Effect of sink layer thickness on damping in CoMnGe (5 nm) / Ag (6 nm) / NiFe (x nm) spin valves

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Introduction

A spin valve structure comprises two ferromagnetic layers (one fixed and one free) separated by a non-magnetic spacer layer. By stimulating precession of the magnetisation within the fixed layer it is possible to drive a spin current across the non-magnetic layer where it is either absorbed or reflected by the free layer. This transfer of spin angular momentum into the free or 'sink' layer modifies the ferromagnetic damping observed in the fixed or 'source' layer. This change in damping is interface dominated and expected to increase with increasing sink layer thickness up to a saturation depth, previously reported to be 1.2 nm regardless of the sink layer's composition [1].

In order to determine the saturation thickness at which spin current is fully absorbed by the sink layer, direct measurements of the dynamic coupling between the two ferromagnetic layers have been made. Experimental confirmation of the saturation thickness is necessary both for substantiating theoretical models, and for the development of spin valve-based devices such as magnetic random access memory (MRAM).

Methods

A series of spin valves was fabricated comprising a 5 nm CoMnGe fixed/source layer, 6 nm Ag spacer and x nm NiFe free/sink layer on a sapphire substrate. The sink layer thickness, x, varied from 0 to 3 nm.

Vector network analyser ferromagnetic resonance (VNA-FMR) was used to investigate the variation in FMR linewidth as a function of sink layer thickness. The samples were placed face-down on a CPW positioned between the poles of an electromagnet, applying a bias field parallel to the signal line of the CPW. A VNA was used to apply RF current through the CPW, inducing an RF magnetic field at the sample surface. Sweeping both bias field and RF frequency allows for the production of a map of RF absorption from which the linewidth of the resonance can be extracted, and the Gilbert damping parameter, α, calculated.

X-ray detected ferromagnetic resonance (XFMR, Figure 1) [2] was used to independently observe the magnetisation dynamics in the source and sink layers. By studying the amplitude and phase of the forced precession in the sink layer as a function of sink layer thickness, it is possible to determine the saturation absorption depth of the spin current, and to gain insight into contributions to the damping in the source layer.

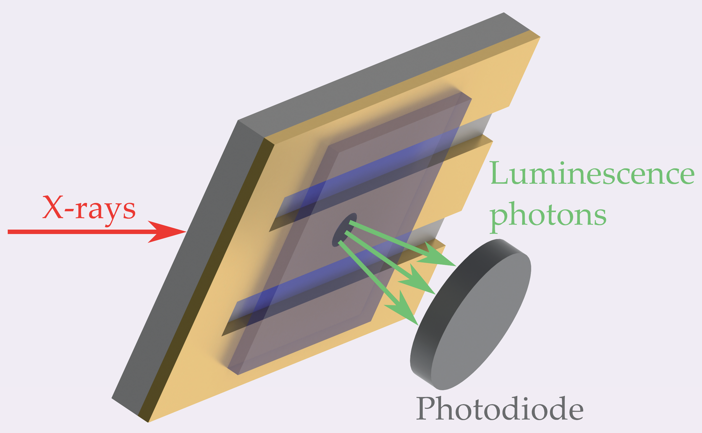

Figure 1: Schematic of x-ray detected ferromagnetic resonance. X-rays pass through a hole in the signal line of the CPW, striking the sample surface. Transmitted x-rays reach the sapphire substrate, which emits photos by luminescence. These are then detected by the photodiode and lock-in amplifier.

Results

VNA-FMR measurements show only small variations in the CoMnGe Gilbert damping parameter for NiFe layer thicknesses $x \leq 1.8$ nm (Figure 2). However, damping is seen to increase slightly at NiFe thicknesses of 0.3 and 0.6 nm.

Figure 3 shows the linewidth of the VNA-FMR peak as a function of frequency for a trilayer spin valve (NiFe thcikness 3 nm), and two reference films: one of CoMnGe (5 nm) and one of NiFe (3 nm). The linewidth of the trilayer is much more similar to that of the NiFe reference film, rather than the CoMnGe.

Element-specific XFMR measurements confirm spin transfer torque due to spin pumping as the origin of the coupling seen at NiFe thicknesses of $x = 1.5$ nm and $x = 1.8$ nm (Figure 4). Where the CoMnGe FMR response is unipolar, the NiFe response appears bipolar and vice versa. This is a key indicator of spin transfer torque due to spin pumping.

Both NiFe thicknesses ($x = 1.5$ nm and $x = 1.8$ nm) have the same spin mixing conductance $g^{\uparrow\downarrow} = 2.17 \pm 0.1 \times 10^{19}$ m^{-2}, supporting the findings of Ghosh et al. [1] that the value saturates at $x = 1.2$ nm.

For sink layers thicker than 1.8 nm the FMR modes for the CoMnGe and NiFe are seen to overlap, hampering the identification of any spin pumping. For thinner layers of NiFe, the small amount of magnetic material reduces the signal to below the noise floor.

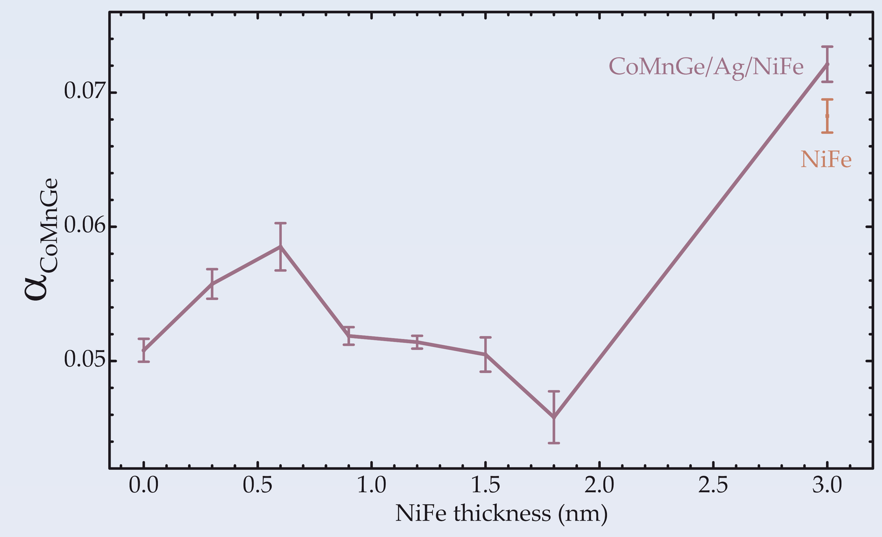

Figure 2: Gilbert damping parameter, α, as a function of NiFe layer thickness in CoMnGe/Ag/NiFe spin valve structures (purple) and a NiFe reference film (red). α varies only slightly up to a NiFe layer thickness of 1.8 nm, although increases are observed at 0.3 and 0.6 nm. Above 1.8 nm a sharp increase in α is seen.

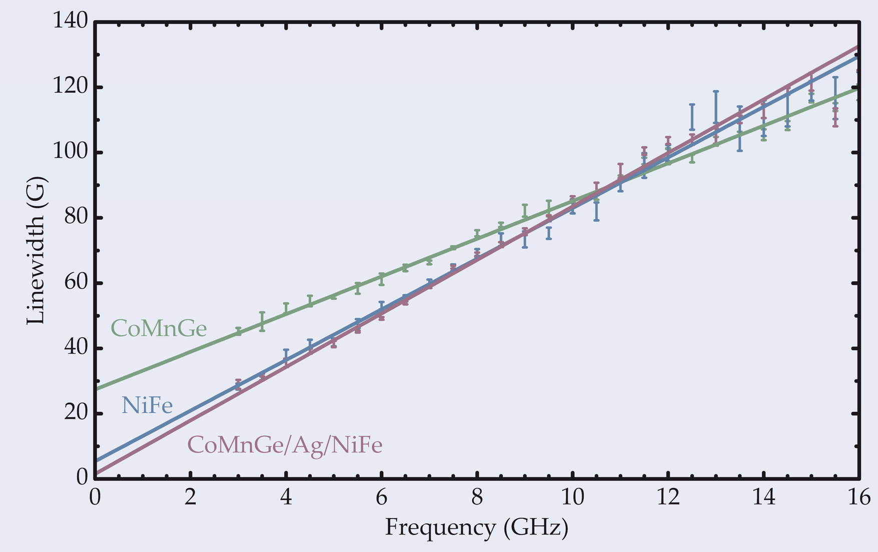

Figure 3: The ferromagnetic resonance linewidth as a function of frequency for three different samples: a NiFe reference film (blue), a CoMnGe reference film (green) and a CoMnGe/Ag/NiFe (3 nm) trilayer spin valve (purple). The linewidth of the spin valve closely matches that of the NiFe reference film, rather than the CoMnGe film.

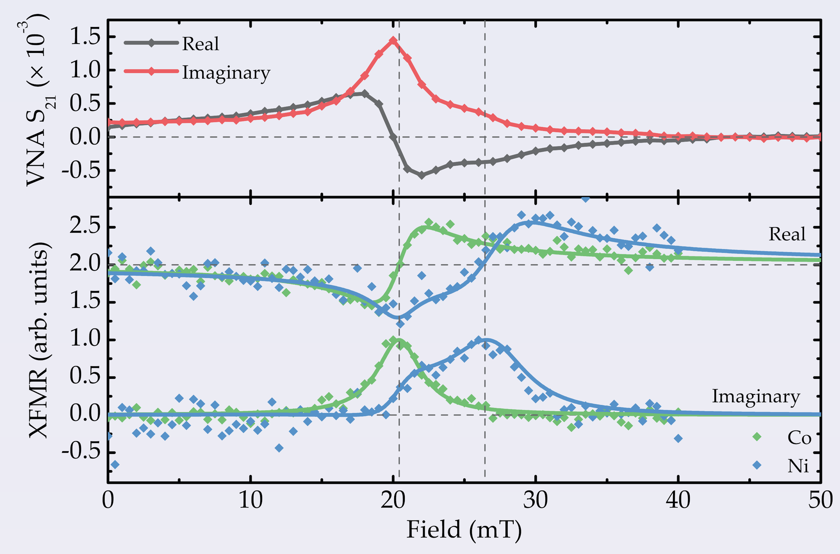

Figure 4: The real and imaginary parts of transmitted RF power (top panel) allow identification of the NiFe and CoMnGe resonant fields. The element resolved XFMR (bottom) shows the response of the NiFe sink layer when the CoMnGe source is driven at resonance. Note that a bipolar NiFe response accompanies a unipolar CoMnGe response and vice versa.

Conclusions

VNA-FMR measurements of a series of CoMnGe/Ag/NiFe spin valves have shown only small variations in the Gilbert damping parameter of the CoMnGe layer as a function of the thickness of the NiFe layer up to a thickness of 1.8 nm.

Element-resolved XFMR measurements have confirmed spin transfer torque due to spin pumping as the origin of coupling in spin valves with NiFe thicknesses of 1.5 and 1.8 nm. This concurs with the previous findings of Ghosh et al. [1].

Measurements of spin valves with thinner sink layers were hampered by the lack of magnetic material reducing the spin pumping signature to below the noise floor. Spin valves with thicker sink layers, however, resulted in the FMR fields for the source and sink layers overlapping, obscuring the signs of spin pumping.

Adjusting the stack structure to separate the FMR modes, while maintaining the element specificity of x-ray techniques, is the next logical step to overcome this issue, allowing identification of spin pumping in thicker sink layers.

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