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PERIODIC MODULATION OF STRAIN FIELDS AND MAGENTIC ANISOTROPY IN (Ga,Mn)As/InAs/GaAs STRUCTURES

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Thin layers of (Ga,Mn)As magnetic semiconductor exhibit magnetic anisotropy which is strongly influenced by lattice-matching strains introduced into these layers during epitaxial growth. Laterally homogeneous strains can be induced by growing these layers on top of GaAs (compressive strain) or (In,Ga)As (tensile strain) buffers [1]. Lithographic techniques can be used to create complicated strain patterns leading to spatially varying magnetic anisotropy [2-4]. We combined e-beam lithography and dry etching with molecular beam epitaxy to create ordered fields of InAs quantum dost on GaAs(001) substrate which were subsequently covered by a $Ga_{0.95}Mn_{0.05}As$ capping layer.

High-resolution X-ray diffraction reciprocal-space mapping is conventionally used to explore the strains in similar cases. However, the low growth temperature required to incorporate Mn atoms into (Ga,Mn)As layers causes that the crystal quality of such heterostructures is often not as good as in the case of continuous epitaxial layers and previously reported approaches to characterize the strain fields using the X-ray data are therefore not directly applicable. Further complications arise from the combined effects of strain and chemical roughness. Here we report on a simple fitting-free methodology to evidence the presence of periodic strain fields from the measured X-ray data and show how kinematical theory of X-ray scattering coupled with the solution of elasticity equations can be used to determine the main features of these strain fields.

The proceedings are organized as follows: first we present the calculations of the strain fields in the case of (Ga,Mn)As layers grown on top of periodic arrays of InAs quantum dots. Then we discuss the evaluation of the intensity profiles along the satellites stemming from lateral periodicity and we show that the presence of strain can be evidenced from the comparison of the relative intensity of the first pair of satellites. Finally, we present the results of X-ray diffraction experiment.

The strain in (Ga,Mn)As/InAs/GaAs structures originates in different intrinsic lattice parameters of the constituent materials. We used a combination of Fourier and finite

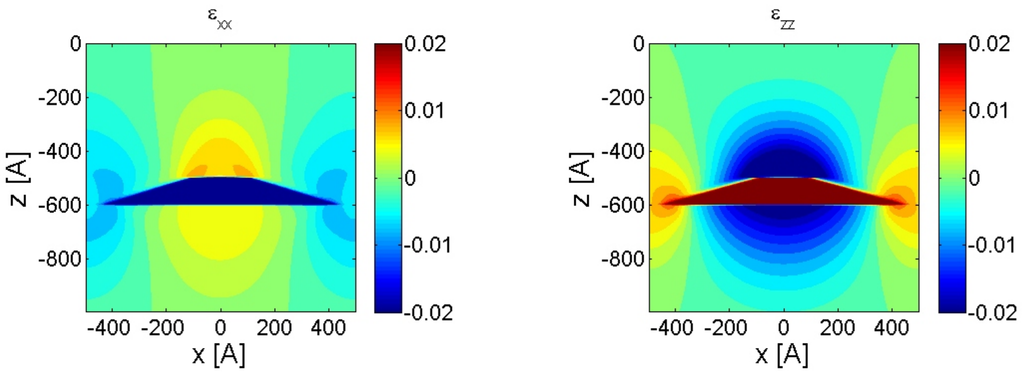

Figure 1. Calculated $_{xx}$ and $_{zz}$ components of the strain tensor in a sample containing periodic array of quantum dots. The dots have the shape of a 10nm high truncated cone with 40nm bottom radius and 10nm top radius and are assumed to be composed of pure InAs.

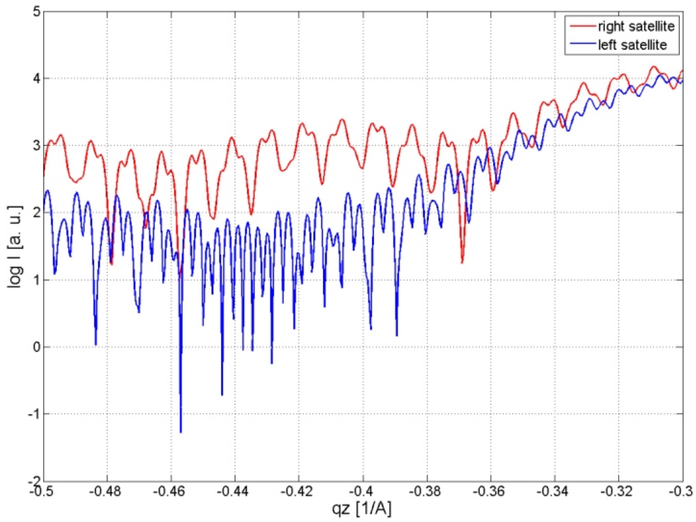

Figure 2. Intensity distribution along the first pair of satellites near the (224) diffraction of InAs calculated within the framework of kinematical scattering theory. The asymmetry of the intensity profiles originates from epitaxial strains present in the sample.

element methods to solve the equations of elasticity and calculated the strain fields for a simplified model of the sample structure. In this model we assumed that (1) the dot array is infinite and perfectly periodic in the lateral direction, (2) the realistic dot shape can be approximated by a truncated cone or pyramid, (3) elastic constants and lattice parameter of GaAs can be used also for (Ga,Mn)As and (4) the surface is ideally flat and force-free. A typical result of such a simulation is shown in Fig. 2 for conical dots with 40nm bottom radius, 10nm top radius and 10nm high; the separation between dots is 100nm. We see that tensile strain is confined to the vicinity of the dot apex whereas the regions between the dots are compressively strained.

The reciprocal-space distribution of measured intensity in an X-ray scattering experiment exhibits lateral satellites stemming from the periodicity of both the chemical composition and the strain fields. The intensity distribution along a given satellite can be calculated within the framework of kinematical theory of X-ray scattering and the resulting formula predicts that the intensity ratio of the left and corresponding right satellite is equal to one regardless of the diffraction if there is no strain in the sample; however, if strain is present, this ratio is different from one in some diffractions as can be seen in Fig. 2 which shows the calculated intensity distribution along the first pair of satellites. The predicted asymmetry is indeed observed in the measured X-ray data for the (224) diffraction (see Fig. 3) which provides a strong proof of the presence of periodically modulated strain in the structures studied.

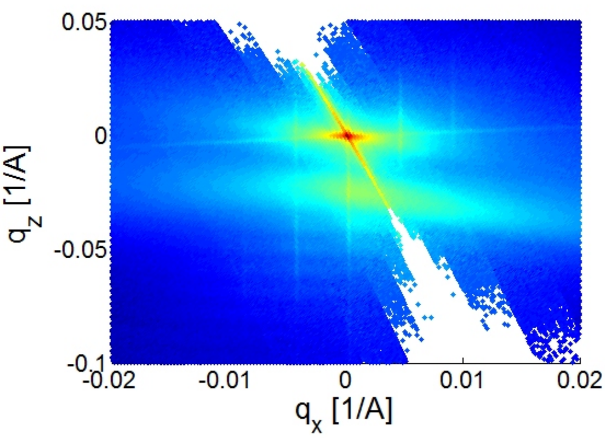

Figure 1. Measured X-ray diffraction data close to the (224) substrate peak. The large area of diffuse scattering corresponds to the (Ga,Mn)As layer; lateral satellites originate from the periodicity of the underlying quantum dot array. The strong asymmetry is a hallmark of the epitaxial strain.

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