8. Summary and Outlook

The aim of the present treatise was to assemble a high-field magneto-optic Kerr (MOKE) spectrometer for operation in ultra-high vacuum and to investigate the magnetic and magneto-optic properties of magnetic multilayers (MLs) composed of transition and rare earth metals. In addition to MOKE spectrometry, SQUID and torque magnetometry supplemented by conversion electron Mössbauer spectroscopy (CEMS) are performed. Emphasis has been put on investigating the influence of interfaces on the magnetization reversal and the origin of perpendicular magnetic anisotropy (PMA) in the system iron/terbium (Fe/Tb), which has a high technological potential for use as a high-density perpendicular magneto-optic recording material.

The influence of the growth temperature on morphology and magnetic properties of the interfaces was studied by measuring the polar MOKE ellipticity (ε_K) of Fe/Tb MLs with variant Fe and constant Tb thicknesses, t_{Fe} = 1.0 - 5.0 and t_{Tb} = 1.9 nm, prepared by thermal evaporation in UHV at different substrate temperatures, T_s = 150 (LT) and 300 K (HT). Different Fe modifications, „bulk“ amorphous Fe (a-Fe), uncoupled a-Fe (see below) and a-Fe_xTb_{1-x} alloys located at the interfaces can be identified by both the shape of their ε_K hysteresis loops and the temperature dependencies of the saturation Kerr ellipticity, ε_K^s, described by power laws within the range $50 \leq T \leq 300$ K. Equimolar a-$Fe_{0.5}Tb_{0.5}$ alloys at the interfaces of HT MLs are shown to bear characteristics of the two-dimensional Ising model, whereas LT MLs exhibit interfaces composed of Tb-rich a-$Fe_{0.4}Tb_{0.6}$ alloys with three-dimensional character in the temperature range between 210 K and the Curie temperature, T_C(Tb/Fe) ≈ 330 K. MO contributions of „bulk“ a-Fe to ε_K^s are observed below its T_C ≈ 200 K.

PMA at room temperature (RT) induced by the interfaces is observed on all MLs with t_{Fe} < 4.0 nm, whereas for t_{Fe} > 4.0 nm in-plane anisotropy dominates. Special attention is paid to the development of PMA at decreasing temperatures in crystalline Fe (α-Fe)/Tb MLs with t_{Fe} = 5.0 nm, where two different morphologies and magnetic properties of the Tb-on-Fe (top) and Fe-on-Tb (bottom) interfaces are discovered by CEMS studies using ultrathin ^{57}Fe probe layers. In order to investigate the influence of the individual interfaces on the PMA, either the top or the bottom interfaces of the individual Fe layers were replaced by blocking layers of diamagnetic yttrium, Y, and investigated via torque magnetometry as a function of the angle between the applied field and the film plane at $15 \leq T \leq 300$ K. In MLs with rough bottom interfaces, $[Tb(1.4)/Fe(5.0)/Y(1.2\ nm)]_{10}$, PMA becomes noticeable below the ordering temperature of the a-FeTb alloy ($T_C \geq 330$ K) in the interfaces. Contrastingly, the PMA of MLs with sharp top interfaces, $[Fe(5.0)/Tb(1.4)/Y(1.2\ nm)]_{10}$, dominates only at low temperatures, where Tb becomes polarized and couples antiferromagnetically with the Fe moments. The torque curves can be described within the framework of uncoupled ($T > 200$ K) and coupled ($T \leq 50$ K) two-layer models based on the coherent rotation model of Stoner and Wohlfarth. The PMA in MLs without Y blocking layers, $[Fe(5.0)/Tb(2.6\ nm)]_{10}$, is significantly enhanced by interlayer coupling supported by dipolar coupling of the α-Fe layers via the intercalated magnetic Tb layers. At low temperature a cone structure of the Fe moments due to antiferromagnetic coupling between Fe and Tb moments and strong PMA of Tb is evidenced by the model calculation.

When decreasing the thickness of the α-Fe layers to $t_{Fe} = 3.5$ nm, PMA is observed even at RT by SQUID magnetization and polar Kerr ellipticity measurements in agreement with CEMS studies. Obviously the interface-induced PMA outweighs the shape anisotropy of the α-Fe layers, where the bottom interfaces give rise to much stronger PMA than the top ones at all temperatures. This is tested on MLs of $[Fe(3.5)/Tb(1.4\ nm)]_{10}$, whose top and bottom Tb layers, respectively, are replaced by Ag blocking layers with thickness $t_{Ag} = 5.0$ nm. In addition, MOKE ellipticity reveals an uncoupled soft-magnetic contribution in the near infrared, where it is spectrally separated from the contribution to α-Fe. It is attributed to a-Fe segregated within the bulk of the α-Fe layers and contributes to about 10% of their volume.

The influence of the number of Fe/Tb interfaces on the PMA and on the magnetization reversal was studied by in-situ polar Kerr effect measurements on samples of $[Tb(1.4)/Fe(3.5\ nm)]_n$ covered with one additional Tb layer, where n = 1, 2, 3 and 10. In agreement with results of CEMS studies the PMA first increases with the number of Fe/Tb interfaces up to 6 (n = 3) and slightly decreases with n. This is also reflected by the rectangularity and the coercivity of the polar Kerr loops. The changes in the shape of the ε_K loops with n are attributed to increasing inhomogeneity of the Fe layers due to growing admixtures of a-Fe. This is also evidenced by the saturated Kerr ellipticity spectra at T = 50 K. The Kerr spectra of the ML with n = 10 can phenomenologically be analyzed by the superposition of MO contributions of α- and a-Fe.

In conclusion, it has been shown that the PMA of the α-Fe/Tb MLs is primarily induced by the Fe/Tb interfaces, but different mechanisms are involved due to their variant structures. At $T > T_C(Tb) = 219$ K the rough bottom interfaces develop PMA due to alloying, whereas at low T the PMA of the sharp top interfaces dominate owing to both the abrupt breaking of translational symmetry (Néel mechanism) and the strong coupling of Fe and Tb magnetic moments at the interfaces. Furthermore different Fe modifications have been found by MOKE spectroscopy and are classified as individual components, a- and α-Fe.

In the course of the research on the present treatise it has been evidenced that the magneto-optical probe reveals unexpected and unprecedented properties of the TM/RE ML system iron/terbium. Clearly, the discovery of different amorphous iron modifications calls for more quantitative analysis. It will be a challenging task to explain the Kerr spectroscopical peculiarities of a-Fe with large and prevailing negative contributions to the ellipticity in the near infrared spectral region. A band structural concept of the magneto-optic response differentiating between crystalline and amorphous iron is highly desirable.

Another still open question concerns the very mechanisms of the enhancement of the perpendicular anisotropy when increasing the number of Fe/Tb bilayers in the low n limit. Very probably not only the interlayer exchange, but also the dipolar coupling between the ferrimagnetically coupled bilayers will be at the origin of the observed behavior.