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Detection of microwave phase variation in nanometer-scale magnetic heterostructures

CHENG CHENG, coracoracheng@gmail.com

The internal phase profile of electromagnetic (EM) radiation determines many functional properties of metal, oxide, or semiconductor heterostructures. In magnetic heterostructures, emerging spin electronic phenomena depend strongly upon the phase profile of the magnetic field $\tilde{H}$ at gigahertz frequencies. Here we demonstrate nanometer-scale, layer-resolved detection of EM phase through the rf magnetic field $\tilde{H}_{\rm rf}$ in magnetic heterostructures. Time-resolved x-ray magnetic circular dichroism reveals the local phase of $\tilde{H}_{\rm rf}$ acting on individual magnetizations $\tilde{M}_i$ through the susceptibility as $\tilde{M} = \tilde{\chi}\tilde{H}_{\rm rf}$. An unexpectedly large phase variation, $\sim 40^\circ$, is detected across spin-valve trilayers driven at 3 GHz. The results have implications for the identification of novel effects in spintronics and suggest general possibilities for EM phase profile measurement in heterostructures.