Highly-sensitive tunnel magnetoresistance sensor devices with NiFe/CoFeBTa free layers

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Tunnel magnetoresistance (TMR) sensors consisting of CoFeB/MgO/CoFeB magnetic tunnel junction (MTJ) has attracted much interest in the detection of small magnetic fields. The figure of merit of magnetic sensor is the magnetic field detectivity (D), defined by $D = \frac{\sqrt{S_V}}{\Delta V/\Delta H}$, where $\sqrt{S_V}$ is noise voltage density in V/$\sqrt{\text{Hz}}$, ΔV is the full output voltage and ΔH is the operating magnetc field range of the sensor [1]. We recently showed TMR sensors with linear and closed resistance (R)-field (H) curve using a top-pinned spin-valve TMR sensor with CoFeBTa (CFBT) (20)/Ta(0.3)/CoFe(3) free-layer (FL), where the CFBT layer is an amorphous soft-magnet [2]. The sensor's detectivity was as low as 2.2 nT/Hz$^{0.5}$ at 10 Hz. However, the sensor showed a wide ΔH range of 2.5 mT. This means that there is a room to improve D by decreasing ΔH.

In this talk, we present a technique to reduce ΔH and thereby improve D by laminating NiFe with the CFBT/Ta/CFB FL. The TMR structures with different FLs are shown in Fig. 1(1 & 2). We applied a two-step annealing technique to obtain linear R-H curves. The first annealing step was performed at T_{1st}= 350 °C for 1 h under a horizontal magnetic field of 0.7 T. Thereafter, the samples were rotated by 90° and the second annealing step was performed at T_{2nd} = 200-220 °C for 20 min as shown in Fig. 1(3). Due to this annealing process, the pinning direction of spin-valve and the annealing-induced anisotropy in the FL are set orthogonally, which gives rise to linear R-H curves with small hysteresis as shown in Fig. 2. ΔH was strongly decreased by introducing a thin layer of NiFe ($t_{\text{NiFe}} \leq 5$ nm) and then increased gradually for $t_{\text{NiFe}} > 5$ nm (inset of Fig. 2). TMR ratio increased and reached to a maximum value for the MTJ sensor with NiFe 10/ CFBT 20/ Ta 0.3/CFBT 20 FL then decreased. The maximum magnetic field sensitivity S (= TMR/ΔH) has achieved for the MTJ sensor with NiFe 5/ CFBT 20/ Ta 0.3/CFBT 20 FL. Fig. 3 showed the noise voltage density $\sqrt{S_V}$ of all MTJ sensors measured at the intermediate state of magnetization (1 mT) under a bias voltage of 30 mV. We have found that $\sqrt{S_V}$ for all sensors was in the range of 45-53 nV/Hz$^{0.5}$ and there was no distinct change in the behavior of 1/f noise between all MTJ sensors. Remarkably, the MTJ sensor with NiFe 5/ CFBT 20/ Ta 0.3/CFBT 20 FL showed the minimum D of ~1.55 nT/Hz$^{0.5}$ at 10 Hz, which is lower than we previously reported [2].

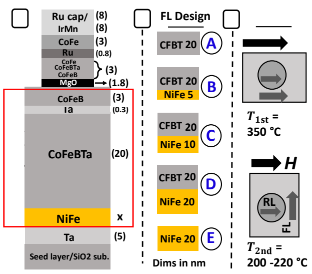

Fig. 1: (1) Layer structure, (2) FL designs (3) annealing technique.

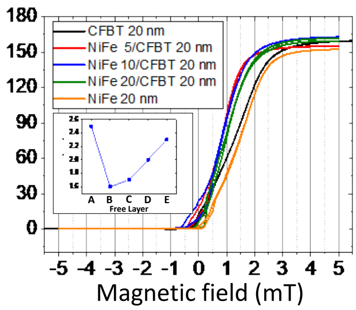

Fig. 2: TMR-H curves. Inset (ΔH).

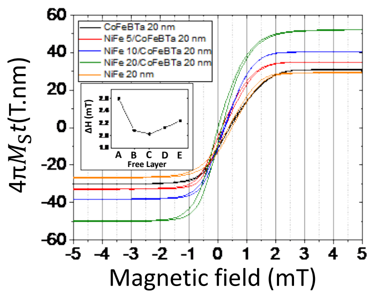

Fig. 3: Noise voltage spectra. Inset (detectivity).

References
[1] Silva et al. Eur. Phys. J. Appl. Phys. **72**, 10601 (2015).
[2] Rasly et al. J. Phys. D: Appl. Phys. **54**, 095002 (2021)