Inelastic Light Scattering Spectroscopy of GHz Spin Dynamics in Ferromagnet/semiconductor Nanostructures Based on Conformal $Ni_{80}Fe_{20}$ Shells on GaAs Nanowires

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Core-shell ferromagnet/semiconductor nanowires have generated interest in spintronics and optoelectronics which harnesses the spin information of electrons via e.g. spin-light emitting diodes (spin-LEDs). After the growth of single-crystalline semiconductor nanowires standing vertically on a substrate, different ferromagnetic shells were deposited in molecular beam epitaxy (MBE) systems such as Fe [1], MnAs [2], GaMnAs [3] and Fe_3Si [4]. The epitaxial growth on nanowire side facets induced magnetocrystalline anisotropy and the interesting global vortex state was not reported. In this state, magnetic moments align azimuthally around the shell and avoid a stray field acting on the semiconductor core. Recently, the vortex state was realized in 30 nm thick $Ni_{80}Fe_{20}$ (permalloy) grown around GaAs nanowires by MBE [5,6]. These samples allowed for studying the magnetization dynamics and spin wave modes in the vortex state. The detailed understanding of their eigenfrequencies is of key importance for spintronics and spin-LEDs operated at GHz frequencies. However, MBE introduces an enormous growth induced anisotropy [5] and thereby modifies eigenfrequencies and spin orientations.

We have optimized a chemically assisted deposition technique for the creation of conformal ferromagnetic shells on vertically standing GaAs nanowires. We apply atomic layer deposition (ALD) of either Ni [7] or $Ni_{80}Fe_{20}$ [8] which avoids both magnetocrystalline and growth induced anisotropies. We have realized unprecedented film qualities on high-aspect core-shell nanostructures with commercially relevant anisotropic magnetoresistance values and low damping [7,8]. We present experimental studies and simulations of magnetization dynamics and spin-wave modes in individual 22 nm thick $Ni_{80}Fe_{20}$ shells on GaAs nanowires with a diameter of about 150 nm. Depending on an applied magnetic field the tubular shells show the axial, mixed and global vortex configuration [9]. We exploit inelastic light scattering and detect the microwave-induced spin dynamics in the center of tubular shells, covering a frequency regime from 2.5 to 12.5 GHz consistent with Ref. [6]. We identify different series of resonant eigenmodes depending on the three magnetic configurations. The mixed and vortex configurations give rise to spin precession with helical phase profiles indicating an unusual nature of confined spin-wave modes. The finding is attributed to magnetochiral effects and a non-reciprocal spin wave dispersion relation. Our study provides microscopic insight into the spin dynamics of tubular ferromagnets around semiconductor nanowires which are subject to radiofrequency signals in the GHz frequency regime. Such signals are relevant in modern spintronics and information technologies. The developed ALD processes are technologically relevant as they allow for the realization of high-density arrays of free-form spintronic nanoelements on the wafer scale. We thank D. Bouvet, A. Fontcuberta i Morral, G. Tütüncüoglu, and S. Watanabe for support and SNSF for funding via grants 177550 and 197360.

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