Title
In-situ TEM studies of the interaction between dislocations in SiGe heterostructures

Author
Bean, J.C.

Publication Date
1999-07-29

LBNL - 44049

IN-SITU TEM STUDIES OF THE INTERACTION BETWEEN DISLOCATIONS IN SiGe HETEROSTRUCTURES

E.A. Stach,* R. Hull,† R.M. Tromp,‡ F.M. Ross,‡ M.C. Reuter‡ and J.C. Bean¥

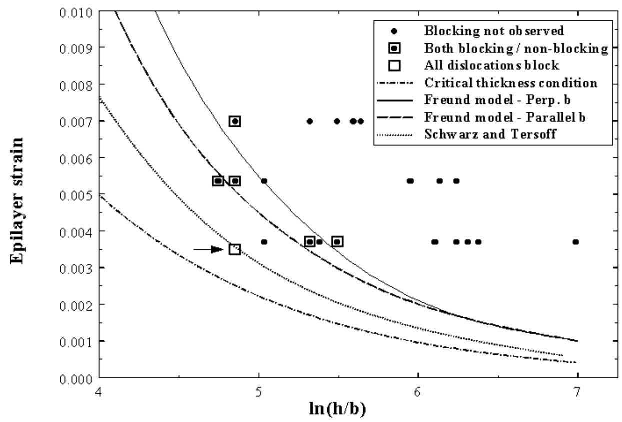
* National Center for Electron Microscopy, Lawrence Berkeley National Laboratory
† Department of Materials Science, University of Virginia
‡ IBM Research Division, IBM Watson Research Center
¥ Department of Electrical Engineering, University of Virginia

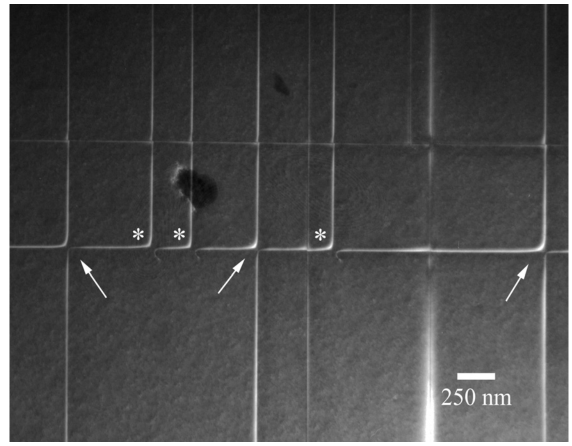
Strain relaxation in lattice mismatched heterostructures can be accomplished via epilayer roughening, interdiffusion between the layers, or by the introduction of an array of misfit dislocations at the interface between the two materials, provided that the epilayer thickness is above the equilibrium critical thickness. The rate of strain relaxation via misfit dislocation introduction is strongly limited by the kinetics of dislocation nucleation, propagation and interaction.[1] In this work, we describe real-time observations of the interaction between moving threading dislocations and pre-existing interfacial misfit dislocations using *in-situ* transmission electron microscopy. This was accomplished both during *in-situ* observations of the heteroepitaxial growth process using a modified ultrahigh vacuum TEM (UHV-TEM) equipped with chemical vapor deposition capabilities,[2] as well as during *in-situ* anneals of metastable structures grown by molecular beam epitaxy.

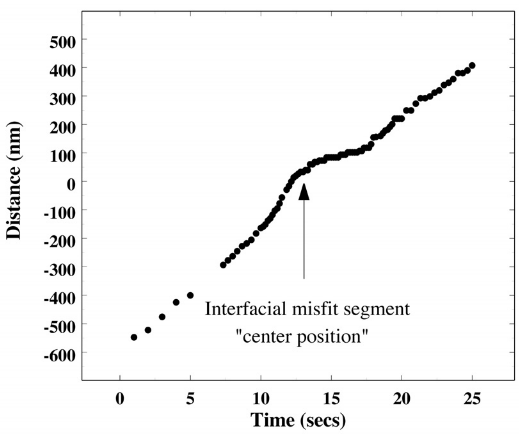
In Figure 1, we present our UHV-TEM observations of the epilayer thicknesses and compositions at which dislocation interactions result in blocking of the propagating threading segment, and compare these with the predictions of Freund[3] and those of Schwarz and Tersoff.[4] Our results show that dislocation blocking can significantly affect the overall rate of strain relaxation in these structures. This is important, as blocked threading segments introduce undesired band gap states into electronic devices made from these structures[5] and can act as easy diffusion paths for impurities and dopants. Additionally, blocked threading segments have been shown to provide an upper limit to the relaxation of strain in graded buffer structures.[6]

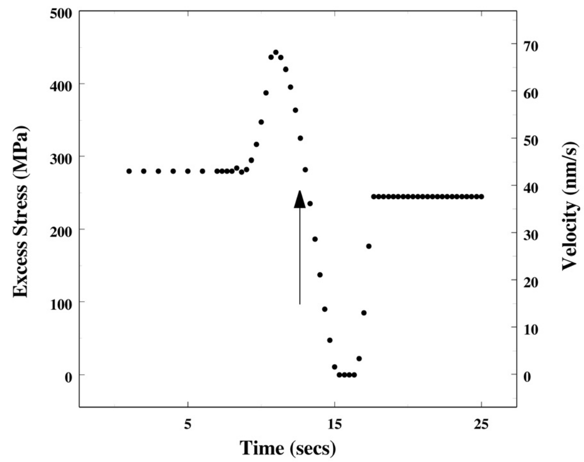
We also observe that only at the lowest epilayer thicknesses and compositions do all dislocation interactions result in blocking. At higher thicknesses and compositions - when the overall strain in the heteroepitaxial layer is larger – it is found that only those dislocations that exhibit a splitting reaction result in blocking, as shown in a 400 dark field image in Figure 2. This reaction is predicted to occur when the Burgers vectors of the two dislocations are parallel. Systematic analysis of the Burgers vectors using $(\mathbf{g} \cdot \mathbf{b})s$ diffraction contrast analyses has confirmed this dislocation geometry.[7] We find that even when this splitting reaction occurs, propagating threading segments do not necessarily become blocked.

Finally, using previously established empirical relationships between the velocity of propagating dislocations and the amount of excess stress driving their motion, we have experimentally determined the magnitude of the stresses present during the interaction process. In Figure 3, we plot the distance between a propagation threading segment and a pre-existing interfacial segment as measured by grabbing frames every 1/6 of a second from a videotaped observation of an interaction between dislocations with parallel Burgers vectors.









---

[1] For a recent review of strain relaxation in SiGe heterostructures see R. Hull and E.A. Stach, “Strain accommodation and relief in SiGe / Si heteroepitaxy” in Heteroepitaxy, Thin Film Systems, A.W.K. Liu and M.B. Santos (ed.). Rivers Edge, NJ: World Scientific Publishing Co., Inc. (1999) in press.

[2] E.A. Stach, R. Hull, R.M. Tromp, M.C. Reuter, M. Copel, F.K. LeGoues and J.C. Bean, J. Appl. Phys. **83**, 1931 (1998).

[3] L.B. Freund, J. Appl. Phys. **68**, 2073 (1990); J. Mech. Phys. Solids, **38**, 657, (1990).

[4] K.W. Schwarz and J. Tersoff, Appl. Phys. Lett. **69**, 1220 (1996).

[5] F.M. Ross, R. Hull, D. Bahnck, J.C. Bean, L.J. Peticolas and C.A. King, Appl. Phys. Lett. **62**, 1426 (1993).

[6] S.R. Samavedam and E.A. Fitzgerald, J. Appl. Phys. 81, 3108 (1997).

[7] P.B. Hirsch, A. Howie, R. Nicholson, D.W. Pashley, and M.J. Whelan, Electron Microscopy of Thin Crystals, Krieger, Malabar, FL (1977).