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Probing equilibrium by nonequilibrium dynamics: Aging in Co/Cr superlattices[1]

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Magnetic aging phenomena are investigated in a structurally ordered Co/Cr superlattice through measurements of magnetization relaxation, magnetic susceptibility, and hysteresis at various temperatures above and below the onset of collective magnetic order. We take advantage of the fact that controlled growth of magnetic multilayer thin films via molecular beam epitaxy allows tailoring the intra and inter-layer exchange interaction and thus enables tuning of magnetic properties including the spin-fluctuation spectra. Tailored nanoscale periodicity in Co/Cr multilayers creates mesoscopic spatial magnetic correlations with slow relaxation dynamics when quenching the system into a nonequilibrium state. Magnetization relaxation in weakly correlated spin systems depends on the microscopic spin-flip time of about 10 ns and is therefore a fast process. The spin correlations in our Co/Cr superlattice bring the magnetization dynamics to experimentally better accessible time scales of seconds or hours. In contrast to spin-glasses, where slow dynamics due to disorder and frustration is a well-known phenomenon, we tune and increase relaxation times in ordered structures. This is achieved by increasing spin-spin correlation between mesoscopically correlated regions rather than individual atomic spins, a concept with some similarity to block spin renormalization. Magnetization transients are measured after exposing the Co/Cr heterostructure to a magnetic set field for various waiting times. Scaling analysis reveals an asymptotic power-law behavior in accordance with a full aging scenario. The temperature dependence of the relaxation exponent shows pronounced anomalies at the equilibrium phase transitions of the antiferromagnetic superstructure and the ferromagnetic to paramagnetic transition of the Co layers. The latter leaves only weak fingerprints in the equilibrium magnetic behavior but gives rise to a prominent change in nonequilibrium properties. Our findings suggest that scaling analysis of nonequilibrium data can serve as a probe for weak equilibrium phase transitions.

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