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Self-organized magnetic GeMn nanocolumns in germanium

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Spintronics requires spin injectors compatible with silicon technology and operating at room temperature. Potential candidates are group-IV ferromagnetic semiconductors like Mn-doped silicon or germanium. In this presentation, we show that co-evaporating Ge and Mn on Ge(001) and GaAs(001) substrates using low-temperature MBE leads to the formation of self-assembled Mn-rich nanocolumns. These nanocolumns are observed in a wide range of growth temperatures (80 $^\circ$C to 180 $^\circ$C) and Mn concentrations (1% to 11%). However the deposition rate is kept very low in order to favor the 2D spinodal decomposition which promotes the growth of nanocolumns. In this talk, we first present a complete phase diagram of nanocolumns as a function of growth temperature and Mn concentration focusing on their size, density, crystalline structure and magnetic properties. In particular, we could demonstrate that at low growth temperature it is possible to tune the columns density and at higher growth temperatures their size distribution. Moreover vertical self-organization of nanocolumns in (GeMn/Ge) superlattices could be achieved. At low growth temperatures, nanocolumns exhibit the diamond structure of Ge and contain up to 30 % of Mn. By combining ab-initio calculations and EXAFS measurements, we could suggest a realistic building block of the nanocolumns. In parallel we have studied the crystalline structure of nanocolumns using grazing incidence x-ray diffraction on synchrotron radiation facilities. We then correlated the magnetic properties like magnetic anisotropy of nanocolumns to their structure by combining SQUID and EPR measurements in a three-dimensional geometry. Finally magneto-transport measurements were performed to evidence the coupling between carriers and the magnetic nanocolumns. CIP measurements mostly give information on the Ge matrix electronic properties and CPP measurements on the nanocolumns. We show the first CPP measurements on a single nanocolumn using nanocontacts.