Nanotesla-field detectivity with hysteresis-free magnetic tunnel junctions

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Magnetic field sensors are required to show linear change of output voltage as magnetic field strength changes. For that, a few methods have been reported to stabilize the magnetization of the free layer ($\vec{\mathbf{M}}_{\mathrm{FL}}$) orthogonal to that of the reference layer ($\vec{\mathbf{M}}_{\mathrm{RL}}$), e.g. "2-step annealing" to induce exchange bias on RL by the first annealing and magnetic anisotropy on FL by second annealing or vice versa [1]. Firstly, $\vec{\mathbf{M}}_{\mathrm{RL}}$ is defined by setting the direction of exchange-bias field ($\vec{\mathbf{H}}_{\mathrm{ex}}$) through the 1$^{\mathrm{st}}$ annealing in a uniformly magnetic field ($\vec{\mathbf{H}}$). Secondly, for SL; it is coupled with a thick layer of NiFe to induce a magnetic anisotropy field ($\vec{\mathbf{H}}_{\mathrm{k}}$) having an orthognal direction to $\vec{\mathbf{H}}_{\mathrm{ex}}$ through the 2$^{\mathrm{nd}}$ annealing [2]. However, NiFe has an fcc 111 texture and CoFeB (CFB) must aquire bcc out-of-plane 001 texture in order to achieve high TMR ratios. Thus, a dust layer of Ta is often introduced to improve the 001 texture of CFB. However, TMR is still influenced and no hystersis-free curve is reported up to date [1-4]. Indeed, searching for alternative materials for the soft-magnetic layers is indispensable.

In this study, as shown in Fig. 1a, we incorporate an amorphous CoFeBTa (CFBT) as a soft-magnetic free layer which is ferromagnetically coupled with the CFB layer through the Ta (0.3 nm) insertion layer. Unlike the previous reports [1, 2], in our MTJ stack, the free-layer magnetic anisotropy was induced by the 1$^{\mathrm{st}}$ annealing at 350°C and the exchange-bias on RL was set by the 2$^{\mathrm{nd}}$ annealing at 200°C as clarified by arrows in Fig. 1b. By doing this, a cross-magnetic anisotropy between $\vec{\mathbf{M}}_{\mathrm{FL}}$ and $\vec{\mathbf{M}}_{\mathrm{RL}}$ is formed. Therefore, $\vec{\mathbf{M}}_{\mathrm{FL}}$ changes with $\vec{\mathbf{H}}$ smoothly without abrupt changes, providing a hysteresis-free transfer curve with a small linear operating range (< 3 mT) as shown in Fig. 2(*Red curve*).

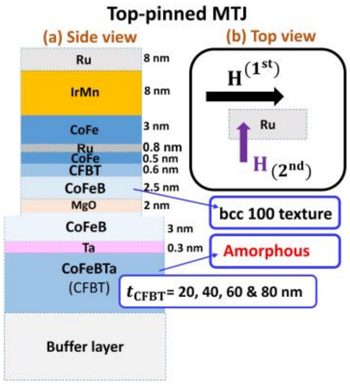

Fig. 1: The newly-proposed layer structure.

Furthermore, we systematically investigated the CFBT thickness dependence (t_{CFBT}) of noise voltage for the proposed layer structure. All fabricated devices showed 1/f noise behaviors with a strong magnetic-field dependence as shown in Fig. 3. The noise voltage is smaller in P ($\mu_0 H \approx$ -5 mT) and AP ($\approx$ 5 mT) states than that during the transition of magnetization between P and AP states. Moreover, the noise voltage increased as the bias voltage across junctions increased as shown in Fig 4. We evaluated the Hooge's parameter (α_{H}) from the 1/f noise; MTJ having t_{CFBT} = 20 nm giving rise to $\alpha_{\mathrm{H}} \approx 2.7 \times 10^{-8}$ μm^2 at P state. Such smaller value than that reported elsewhere [2] for a single MTJ sensor is considered to be due to the hysteresis-free transfer curve in our MTJs. We studied also the magnetic field detectivity dependence on t_{CFBT} at 5 Hz as shown in Fig. 5. We found that a detectivity as low as 4 nT/Hz$^{0.5}$ is obtained for the sensor having t_{CFBT} = 20 nm. Nevertheless, detectivity increased as t_{CFBT} increased.

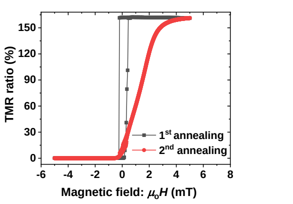

Fig. 2: Small field RH-loops showing the free layer transfer curve after 1$^{\mathrm{st}}$-& 2$^{\mathrm{nd}}$-annealing.

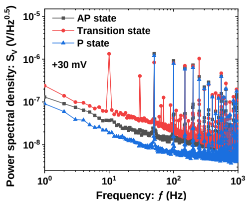

Fig. 3: Magnetic-field dependence on noise voltage of MTJ having t_{CFBT}= 20 nm.

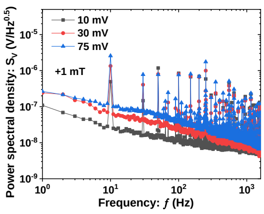

Fig. 4: Bias-voltage dependence on noise voltage of MTJ having t_{CFBT}= 20 nm.

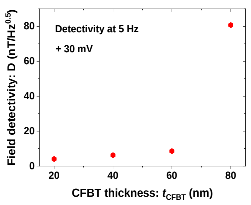

Fig. 5: Magnetic field detectivity dependence on t_{CFBT}.

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