Zoological Studies 34, Supplement I (1995)

Zoological Studies

Near-Field Scanning Optical Microscopy Imaging of Individual threading Dislocations on Relaxed Ge_xSi_{1-x} Films

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Using a near-field scanning optical microscpe (NSOM), we investigate defects and morphology on the surface of relaxed GeSi films that arise from the strain release caused by lattice mismatch between the heteroepitaxial films and the Si substrates. Threading dislocations are identified by simultaneously imaging the surface topography and the photoelectric signals. Characterization using an electron microscope is commonly used for this type of defect imaging. Images based on photoelectrical contrast is analogous to electron beam induced current (EBIC) imaging. The resolution achieved with a NSOM it ten times higher than with conventional far-field optical techniques, and similarto that of EBIC. We will present results of surface morphology and photoelectic response near threading dislocations, as well as compare our results with EBIC results.

The ability to integrate devices made of different materials is the key to advancing modern electronic and optoelectronic technologies. Thus, the growth of good quality films having bulk properties on lattice mismatched substrates and the characterizations of such flms have been major area of study in material science. We will rport the use of a novel optical technique, the near-field scanning optical microscope (NSOM), to simultaneously study, with spatial resolution better than 100 mm, the surface morphology and electric-optical activity of individual threading dislocations on relaxed Ge_xSi_{1-x} films. Because the size of each crystalline defect is much smaller than the diffraction limit of visible light, such defect characterization has been limited until now to electron microscopy techniques. This study also demonstrates the power of the NSOM, which achieves a more than tenfold increase in spatial resolution from conventional far-field optical methods. The capability to simultaneously study morphology and photoresponse of the same defect structure is the major advantage of the NSOM over electron microscopy.

The NSOM used in this experiment operates in reflection mode, and was modified from a commercial scanning force microscope (PSI BD-2). The tips were tapered, Al-coated optical fibers similar to those reported in Betzig et al. 1991. Shear force feedback (Betzig et al. 1992, Burrato et al. 1994) was used to regulate the tip-sample separation between 10 and 20 nm. Topographic images are generated by applying a voltage to the z piezo scanner to keep the shear force signal constant, while the spatially resolved near-field photoresponse is measured simultaneously.

Samples studied in this experiment are grown by molecular beam epitaxy and consist of a uniform Ge_xSi_{1-x} cap layer of ~1μm on top of a compositionally graded layer on Si (100) substrates. They are completely relaxed, exhibiting bulk Ge_xSi_{1-x} optical properties. (Fitzgerald et al. 1991, Xie et al. 1992) Typicaly, these graded films have threading dislocation densities $\leq 5 \times 10^6$ cm^{-2}. This was determined with electron beam induced current (EBIC) (Fitzgerald et al. 1992) because the density is too low to be detected by transmission electron microscopy. Fig. 1 shows side by side (a) topographic and (b) photovoltage images in a 10.9μm x 10.9 μm area taken simultaneously. In Fig. 1b, three threading dislocations are easily identified by the three dark spots in the image. The corresponding topographic image (Fig. 1a) is dominated by the cross-hatch pattern that is due to the underlying misfit dislocation network characteristic of these graded samples. Nevertheless, three shallow depressions corresponding to the region of reduced photoresponse can be identified. These electrically-active shallow depressions are individual

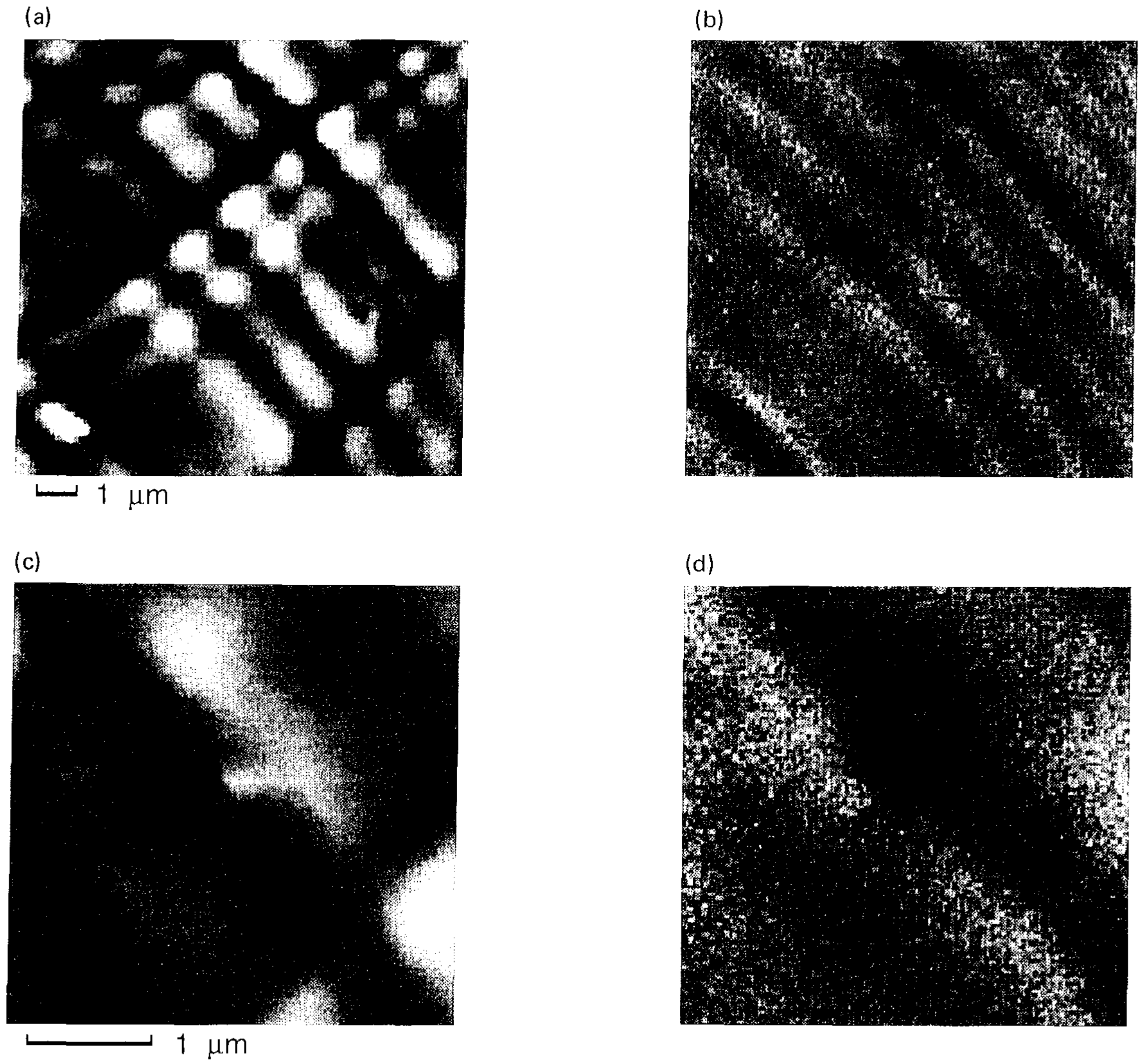

Fig. 1. (a) Topographic and (b) photovoltage images taken sim-ulateously of a 10.9 µm x 10.9 µm area. (c) Topographic and (d) photovoltage images of a 3.6 µm x 3.6 µm area near dislocation #1, indicated in (b). The full gray scale for (a) & (c) represent 100 Å and for (b) & (d) correspond to a 10% change.

defects since their photoresponse is similar in both magnitude and spatial extent to their morphoogy. Fig. 1c and d show topography and photoresponse near threading dislocation #1 from Fig. 1a and (b) with higher manification (3.6 µm x 3.6 µm). It is now clear that these threading dislocations display a distinctive morphology as reported in Hsu et al. 1992 and act as carrier recombination centers. The average spatial extent of the photovoltage reductionfor a threading dislocation is (0.66±0.16) µm, larger than that of the depressions, (0.39±0.11) µm. This is because the electrical activity length scale is determined by carrier diffusion length,which can be large in good materials, as well as aperture size. EBIC images of threading dislocations in these samples show dark spots with ~1 µm diameters. The full scale of Fig. 1b and d represents a 10% change about the average photovoltage. Typical reduction of threading dislocation photoresponse is measured to be 5 ~ 10%. A few precent change is also what is observed in EBIC.

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