Type of presentation: Poster

MS-8-P-1983 Investigations of segregation phenomena in highly strained Mn-doped Ge wetting layers and Ge quantum dots embedded in silicon

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Mn-doped Ge quantum dots (QDs) embedded in Si are particularly interesting since their small size and the confinement effects may affect the electronic structure, the spin interactions and thus their ferromagnetic properties. Room-temperature and electric-field-controlled ferromagnetism were demonstrated in self-assembled $Mn_{0.05}Ge_{0.95}$ QDs [1].
Highly strained Mn-doped Ge wetting layers (WLs) and QDs embedded in Si have been prepared by Molecular Beam Epitaxy via Stranski-Krastanow growth mode on Si. High resolution scanning transmission electron microscopy (HRSTEM) imaging and Electron energy loss spectroscopy (EELS) spectrum imaging were performed at 200 kV on a FEI Titan^3 Ultimate fitted with probe- and image-side aberrations correctors. EELS measurements were done in STEM mode using a Gatan Quantum spectrometer. TEM specimens were prepared using chemical mechanical wedge polishing to obtain clean and damage-free specimen.
In this presentation we report on Mn diffusion and the formation of Mn-rich precipitates in highly strained few monolayer thick Ge WLs and nanometric size Ge QDs heterostructures embedded in silicon. In the Ge/Si system Mn always precipitates and the size and the position of Mn-rich precipitates depend on the growth temperature (figure 1). At high growth temperature manganese strongly diffuses from germanium to silicon. By decreasing the growth temperature manganese diffusion is reduced [2]. In the Ge QDs system grown at low temperature Mn precipitates are detected, not only in partially relaxed Ge QDs but also in fully strained Ge WLs, between dots, as shown by the figure 2 [2]. Mn precipitates are identified by EELS (figure 2e) and three of them are indicated by white arrows in figure 2a.
In the GeMn system, the growth has to be performed at low temperatures (< 150 °C) to incorporate Mn and avoid the formation of Ge_3Mn_5 clusters [3,4]. Nevertheless, lateral segregation is still observed and leads to the formation of Mn-rich nanocolumns, i.e. elongated nanostructures parallel to the growth direction [4]. The nucleation of these GeMn nanocolumns required a critical thickness of 4 nm, which was explained by a subsurfactant epitaxial growth with Mn atoms occupying subsurface interstitial sites [4,5]. In this work we demonstrate that it is possible to incorporate Mn into extremely thin strained Ge layers. This feature is likely due to the electronic structure modification in these few Ge layers grown in compressive strain on silicon [6].

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[3] M Jamet et al, Nat. Mater. 5 (2006), p. 653.
[4] T Devillers et al, PRB 76 (2007), p. 205306.
[5] C Zeng et al, PRL 100 (2014), p. 066101.
[6] T Dietl, Nat. Mater. 5 (2006), p. 673.

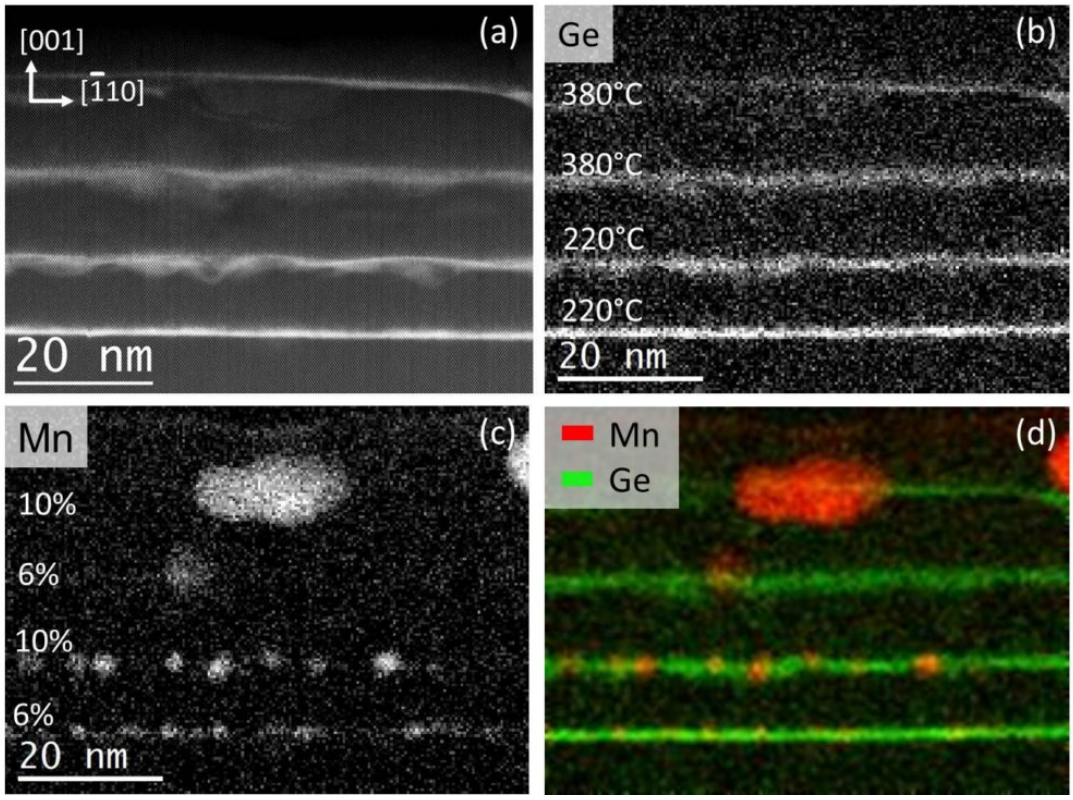

Fig. 1: Cross-sectional STEM-EELS of Mn-doped Ge WLs growth at different temperatures and different Mn concentrations. (a) High angle annular dark field (HAADF) image of the four layers: the two lowest are grown at 220 °C and the two at the top are grown at 380 °C. (b) Ge map and (c) Mn map obtained by EELS. In (d) Mn (green) versus Ge (red) composite map.

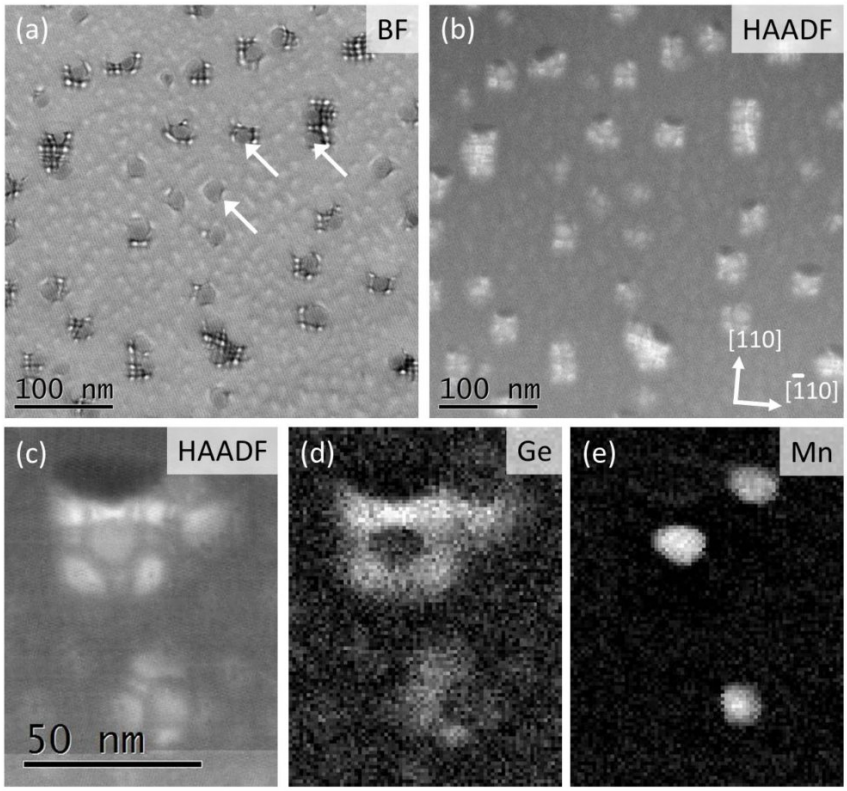

Fig. 2: Plane view (a) Bright field- and (b) HAADF-STEM images of one Ge(Mn) QDs layer grown on Si substrate. (c-f EELS analysis of two Ge(Mn) QDs. (c) HAADF-STEM image acquired simultaneously than the EELS SI. (d) Ge map (e) Mn map and (f) Si map obtained by EELS. The arrows in (a) indicate Mn precipitates.