



	<b>Experiment title:</b> Nuclear resonant scattering on magnetic multilayers containing $^{57}\text{Fe}$ probe atoms	<b>Experiment number:</b> SI-142
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**Names and affiliations of applicants** (\* indicates experimentalists):

Prof. dr. L. Niesen \*

Nuclear Solid State Physics, Materials Science Center, University of Groningen,  
Nijenborgb 4, 9747 AG Groningen, The Netherlands

Prof. dr. R. Coehoorn

Philips Research Laboratories, Prof. Holstlaan 4, Box WA-14, 5656 AA Eindhoven,  
The Netherlands

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**Report:**

The magnetic behaviour of epitaxial probe layers of  $^{57}\text{Fe}$  down to a thickness of 1 monolayer (ML) has been investigated with the novel technique of nuclear resonant scattering by synchrotron radiation in a grazing incidence geometry. A sample of  $^{57}\text{Fe}$  nuclei is coherently excited by a short (100 ps) pulse of synchrotron radiation. If a hyperfine interaction is present, the time evolution of the nuclear excitation shows a characteristic beat pattern, with frequencies corresponding to the energy level differences, superimposed on a decay with a characteristic time of the order of the lifetime of the nuclear level (141 ns). In contrast, the coherent and incoherent electronic response of the system (elastic scattering, photoeffect, Compton effect) is "prompt" on this time scale. Even though the electronic response is normally much stronger than the nuclear response, the latter can be observed with very low background in a suitable time window after the exciting pulse [1]. Provided one can obtain a sufficiently high counting rate, this method will be clearly superior to the conventional conversion electron Mossbauer spectroscopy (CEMS) technique. Another advantage is that one can easily study the hyperfine interaction as a function of temperature and/or external magnetic field.

To test the possibilities of this technique for the study of thin layer and interface magnetism we have chosen the system Fe/Au(001), which can be grown epitaxially with good quality on a Ge or GaAs substrate [2]. Three samples were grown with MBE on a S-passivated Ge(001) substrate of 0.3 mm thickness and dimensions  $18 \times 14 \text{ mm}^2$ . Two of them (sample A and B) consisted of 40 monolayers (ML, 1 ML=0.143 nm) natural Fe, followed by 10 ML of  $^{57}\text{Fe}$  and another 5 ML of natural Fe. These and all other samples were covered with  $\approx 2 \text{ nm}$  Au to prevent oxidation and to provide a well defined interface. For these samples we use the notation  $\text{Ge}/40\text{Fe}/10^{57}\text{Fe}/5\text{Fe}/\text{Au}$ . The composition of sample C was  $\text{Ge}/5\text{Fe}/4^{57}\text{Fe}/2\text{Fe}/\text{Au}$ . After the first measurements two other samples were grown on a 6 mm thick, non S-passivated Ge substrate, with dimensions

20x45 mm<sup>2</sup>. Compositions were for sample D: **Ge/10Fe/1<sup>57</sup>Fe/4Fe/Au** and for sample E: **Ge/14Fe/1<sup>57</sup>Fe/Au**. Sample A was grown at 200°C all other samples at room temperature.

Nuclear resonance scattering was performed at beamline ID18 of the ESRF, with the storage ring running in a mode with 16 bunches, 176 ns apart. The beam from the undulator was monochromatized in two steps to a bandwidth of 6 meV around the 14413 eV resonance in <sup>57</sup>Fe. The sample plane was nearly horizontal, making a small, adjustable angle  $\Theta$  with the beam. A magnetic field (15-50 mT) was applied along the horizontal (010) axis, parallel to the linear polarization of the incoming photon beam. The vertically scattered photons were detected in a 10x10 mm<sup>2</sup> avalanche photodiode (APD), located  $\approx$ 30 cm downstream from the sample. Typical count rates were 10<sup>8</sup> s<sup>-1</sup> for the prompt response and at most 10 s<sup>-1</sup> for the delayed events from the nuclear resonant scattering process. Time spectra of the nuclear reflected intensity were obtained for various rocking angles  $\Theta$  between 3.4 and 9.9 mrad. For each sample a typical spectrum is displayed in fig. 1. Apart from sample C they show a beat pattern typical for a dominant magnetic hyperfine interaction. The pattern originates from the interference between the four simultaneously excited  $\Delta m = \pm 1$  transitions between the sublevels of the  $I=1/2$  ground state and the  $I=3/2$  excited state of the <sup>57</sup>Fe nuclei. The solid lines are fits based on the dynamical theory of nuclear scattering [3]. The magnetic interaction is practically undamped, pointing to an excellent structural quality of the layers. For samples A and B we allowed for a second, quadrupole component with a random orientation of the electric field gradient (relative intensity 7%). The third sample is completely nonmagnetic and is fitted with two quadrupole components, the average being equal to the component found with samples A and B. Comparison with the literature strongly suggests that this component is due to a **Ge/Fe** interlayer. This layer must be at least 10 ML thick and locally much thicker.

Samples D and E, obtained on 1 ML of <sup>57</sup>Fe, do not show this effect. However the damping, associated with a distribution of hyperfine fields, is much stronger. This must be due to the different preparation conditions. The results show that nuclear resonant scattering is capable of detecting interface magnetism on only one interface. The situation becomes even much more favourable when several interfaces can be studied in a multilayer geometry, because the signals are quadratic in the number of scatterers (coherent excitation).

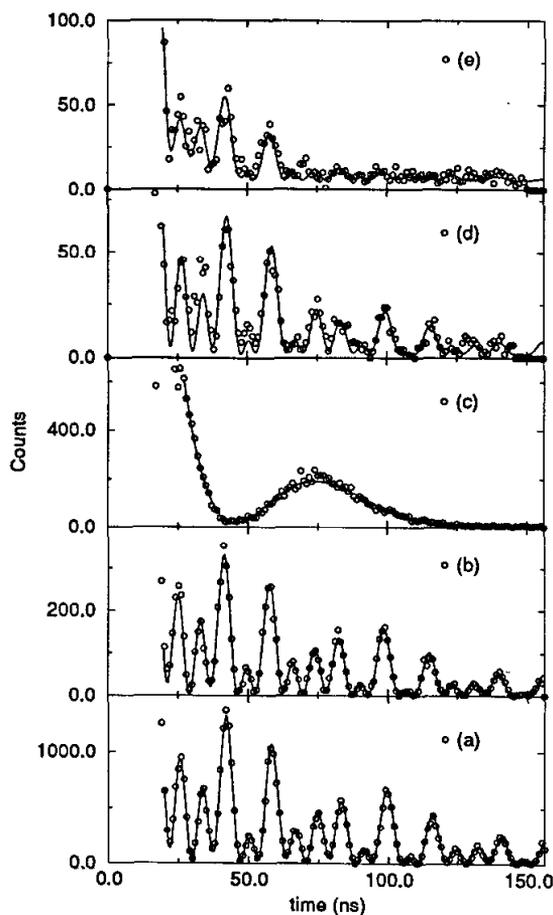


Fig. 1. Time spectra of the delayed response of five different Ge/Fe/Au layers, measured at  $\Theta=4.7-5.2$  mrad. (a) denotes sample A, etc.

- [1] R. Ruffer and A.I. Chumakov, *Hyperfine Interactions* 97/98 (1996) 589.
- [2] W. Folkerts, W. Hoving and W. Coene, *J. Appl. Phys.* 71 (1992) 362.
- [3] J.P. Hannon, G.T. Trammel, N.V. Hung, M. Mueller, R. Gerdau, R. Ruffer and H. Winkler, *Phys. Rev. B* 32 (1985) 6363.