X-Ray Microscopic Observation of Spin Wave Focussing by a Fresnel Lens

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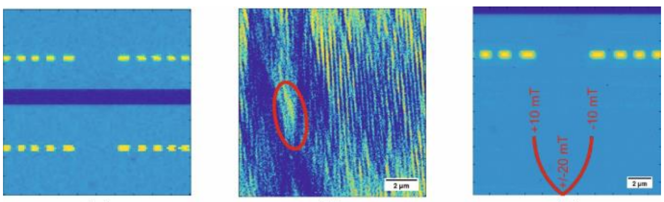
Manipulation of spin waves in artificial structures, the so called field of magnonics, has gained significant scientific interest in the past years [1-4]. These magnonic systems have great potential for technological applications in data processing and storage [3, 4]. In these structures the spin system is influenced on the length scale of the exchange and dipole interactions which allows the engineering of spin wave properties [2-4]. Therefore, nano-structured materials with locally alternating magnetic properties are utilized. An easy way to achieve this variation is by creating holes in a magnetic host material to form so-called antidot structures. The resulting modulation of saturation magnetization and demagnetization fields directly influence the spin wave dispersion in the material [2, 4].
However, the direct observation of the spin wave propagation and interaction within these magnonic structures is of key importance for the understanding and targeted engineering of future magnonic devices. Thus, we use advanced time-resolved scanning x-ray microscopy with high magnetic contrast based on the XMCD effect (MAXYMUS@BESSY). Thereby, we acquire a real space image of the spin wave propagation with a spatial and time resolution of 18 nm and 45 ps respectively.
Directing of propagating spin waves in magnonic wave guides has already been demonstrated [5 ,6], but focusing and steering of a spin wave beam in a large area still remains a challenge. This has partially been addressed by confinement in narrow wave guides due to demagnetizing fields at the sample edges [5, 6]. However, a focusing lens for spin waves resulting in a focal spot in a uniform thin film has not been realized yet [2-4]. Here, we present an interference based Fresnel lens that is based on an antidot structure in permalloy (1a). The spin wave propagation is imaged by time-resolved x-ray microscopy. The interference that leads to the formation of a focal spot (1b) was observed in a wide frequency range (2 – 10 GHz). In the focal spot the spin waves are confined to less than 800 nm. The intensity is increased by more than 20% above the emission intensity. Thus, the lens is effectively overcompensating the damping during spin wave propagation. Furthermore, the focal spot can be moved easily in a 6x6 µm² area by changing the applied magnetic bias field in the mT range. Thus, this type of spin wave lens can provide a flexible intense spot and an effective magnon source for different magnonic or spintronic devices with various possibilities for further improvement.



(a) (b) (c)

Figure 1: *(a)* general layout of the antidot based nano-scaled Fresnel zone plate for spin waves with a strip line excitation source in the center; *(b)* spin wave intensity map generated from the x-ray microscopy movie showing the interference pattern and the focal spot of the spin waves; *(c)* illustration of the trajectory of the spin wave focus that can be scanned by changing the applied magnetic field.

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