Joint Institute for Nuclear Research «JINR»

Frank Laboratory of Neutron Physics

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Investigation of Nb/VGd/Nb/Al2O3 Multilayered Structure by Polarized Neutron Reflectometry

FINAL REPORT ON THE INTEREST PROGRAMM

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Contents

1 Introduction

Nowadays, a many researching are carried out in the field of studying the interaction of superconducting and magnetic materials. Many scientific groups are using different technologies to study the effects that occur in heterostructures at the material boundary. Research methods and methods can be different, experimental groups conduct experiments using neutron research methods, while theoretical scientists investigate and solve mathematical models of structures with the development of a theoretical basis in this area.

One of the methods for studying low-dimensional magnetic heterostructures is the polarized neutron reflectometry method. This method consists in studying the spectra of neutron beams reflected from the investigated surface (structure). From the reflected spectrum, one can obtain data on the properties of the material under study, its thickness, magnetization, and other parameters. This project investigates the effect of magnetizing a superconductor in contact with a ferromagnet, which is called the inverse proximity effect. Studies in this area show that when a structure is magnetized with a superconductor-ferromagnet contact at low temperatures in the contact region, a magnetic field flows into the superconductor layer, where magnetization can penetrate the coherence length. This effect, which occurs on the surface layer of superconductor-magnetic structures, must be taken into account for the design of low-dimensional electronic devices.

In this work, we consider a heterostructure of the following layers $Nb(15nm)/V(70nm)$ $/Gd(3,6,12nm)/Nb(100nm)/Al_2O_3$. We researched changing of neutron and X-ray scatterring properties from thickness, magnetization, grazing angle and number of layers using numerical methods in MatLab and X'Pert.

2 Literature review

Phenomenon of coexistence of superconductivity and ferromagentism in layered structure was considered in(1). The reverse proximity effect may occur in superconductor/ferromagnet structures which implies magnetization of the superconducting layer what was shown in (2), (3) .In (2) and (3), the transport through the S/F interface was considered in the diffusive limit, i.e., for the case of highly disordered (rough, dirty) interfaces. The induced magnetization of the diffusive limit points antiparallel to the magnetization of the FM layer (4). The temperature dependence of the magnetic proximity effect is investigated in (5). In (6), Nb(25nm)/Gd(df)/ Nb(25nm) trilayers has been studied showing that the structures with highly transparent S/F interfaces and rather high correlation length can be grown. Theoretical results with is used for calcuation is represented in (7)

3 Project goals

The aim of the project is to study low-dimensional heterostructures using the numerical simulations of polarized neutron reflectometry method and X-ray method. In the course of the research work, the scientific literature was studied with studies of the proximity effect, the inverse proximity effect for structures of a superconducting material and ferromagnets, work on neutron research methods in condensed matter physics.One of the main tasks of the project is the numerical simulation of the experiment, which would help to analyze experimental data.

4 Simulations

4.1 Comparing reflectivity at different grazing angles

There is used Matlab program which was written by Prof. Vladimir Zhaketov. We calculated only neutron reflectivity, with two different angels without magnetization.

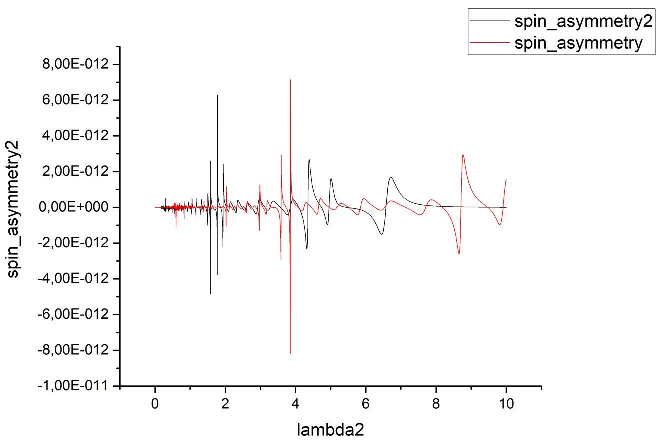

Figure 1: $\theta = 6, 12 mrad$, No magnetization

4.2 Comparing reflectivity at different magnetization

In this case, we change magnetization and study collinear case.

We that increasing of magnetization for z axis significantly change our graph.

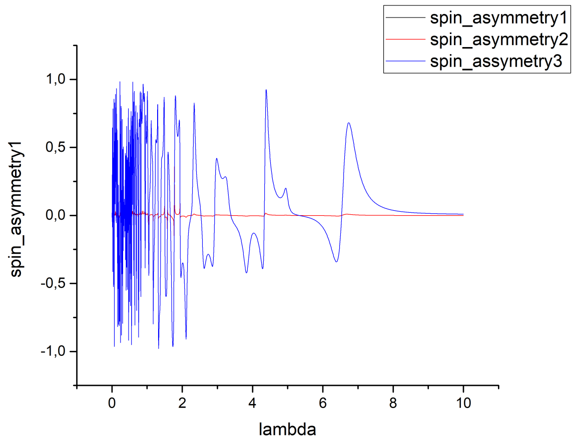

Figure 2: $\theta = 6mrad$,Collinear case: $M_z(Gd) = 100, 1000, 10000Oe$; $M_x(Gd) = 0, M_y(Gd) = 0$

4.3 Comparing structures with different thickness

4.3.1 Neutron reflectivity

Comparing different thickness of Gd using Neutron reflectivity. As we see structure of graphs almost the same, but peaks of more thick layer is much higher.

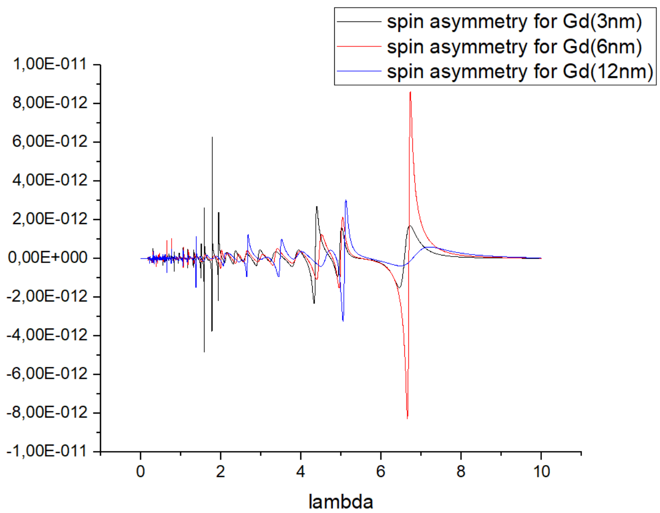

Figure 3: $\theta = 6mrad$,$Al_2O_3/Nb(100nm)/Gd(3, 6, 12nm)/V(70nm)/Nb(15nm)$

4.3.2 X-ray reflectivity

We used "X'Pert" program to simulate X-ray reflectivity with different thickness of Gd layer (3nm,6nm,12nm) pic.4,5,6.

4.4 Comparing structures with different ferromagnets

4.4.1 Neutron reflectivity

Here we compare different ferromagnets in the same structure

$$Al_2O_3/Nb(100nm)/ferromagnet/V(70nm)/Nb(15nm)$$

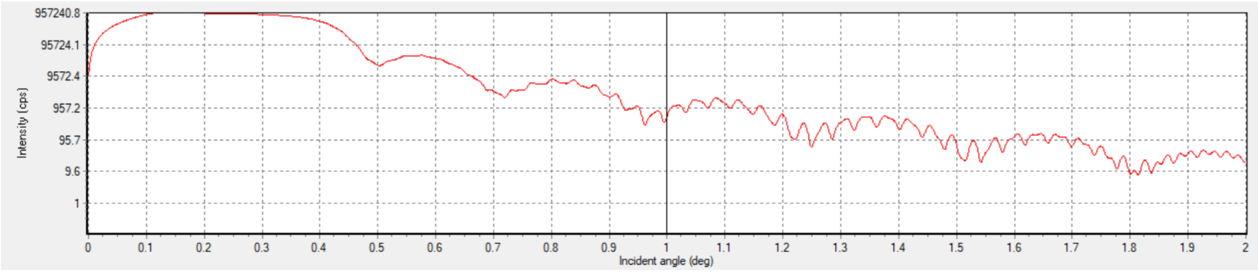

Figure 4: $Al_2O_3/Nb(100nm)/Gd(3nm)/V(70nm)/Nb(15nm)$

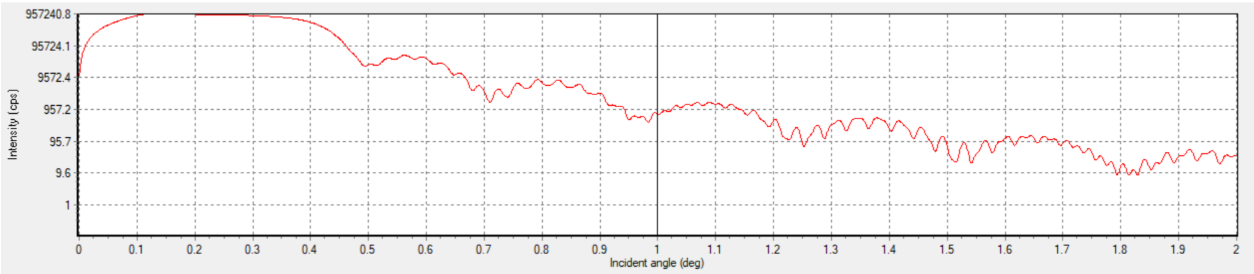

Figure 5: $Al_2O_3/Nb(100nm)/Gd(6nm)/V(70nm)/Nb(15nm)$

4.4.2 X-ray reflectivity

Here we compare different ferromagnets in the same structure, but we used X-ray reflectivity simulations. List of structures:

$$Al_2O_3/Nb(100nm)/Gd/V(70nm)/Nb(15nm),$$
$$Al_2O_3/Nb(100nm)/Fe/V(70nm)/Nb(15nm),$$
$$Al_2O_3/Nb(100nm)/Co/V(70nm)/Nb(15nm),$$
$$Al_2O_3/Nb(100nm)/Ni/V(70nm)/Nb(15nm),$$
$$Al_2O_3/Nb(100nm)/Dy/V(70nm)/Nb(15nm).$$

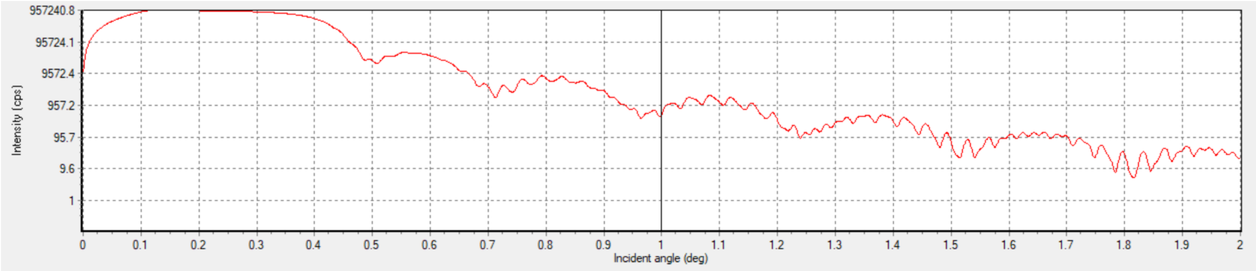

Figure 6: $Al_2O_3/Nb(100nm)/Gd(12nm)/V(70nm)/Nb(15nm)$

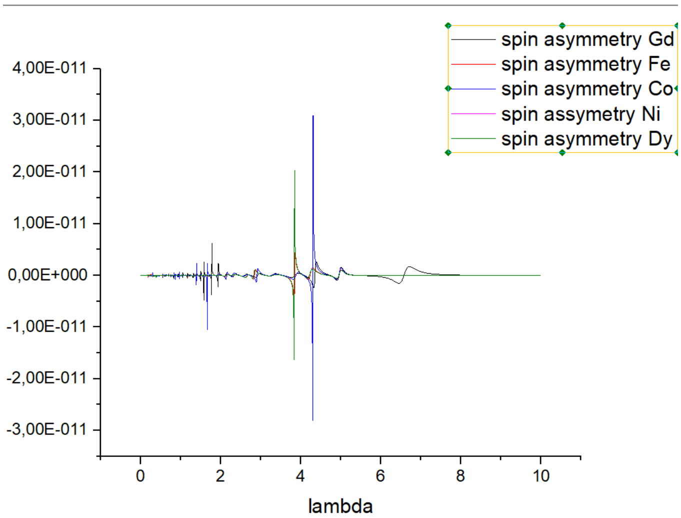

Figure 7: $\theta = 6mrad$ Gd,Fe,Co,Ni,Dy (3nm)

4.5 Superlattice

In this part we modeled superlattices which structure is $Al_2O_3/[Nb(25nm)/Gd(3nm)] \times 10/Nb(15nm)$, $Al_2O_3/[Nb(25nm)/Gd(3nm)] \times 20/Nb(15nm)$, $Al_2O_3/[Nb(25nm)/Gd(3nm)] \times 30/Nb(15nm)$.

4.5.1 Neutron reflectivity

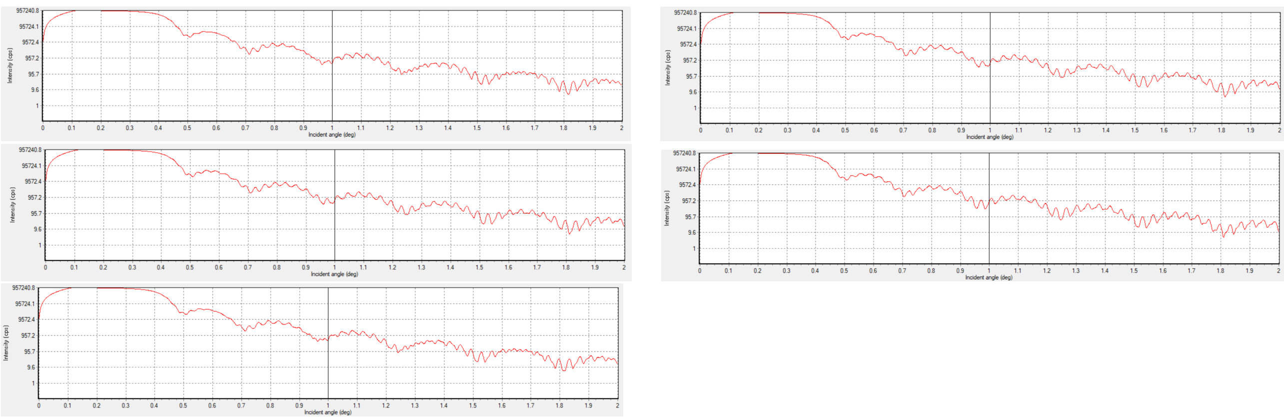

Figure 8: Gd,Fe,Co,Ni,Dy (3nm)

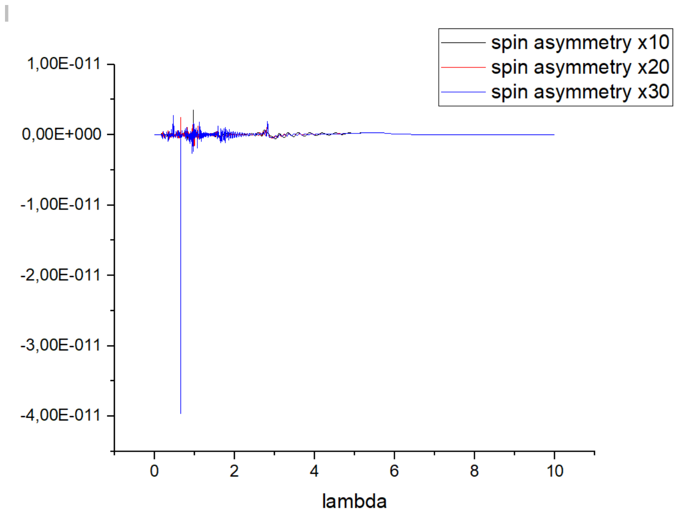

Figure 9: $\theta = 6mrad$ 10,20,30 double layers of NB(25nm)/Gd(3nm)

4.5.2 X-ray reflectivity

We use X-ray reflectivity with the same superlattices .

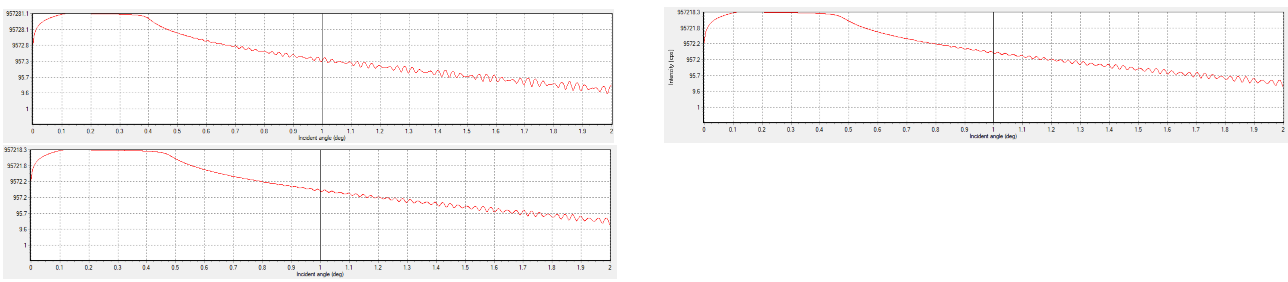

Figure 10: 10,20,30 double layers of NB(25nm)/Gd(3nm)

4.6 Influence of roughness

We wanted to see how different roughness reflects on X-ray reflectivity function. Roughness of Gd layers = 0, 1, 2, 3 nm was checked.

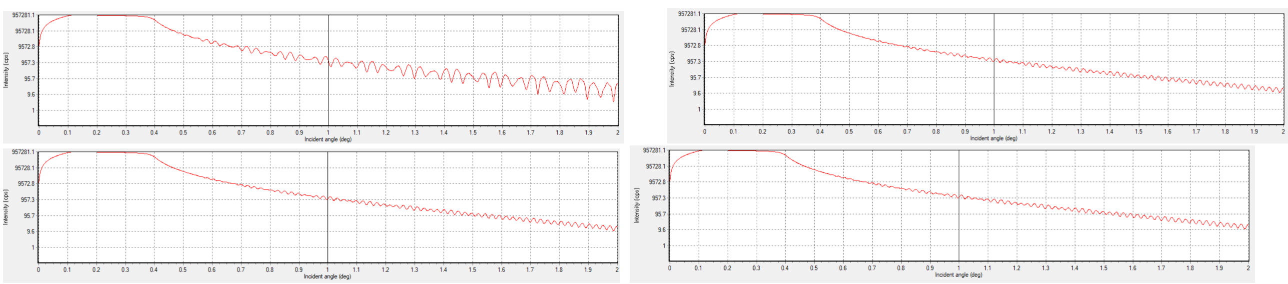

Figure 11: Roughness of Gd layers = 0, 1, 2, 3 nm

5 Conclusion

The neutron reflectometry method is widely used to analyze complex multilayer structures. This method allows one to obtain information about the composition of the structure, and also allows one to study the magnetic properties of materials. This is important for a number of problems to study the proximity effect or the inverse proximity effect upon contact of a magnetic material with the surface of a superconductor. Research in this area will help shape the fundamental theory and develop the application of engineering findings to the design of electronic components.

6 Acknowledgement

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