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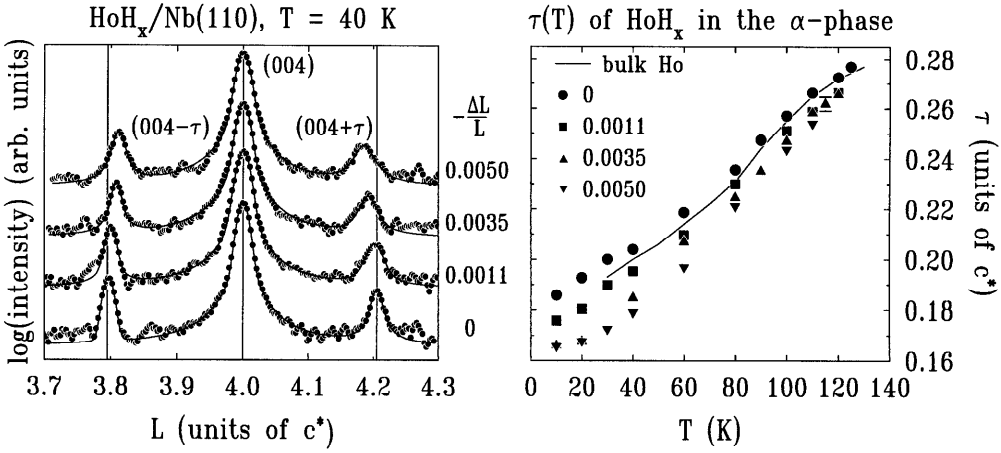
Report:

The hydrogen induced switching of magnetic, optical and electrical properties in thin films and multilayers make metal-hydrogen system to a very interesting topic in modern research. It has been demonstrated in several systems that the spin orientation of ferromagnetic layers coupled through nonmagnetic metal spacers can be switched from parallel to antiparallel by adjusting the hydrogen content inside the nonmagnetic layers.

The aim of this experiment was the study of the influence of hydrogen on the ***intrinsic*** magnetic properties of ***one single*** holmium film by resonant magnetic x-ray scattering. Ho orders in a helical magnetic structure and can be regarded as a prototypal system of localized 4f magnetic moments coupled via the conduction electron system. Hence the influence of hydrogen on the coupling mechanism can be studied in one single system.

A 500 Å Ho film was grown beforehand by MBE in a standard manner on a Al_2O_3 substrate with a Nb buffer layer. The Ho film itself was covered by a Nb layer to prevent it from oxidation and to assure a good growth of the Pd cap layer. Pd purifies and dissociates hydrogen molecules and serves as an inlet window. As only half of the sample was covered with Pd, a hydrogen gradient builds up below the uncovered part as the diffusion along the film plane is much slower than in the perpendicular direction. The sample was loaded at room temperature once and than cooled down to 150 K to keep the gradient stationary.



The figure shows on the left side radial scans through the (004) Bragg reflection and the (004±τ) magnetic satellites taken at four different positions on the non Pd covered part of the sample. As hydrogen enlarges the Ho lattice the L values of the scans were rescaled by a constant factor -AL/L in such way that the (004) reflection is always at its nominal position. The absolute value of the hydrogen concentration cannot be determined with x-ray scattering methods. In the a-phase, the concentration is however proportional to the shift -AL/L of the (004) Bragg reflection. The shift can therefore be calibrated afterwards by hydrogen sensitive methods as e.g.: neutron reflectivity, RBS, N15.

The raw data already shows one effect of hydrogen on the magnetic structure: the magnetic satellites move towards the (004) (smaller z-values) indicating that the magnetic helix becomes longer. The results for the magnetic scattering vector τ as determined from temperature series are shown on the right side. Without hydrogen, the Ho film shows the same $\tau(T)$- dependence as bulk samples. With increasing concentrations we find a shift to smaller values. However, for the two highest concentrations ($-\Delta L/L$ = 0.0035, 0.0050) and the lowest temperatures we find the same $\tau = 0.166$. This value corresponds to a turn angle of 30” between the magnetic moments of two neighbouring basal planes. No smaller turn angles were found which shows the importance of the hexagonal crystal symmetry on the helical structure at low temperatures.

The Neel temperature is found to decrease linearly with increasing hydrogen concentration. Between $\Delta L/L = 0$ and $\Delta L/L = -0.0055$ we find a decrease of 15 K. This can be explained by the fact that hydrogen atoms tend to bind the conduction electrons from the Ho and therefore weaken the RKKY coupling between the localised 4f magnetic moments.

In summary, we have investigated for the first time the influence of hydrogen on the magnetic structure of a single thin Ho film with resonant magnetic x-ray scattering (XMS). The results prove that XMS is a valuable tool in the study of magnetic exchange interactions in thin film and multilayers.