## Spin-orbit torque switching and thermal stability of nanoscale Co/Pt multilayers over a wide range of temperature

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Spintronics memory devices utilizing spin-orbit torques (SOTs) [1-3] are promising for ultralow-power and high-performance integrated circuits. To use SOT devices for versatile applications, including automobile and aerospace, they need to ensure wide-temperature operations in nanoscale dimensions. Thus, it is important to understand temperature dependence of the device performance. We have been studying SOT devices with Co/Pt multilayers having high anisotropy and shown SOT-induced magnetization switching in micrometer-scale Hall-bar devices [4]. In this work, we study the temperature dependence of switching characteristics and thermal stability in nanoscale SOT devices with Co/Pt multilayers and discuss the feasibility of Co/Pt multilayers for those applications that require wide-temperature operations.

The stacks of Ta/Pt/[Co/Pt]<sub>4</sub>/Co/Ta/(Co<sub>25</sub>Fe<sub>75</sub>)<sub>75</sub>B<sub>25</sub>/MgO/ capping layers are prepared on Si substrates and processed into nanowire devices with pairs of Ta/Pt channels and probes. The nanowire width and length are varied down to 20 nm and 300 nm, respectively. To evaluate SOT-induced switching, a dc current is applied to the nanowire devices under an in-plane field  $H_{\text{ext,in}}$  along the collinear direction to the current while monitoring Hall resistances  $R_{\text{Hall}}$ . Thermal stability factor  $\Delta$  ( $\equiv E/k_{\text{B}}T$ , where E is an energy barrier,  $k_{\text{B}}$  the Boltzmann constant, and T an absolute temperature) is determined by switching probability when repeating a sweep of perpendicular magnetic field. During the electrical measurements, stage temperature is controlled in order to examine the temperature dependence of the device properties.

Figures (a) and (b) show temperature dependences of switching current  $I_{sw}$  under  $\mu_0|H_{ext,in}| = 200$  mT and  $\Delta$ , respectively in a device with 30-nm width and 300-nm length. Magnetization switching by

current is observed in all the studied range of temperature. Very high  $\Delta$  of more than 200 is obtained at 125°C. Such properties are obtained owing to the high anisotropy of Co/Pt multilayers and the independence between SOT-switching properties and Gilbert damping. These results indicate that Co/Pt multilayers have potential for wide-temperature operations as nanoscale SOT devices for versatile applications.

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Figure. Temperature dependences of  $I_{sw}$  under  $\mu_0 | H_{ext,in} | = 200 \text{ mT}$  and  $\Delta$  in a device with 30-nm width and 300-nm length.