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Spintronics: nanoscience and nanoelectronics (IEEE Magnetics Society Distinguished Lecture)

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Spintronics explores the physics of interplay between spin and charge in condensed matter. It is one of the most active areas of magnetism. In particular, electrical manipulation of spin and magnetization in nanostructures allows us not only to study the interplay but can also be utilized to reverse magnetization direction, which is of great importance to nanoelectronics. In my lecture, I describe the nanoelectronics side and the science side of spintronics by discussing two topics that delineate the significance and technological importance of such spin manipulation in condensed matter. _I am sure not many of the audience are old enough to remember that magnetic memory was once preferred main memory for modern digital computers. There were reasons it was replaced by semiconductor memories. However, with the advances in spintronics, i.e. the recent development of giant tunnel magnetoresistance and current-induced magnetization switching in magnetic tunnel junctions, it appears that a comeback of magnetic memory may be possible, which now combines the nonvolatile capability of magnetic nanostructure with all the functionalities of current and future complementary metal-oxide-semiconductor (CMOS) integrated circuits. I also show that this hybrid magnetic tunnel junction/CMOS integrated circuit approach can solve many of the major challenges current integrated circuit technology are facing. _On the science side and on out further in the future, I turn to hole-induced ferromagnetism in Mn-doped III-V semiconductors (in particular, GaAs and InAs). This offers a variety of opportunities to explore new and/or unique spintronics physics. Ferromagnetism and magnetization in these materials can be manipulated by various means; by changing its carrier concentration by electric fields and/or by spin-current flowing along with the electric current. In the latter, our latest study on an empirical scaling law found in the creep regime of the current-driven domain walls showed that spin-torque driven creep is quite different from magnetic-field driven (and thus energy driven) creep, belonging to a new and different universality class. In the former, an electrical control of magnetization direction through manipulating magnetic anisotropy by electric-fields was shown to be possible. This opens up a unique opportunity for manipulating magnetization direction solely by electronic means, not resorting to magnetic-field, spin-current, mechanical stress, nor multiferroics.