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Influence of Mn Distribution on Ferromagnetism in Magnetic Semiconductor Mn_xGe_{1-x}

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The ferromagnetism of Mn-doped Ge, grown with molecular beam epitaxy, is studied by controlling Mn distributions in the films via post-annealing and digital doping techniques. Randomly doped Mn_xGe_{1-x} films exhibit a high concentration of Mn trapped at interstitial sites in Ge, and reveal two ferromagnetic transitions. A critical temperature T_C* (~112 K for x ~0.05) is obtained as ferromagnetic spin clusters form, and a second transition occurs at much lower temperature Tc (~12 K for x ~0.05) at the onset of global ferromagnetic ordering. A strong correlation between magnetic and transport properties is observed both at T_C* and T_C. Upon annealing as-grown films at a low-temperature, some interstitial Mn atoms are driven toward the surface of the film and even to the substitutional sites of Ge, as predicted by a theory [1] and revealed by ion channeling and x-ray photoemission spectroscopy. This Mn redistribution leads to a large increase in ferromagnetism with both T_C* and T_C shifting toward higher temperatures, e.g., 150 K and 35 K, respectively, for x~0.05. Spatial control of Mn atoms along the growth direction is achieved in a Mn_xGe_{1-x}/Ge digital heterostructure. Ferromagnetism enhancement is also observed in digital structures as compared to randomly doped material with same nominal x. The ferromagnetism variation is studied by changing undoped Ge spacer layer thickness and x in doped Mn_xGe_{1-x} layer. The Mn distribution effect on ferromagnetism is discussed with a spin-cluster model [2].

1. W. Zhu, et al., Phys. Rev. Lett. 93, 126102(2004).
2. G. Alvarez, M. Mayr, and E. Dagotto, Phys. Rev. Lett. 89, 277202 (2002).

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