 0$ transitions for applied experimental geometry.