Coherent Diffraction Patterns of Individual Dislocation Strain Fields

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Introduction

Gas-source molecular beam epitaxy is a form of the chemical vapor deposition (CVD) growth technique for semiconductors that enables the preparation of semiconductor thin films of exquisitely high quality. It allowed the principles of critical film thickness to be carefully tested in the past. The samples used for these measurements were films of $Ge_{0.3}Si_{0.7}$ grown by gas-source molecular beam epitaxy from Ge_2H_6/Si_2H_6 mixtures at 450°C. They were grown on Si(100) substrates to a thickness very close to the critical thickness. This is the point of onset of the creation of interfacial dislocations, which can be detected as cusp-shaped lines by atomic force microscopy (AFM) when they glide to the surface of the film [1]. Figure 1 shows an AFM image of the surface of such a film, with dislocations spaced more than 1 μm apart.

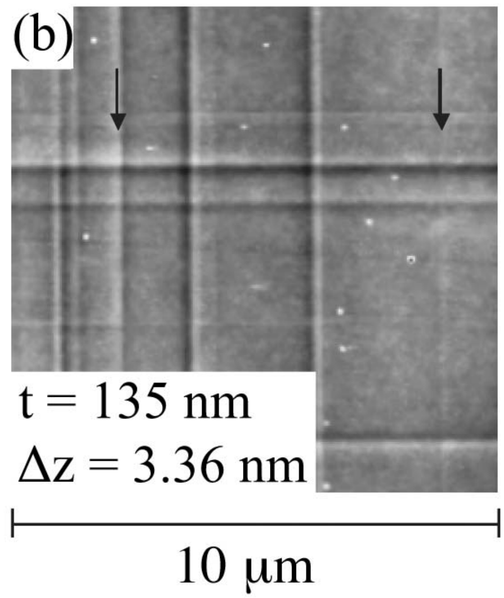

FIG. 1. AFM image of a 1350-Å film of $Ge_{0.3}Si_{0.7}$ grown by CVD methods. The interfacial dislocations appear as cusp-shaped straight lines across the surface [1].

Methods and Materials

These interfacial dislocations and their associated glide-plane structures would be expected to generate strain fields in the surrounding crystal. In our experiments, we prepared a micron-sized beam by using Kirkpatrick-Baez (KB) optics and placed it on one of these dislocation structures. The sample was aligned by means of its Si(100) substrate. The resulting diffraction pattern associated with the $Ge_{0.3}Si_{0.7}$ film, shown in the left panel of Fig. 2, was measured by using a charge-coupled device (CCD) area detector centered at the reciprocal lattice point (2,0,1.92), defined by the Si substrate. The broad peak observed corresponds to the film thickness in the Q_{perp} direction (running approximately up the page) and to the onset of relaxation in the $Q_{parallel}$ direction (running across the page). This is the conventional diffraction behavior for a thin film close to its critical thickness [2]. Because of the high degree of coherence of the beam, some speckle structure can be seen in the center of the pattern.

However, as the small probe was scanned across the surface of the film, at rare locations, it encountered one of the dislocation structures. This generated a modified diffraction pattern like the one shown in the right panel of Fig. 2. The pattern has not yet been interpreted fully, but it appears to correspond to some planar structure inclined to the surface. The structure must resemble an extended planar defect in order to generate such a sharp feature, which is reminiscent of a crystal truncation rod [3]. Indexing of the Ewald-sphere section of reciprocal space cut by the detector in our geometry (see Fig. 2 caption) reveals that the (111) direction lies close to the detector plane. The inclination of the streak is therefore close to one of the {111} directions. This diffraction feature probably corresponds to one of the {111} glide planes expected to relieve the edge dislocation (or accumulation of multiple dislocations) at the $Ge_{0.3}Si_{0.7}$/Si film/substrate interface [2].

Acknowledgments

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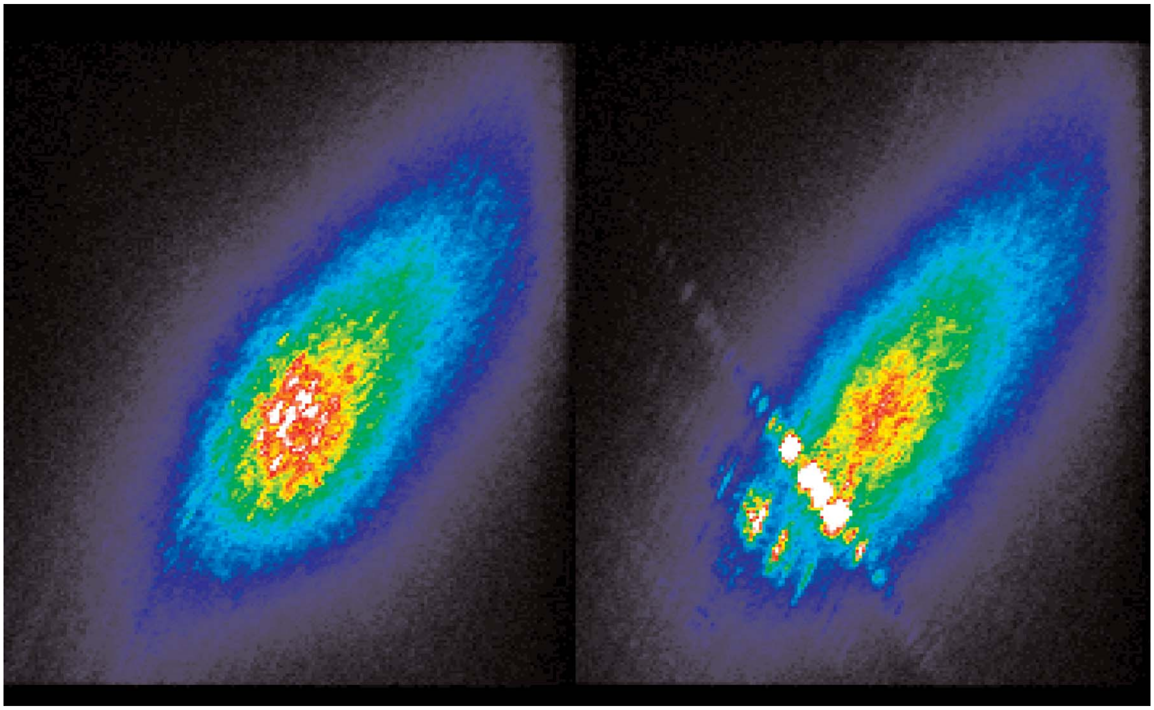

FIG. 2. Measured diffraction pattern of the $Ge_{0.3}Si_{0.7}$ film in the vicinity of its 202 Bragg peak. The pattern is a reciprocal lattice map centered approximately at (2,0,1.92), in the Si coordinate system, with the (0,0.55,1) direction running up the page and (1,0,0) to the right. Image on left is typical of the majority of the film. Image on right shows an additional diffraction feature when the probe beam was sitting on one of the dislocation structures.

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References

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