ESRF	**Experiment title:** **Ferromagnetic / superconducting and other interfaces investigated with nuclear resonant scattering of synchrotron radiation using standing waves at Bragg condition.**	**Experiment number:** **SI-789**
Beamline: ID22 N	**Date of experiment:** from: 21 July 2002 to: 24 July 2002	**Date of report:** Feb, 26, 2004
Shifts: 9	**Local contact(s):** Dr. Rudolf RUEFFER	*Received at ESRF:*

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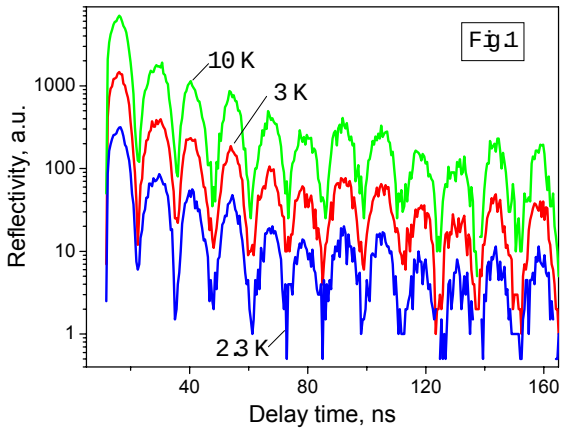
Report:

In order to investigate the interplay between superconductivity and ferromagnetism a multilayer MgO/[$^{56}Fe_{13ML}/V_{13ML}]_{25}$/$^{57}Fe_{13ML}/V_{50nm}/Pd_{5nm}$ was fabricated by magnetron sputtering. The thick V layer was confirmed by resistivity measurements to be superconducting below 3.8 K. CEMS measurement at room temperature reveal a magnetic hyperfine splitting corresponding to ~33T hyperfine field for the majority fraction of the ^{57}Fe nuclei. The periodical multilayer [$^{56}Fe_{13ML}/V_{13ML}]_{25}$ below the ^{57}Fe layer was created in order to obtain a standing wave enhancement of the nuclear resonant reflectivity signal. However, the reflectivity signal at the critical angle of the total external reflection was more intense than that at the superstructure Bragg angle, and most of measurements at ESRF were performed at the critical angle.



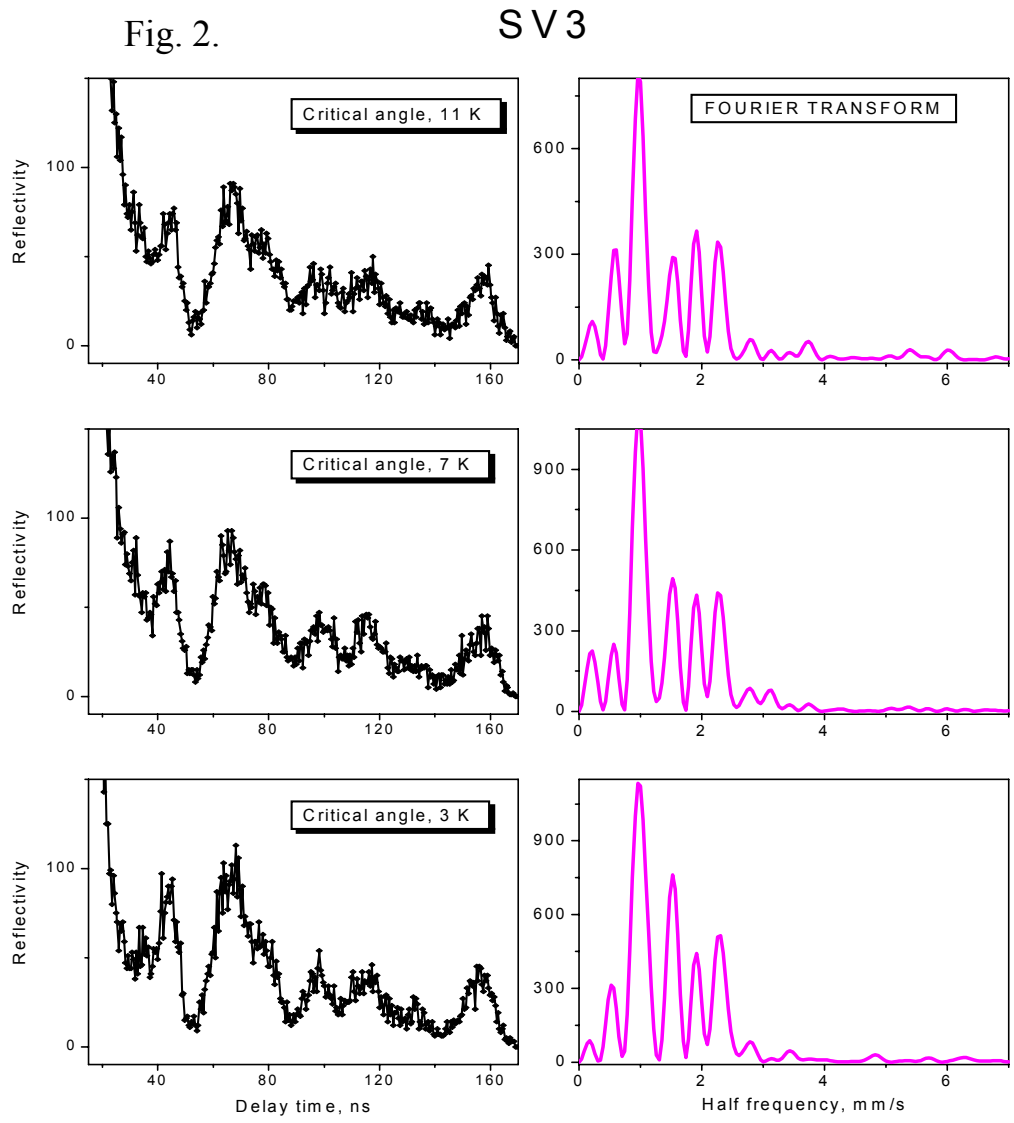
The time spectra of reflectivity measured at different temperatures are shown in Fig.1. We could not reveal any visible variation of the magnetization in the Fe layer below and above the superconducting transition temperature, neither at the critical angle, nor at the Bragg peak. Hence, on the coherent scattering scale, no spatial modulation of ferromagnetic order in the ^{57}Fe layer (cryptoferromagnetism) caused by the superconductivity in the adjacent V layer was observed.

These results were presented at the ICAME-03 conference[1].

A very weak variation of the time spectra below the superconducting transition temperature was, however, observed for a ^{57}Fe/Nb structure (sample "SV3"), where the ^{57}Fe layer was partially oxidized and the magnetic ordering was much weaker (appeared only at low temperatures) . As we see from the Fourier transform of the time spectra in Fig. 2., measured near the critical angle of the total external reflection ϑ = 5.76 mrad at different low temperatures, several beat frequencies are present and the hyperfine distribution in the ^{57}Fe layer is not simple. The slight variation of the spectrum shape (as well as in the relative intensities of the Fourier frequencies, but not in their positions) is observed when the temperature goes below the superconducting transition temperature. It could be explained by the change of the orientation of the magnetic domains in the ^{57}Fe layer due to the penetration of vortex cores to Fe layer below superconducting temperature.

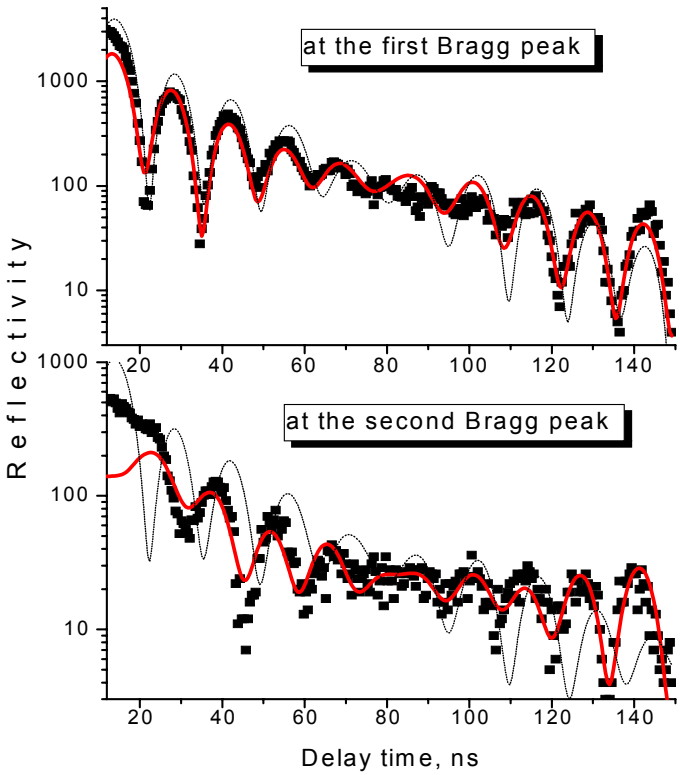
A more comprehensive analyses of this sample has been published[2] including a determination of the position and thickness of the resonant layer in the multilayer structure from the observed small shift and asymmetry of the delayed Bragg reflectivity peak relative the prompt reflectivity Bragg, as well as comparisons with SQUID-magnetization and polarized neutron reflectivity data.

Fig. 2.



In another type of experiments the nuclear resonant reflectivity time spectra at the first and second order Bragg peaks were measured for 3 different Fe/V-multilayers at 10K (as a continuation of SI-553). Results for MgO(001)/V(5ML)/[^{57}Fe(7ML)/V(5ML)]$_{20}$/V(5ML), are shown in Fig. 3. A simultaneous fit of the two Bragg angle time spectra give us the depth distribution of the hyperfine fields within the repetition of the superstructure, using a model with one average field attributed to each ^{57}Fe atomic layer. Calculations were performed on the bases of the full theory[3].

A time-spectrum measured at the critical angle of the total external reflection was not consistent with this distribution. However, recent for X-ray resonant magnetic scattering (XRMS) measurements at the Fe L_3-edge on an equivalent sample show that the top iron layers are oxidized. More analyses are in progress in order to find out the dept profil of this oxidization.



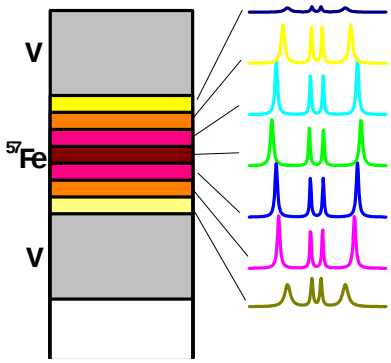


Fig. 3. Left: Time spectra measured from the $[Fe_7/V_5]_{20}$ sample. Full thick lines (red) show the fitted curves from then model indicated above. The thin (black) lines show the expected result if all the hyperfine fields were homogenously distributed in the Fe-layer.
The magnitude of the hyperfine fields are from top to bottom:
23.1, 27.1, 32.4, 35.6, 32.4, 30.3, 23.1 T.

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[1] M.A. Andreeva, L. Häggström, B. Lindgren, B. Kalska, A.-M. Blixt, S. Kamali-M, O. Leupold and R. Rüffer, "Investigation of thin magnetic 57Fe layer being in contact with superconducting V layer by means of the nuclear resonant reflectivity", poster at ICAME-03.

[2] M.A. Andreeva, S.A. Vdovichev, Yu.N. Nozdrin, E.E. Pestov, N.N. Salashchenko, V.G. Semenovc, B. Lindgren, L. Häggström, P. Nordblad, B. Kalskad, O. Leupold, R. Rueffer, " Investigation of the thin 57Fe layer inside superconducting structure Nb(70nm)/57Fe/[Mo/Si]*45/Si substrate with standing waves at the nuclear resonant scattering beamline at ESRF", Proceeding of the Workshop "X-ray Optics - 2003" (Institute of Physics for Microstructures RAS, Nizhnii Novgorod (Russia, 11-14 March 2003) p.214-219.

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