Instytut Fizyki Molekularnej
Polskiej Akademii Nauk w Poznaniu

Rozprawa doktorska

# Właściwości magnetyczne warstw wielokrotnych V/Fe i Nb/Fe

**mgr inż. Agnieszka Ranecka**

**(Marczyńska)**

Promotor: dr hab. Lesław Smardz

Promotor pomocniczy: dr inż. Karol Synoradzki

Poznań, 2022

# Abstract

The interlayer exchange coupling through non-magnetic spacers plays an important role in the potential application of magnetic systems. However, the type and strength of the interlayer exchange coupling dependence on the thickness of non-magnetic spacer have not been completely explained. The objective of the dissertation is to determine the mechanisms leading to noncolinear exchange coupling in V/Fe and Nb/Fe multilayers. A capping layer of palladium with a thickness of 5 nm protects the iron, vanadium, and niobium sublayers from oxidation in air. This layer also acts as a catalyst in the process of hydrogen absorption and desorption at room temperature. The surface chemical composition and mixed layer thicknesses near the interfaces of the studied multilayers were determined *in-situ* using X-ray photoelectron spectroscopy (*XPS*). *Ex-situ* studies using standard X-ray diffraction (*XRD*) confirmed the strong (110) texture of the multilayers. The magnetic properties were studies with a Vibrating Sample Magnetometer (*VSM*) in the temperature range 5-300 K in a magnetic field up to 9 T.

So far, in the analysis of the interlayer exchange coupling based on the fit of the Stoner-Wohlfarth model to the experimental hysteresis loops have been limited to two terms: bilinear ($J_1$) and biquadratic ($J_2$). In the case of V/Fe and Nb/Fe multilayers, the measured hysteresis loops could not be satisfactorily fitted to the model considering only these two terms. Therefore, the hysteresis loop analysis additionally takes into account the contribution from the cubic constant ($J_3$) of the interlayer exchange coupling, which may also make a significant contribution to the total energy. Assuming negative values of the coupling constants $J_1$, $J_2$, and $J_3$ favouring the antiferromagnetic coupling of Fe sublayers, after adding the cubic term much better conformity to the model fit was observed. For the majority of V/Fe and Nb/Fe multilayers showing antiferromagnetic coupling (~ zero remanence) of Fe sublayers, the contribution of the biquadratic and cubic coupling constants is much smaller than that of the bilinear coupling constant. The higher-order interactions ($J_2$ and $J_3$) are especially important for V and Nb spacer thicknesses greater than 7 monolayers.

Investigations of V/Fe multilayers with constant thicknesses of Fe sublayers equal to 0.6 nm (approximately 3 atomic layers) confirmed the oscillatory nature of the interlayer coupling with the period of 3-4 vanadium atomic layers. At a temperature of 300 K, four energy minima are visible confirming local maxima of antiferromagnetic coupling for V thickness of about 6-7; 9-10; 13-14; and 16-17 atomic layers. The determined value of the coupling energy as a function of V layer thickness is consistent with the values obtained from the *ab-initio* calculations. The antiferromagnetic coupling of the V/Fe multilayers was also confirmed in magnetoresistance studies. In addition, an invers magnetoresistance of -5.2% was observed at 2 K for a sample with a thickness of about 10.6 V atomic layers. The Nb/Fe multilayers for the thickness of the niobium sublayers of about 3, 5, 7, 10, 13 atomic layers showed clear maxima of antiferromagnetic coupling at the temperature of 300 K. The above result is also consistent with the *ab-initio* calculations. Moreover, the absorption of hydrogen in Nb/Fe multilayers at room temperature and pressure up to 1000 mbar causes practically the disappearance of the cubic coupling constant $J_3$, the decrease of the $J_1$value, and the increase of the biquadratic coupling constant $J_2$. The modification of the coupling using hydrogen absorption is fully reversible. After desorption of hydrogen in air at room temperature, all the samples returned to their original state.