CHARACTERIZATION OF MgO-BASED MAGNETIC TUNNEL JUNCTIONS' NONLINEAR FERROMAGNETIC RESONANCE MODES

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I. INTRODUCTION

In a simple MgO-based magnetic tunnel junction (MTJ), two ferromagnetic layers are separated by a thin, crystalline MgO barrier. The two ferromagnetic layers are known as the free layer (FL) and the pinned layer (PL). The tunneling of electrons through the MgO insulating layer results in electrical conductivity, which depends on the relative orientation between the magnetizations of the FL and PL. Thermal fluctuations of the FL and PL magnetizations cause magnetic noise, the fundamental limit of the MTJ's signal-to-noise ratio (SNR) [1]. Magnetic thermal noise is closely related to the ferromagnetic resonance (FMR) described by the Kittel equation, which connects the resonance frequency and applied field. Two commonly used techniques are thermal noise FMR (T-FMR) and spin-torque FMR (ST-FMR) [2]–[4]. Here we present an alternative FMR measurement technique, which compensates for some of the known techniques' drawbacks. Measured FMR spectra revealed not only the linear FL and PL modes but also the nonlinear ones.

II. MEASUREMENT TECHNIQUE

In Fig. 1(a), the signal generator and the spectrum analyzer are synchronized. The directional coupler is used to make the RF wave travel preferably towards the MTJ before being reflected in the direction of the instrument. The DC power supply provides the DC bias so that the MTJ is excited by a combination of AC and DC signals. The signal generator's frequency is swept from 1 to 10 GHz. At each frequency, the noise level difference (ΔNL) between the two states is computed: at zero and non-zero DC bias. Under non-zero DC bias, magnetization fluctuations of the FL and PL add to the noise floor of the carrier (Fig. 1(b)).

Similar to T-FMR and ST-FMR in the frequency domain, this measurement technique is susceptible to artifacts arising from heating. Compared to commonly used FMR techniques, the proposed measurement system has several advantages: 1) it does not suffer from the large background arising from mismatched interfaces, 2) its observation time is independent from the FL/PL magnetizations' relaxation time constants, and 3) the spectrum analyzer's resolution bandwidth (RBW) can be as low as 1 Hz, which significantly improves the system's noise performance.

III. RESULTS

The FMR spectra were obtained for a set of AC power levels (Fig. 2). Higher signal generator power levels revealed not only the linear FL and PL FMR modes but also mode splitting and sub-harmonics below the FL resonance frequency. The nonlinear FL and PL sub-harmonics are located at precisely 1/3 the frequency of the FL and PL. We suggest that these modes appear due to fractional synchronization, which may happen at $r < 1$, where r is the ratio between the driving frequency and the oscillation frequency [5]. For large AC power levels, the coupling between the oscillating magnetic layer and the source becomes nonlinear, resulting in a fractional synchronization regime. At higher AC power levels, both the nonlinear FL and PL sub-harmonics also exhibit splitting.

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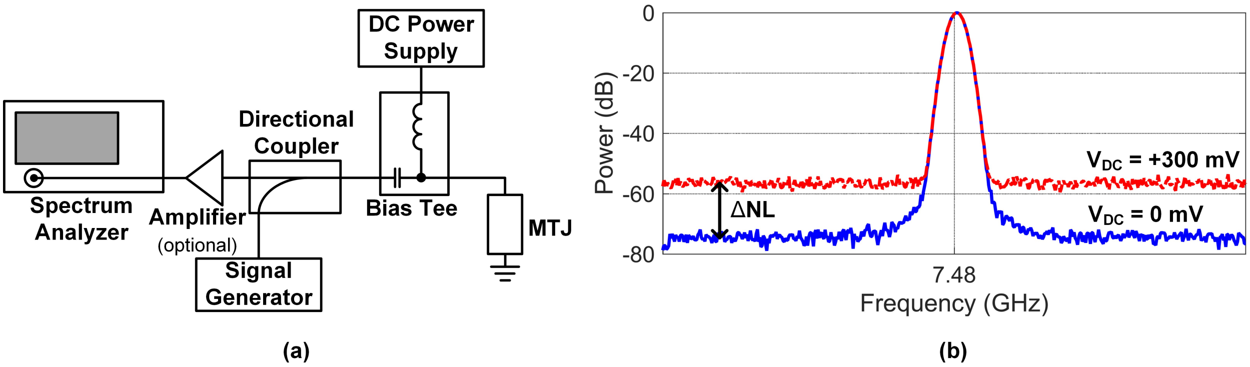

Fig. 1 (a) Proposed FMR measurement system. (b) Change in the noise floor with the bias voltage around the central frequency of the FL mode. Positive DC bias corresponds to the electron flow from the PL to FL.

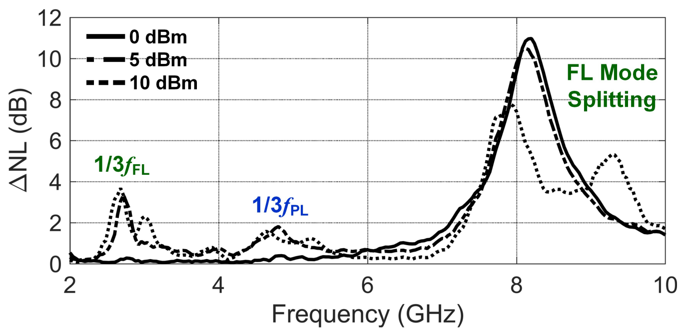

Fig. 2. FMR spectra showing nonlinear FL and PL sub-harmonics and mode splitting. The DC bias voltage is +300 mV while the AC powers are readings from the signal generator.