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Spin-orbit Torque Devices for Digital and Neuromorphic Computing

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I review our study on realizing three-terminal spintronics devices for integration with CMOS VLSI and for neuromorphic computing. Three-terminal devices separate the two current paths, one for magnetization switching and the other for reading the state of magnetization, thereby, allowing a relaxed operation window that result in high speed operation compared to their two-terminal counterpart [1]. In addition, by introducing an antiferromagnet layer below the ferromagnetic layer, one can realize an analog operation suitable for neuromorphic computing application. The devices of interest utilize spin-orbit torque (SOT) for magnetization switching, which consist of a heavy metal or antiferromagnet layer and a target ferromagnetic structure placed on top of it. I first discuss a new configuration that allows high-speed operation of an SOT switching with a target ferromagnetic pillar having an in-plane magnetic easy axis collinear with the current flow direction in the underneath heavy-metal [2, 3]. We show that one can switch magnetization as fast as 500 ps in this structure without significant increase in switching current; 500 ps switching speed is not readily available in two-terminal devices utilizing spin-transfer torque (STT) switching without applying considerably large current - STT requires switching current inversely proportional to the switching speed in this speed range. We also show that there is a device configuration to avoid application of static magnetic field otherwise needed to induce switching. The second topic I will discuss is to use an antiferromagnetic layer as a source of SOT as well as the source of an exchange field: The former is for the switching and the latter is for the switching in the absence of an external magnetic field. It was shown in a (Co/Ni)-multilayer/PtMn structure one can switch magnetization in the absence of external magnetic field [4]. The use of antiferromagnet led us to realize an analog memory, which we used to demonstrate an associative memory operation in a spintronics-device based artificial neural network [5]. We show that analog operation comes about from the fact that ferromagnetic domains comprising a number of polycrystalline grains reverse individually and among the domains both out-of-plane and in-plane components of exchange bias vary [6].

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