DOE/ER/45278--4

Ast, Cornell (607 255 4140

DOE DE-FG02-86ER45278

# PROGRESS REPORT 89/90

We have shown previously that the number of misfit dislocations that form at the interface of GaAs and lattice mismatched InGaAs - when the latter is grown to a thickness in excess of the critical thickness - can be sharply reduced or even eliminated to by prepatterning the substrate [1]. (The critical thickness is the thickness at which the strain energy of the originally coherent overlayer exceeds the energy required to form interface dislocations).

The discovery is of technological interest since it relaxes the material matching requirement in device construction and permits a better optimization of electrical properties. E.g., during 89/90, patterning was taken up by IBM and HP to improve the materials quality of detectors (IBM) and Ge-Si HBT's (HP).

In 89/90, our research has focused mainly on the continuation of the control of misfit dislocations in strained epitaxial layers through such patterning [1]. Since we lack growth facilities, we co-operate with H-P Labs (MBE), IBM (MBE), and the University of Florida at Gainesville (OMCVD).

In this work, we have concentrated on three aspects of misfit control. Two of them are related to the fact that patterning and etching trenches into GaAs substrates prior to epitaxial growth results in a non-planar wafer surface. Device fabrication, in general, is more difficult on a non planar surface.

To prevent or minimize this problem, we have investigated the possibility of confining misfit dislocations by selectively ion damaging the substrate prior to growth. Growth on such wafers yields single crystal regions separated by small grain poly-Si barriers, resulting in a planar wafer after MBE. We could show that along the substrate-overlayer interface the (ion) damaged portions act as dislocation obstacles for dislocations gliding in the undamaged interface. Unfortunately, ion damage also acts as a source of new dislocations, so that this process is not technologically viable. However, it the ability to introduce, at will, dislocation nucleation sites has been quite valuable scientifically to answer questions of the relative role of nucleation and friction (Peierls force) in the formation of misfit dislocations.

Our second approach has been to determine if the overlayer must or must not be physically discontinuous for our scheme to work, that is: Does the trench depth have to be greater than the overlayer thickness (a) or can it be

# DISCLAIMER

# DISCLAIMER

less, resulting in a physically continuous overlayer (b) with a less "bumpy" surface:

a) Discontinuous Overlayer
Highly Non-planar surface

b) Continuous overlayer
Less non-planar surface

While b) does not result in a planar wafer, it does greatly reduce the step height on the surface. In 89/90 we established that approach b) does work and began to investigate on how deep these etched trenches had to be, relative to the overlayer thickness, to prevent the misfit dislocations from gliding from one region to another.

Our third research direction has been to extend our results from molecular beam epitaxially grown material (MBE) to another important growth process - organometallic chemical vapor deposition (OMCVD). One important difference between these two is that OMCVD tranfers material through a gas that can in some sense conformally coat a substrate surface. With this growth technique, we could study the effect of misfit dislocation isolation by trenches that only change the surface topology of the epitaxial layer and not the continuity.

Concurrent with this research has been an increasing effort to characterize the patterning processes and the damage it introduces into the substrate.

This, of course, is the common observation that progress from witchcraft to science in epitaxial growth requires a thorough characterization of the substrate. In our case, this investigation was precipitated by the observation that after an upgrade of the dry-etching equipment in the National Nanofabrication Facility our process did no longer function reliably. This was traced to fact that low energy ( 500 eV) dry etching processes in GaAs damage the substrate much deeper than the ion range (Rp) and that this damage - in general - must be eliminated prior to growth by suitable wet etching steps. Otherwise, those damaged regions can recrystallize during

the time the wafer is heated up to the deposition temperature. The recrystallized regions than can act as heterogeneous nucleation sites at the island edges and peripheries, defeating the purpose pf patterning.
*Technical Details:*

Our preparation of ion damage isolation material consisted of wafer processing, growth of strained InGaAs layers several times larger than their critical thicknesses, and characterization of the material by cathodoluminescence (CL), transmission electron microscopy (TEM), x-ray diffraction, Rutherford back-scattering (RBS), and ion channeling. The substrates were patterned with standard photolithography techniques and exposed substrate regions were ion-implanted with high energy Xe ions. The substrates were used to grow 350 nm thick $In_{0.05}Ga_{0.95}As$ layers by MBE by collaborators from Hewlett Packard Laboratories. Our analysis showed that the ion damaged areas did isolate the regions they surrounded from misfit dislocations gliding from other areas of the wafers, but these regions were also copious nucleation sources of misfit dislocations, which in effect defeats the purpose of the isolation.

Several interesting features of this material were found however. One important fact was that the misfit dislocations formed in virtually only one direction at the GaAs/InGaAs interface. In unpatterned material, researchers have found that the density of dislocations in the 110 and $1\bar{1}0$ crystallographic directions differ only slightly and in one report they are equal. Figure 1 is a TEM image of misfit dislocations that formed at the GaAs/InGaAs interface of the ion damaged material. Notice that the great majority of them lie in one direction in the plane. We believe that the asymmetry found in our material is connected to how misfit dislocations are formed from gliding dislocation segments that nucleate at the edge of anion damaged area and to the effect that the Fermi level has on the motion of these segments. These results are discussed in Reference 2.

Another feature of this material is that the ion damaged regions do create many misfit dislocations (as they are expected to!) but still not enough are created to relax the strain in the epitaxial layer to the expected equilibrium value. The addition of "frictional" forces that inhibit dislocation glide cannot account for the observed density of dislocations. Figure 2 shows how the strain energy changes with misfit dislocation density. Our material should possess a dislocation density that lies at the minimum of the 350 nm curve; the experimentally determined value is shown on that curve. This problem is also discussed in Reference 2.

Our second research concentration, finding the minimum trench depth necessary to stop misfit dislocations, is discussed in Reference 3. The OMCVD InGaAs strained layers 350 nm thick were grown by collaborators from the University of Florida. Substrates were prepared by patterning and etching as in Reference 1 but with trenches that varied in depth from 70 nm to 1200 nm. The minimum isolation depth was found to be lower than even the epitaxial layer itself - a depth of only about 160 nm. The exciting point of this work is that no special steps should be necessary to fabricate devices on the surface of the material. The resulting surface is in effect planar, as far as photolithography and metallization steps are concerned.

Our investigation of OMCVD grown, isolated InGaAs yielded interesting phenomena. The density of misfit dislocations in the 110 and $1\bar{1}0$ directions were found to differ in the patterned MBE material [1]; the difference was assumed to be due to the different properties of the cores of the dislocations that lie in the two directions. However, the densities in OMCVD material were found to be precisely the same. The reason that the MBE and OMCVD material differ has been speculated on in Reference 3 and is currently being studied.

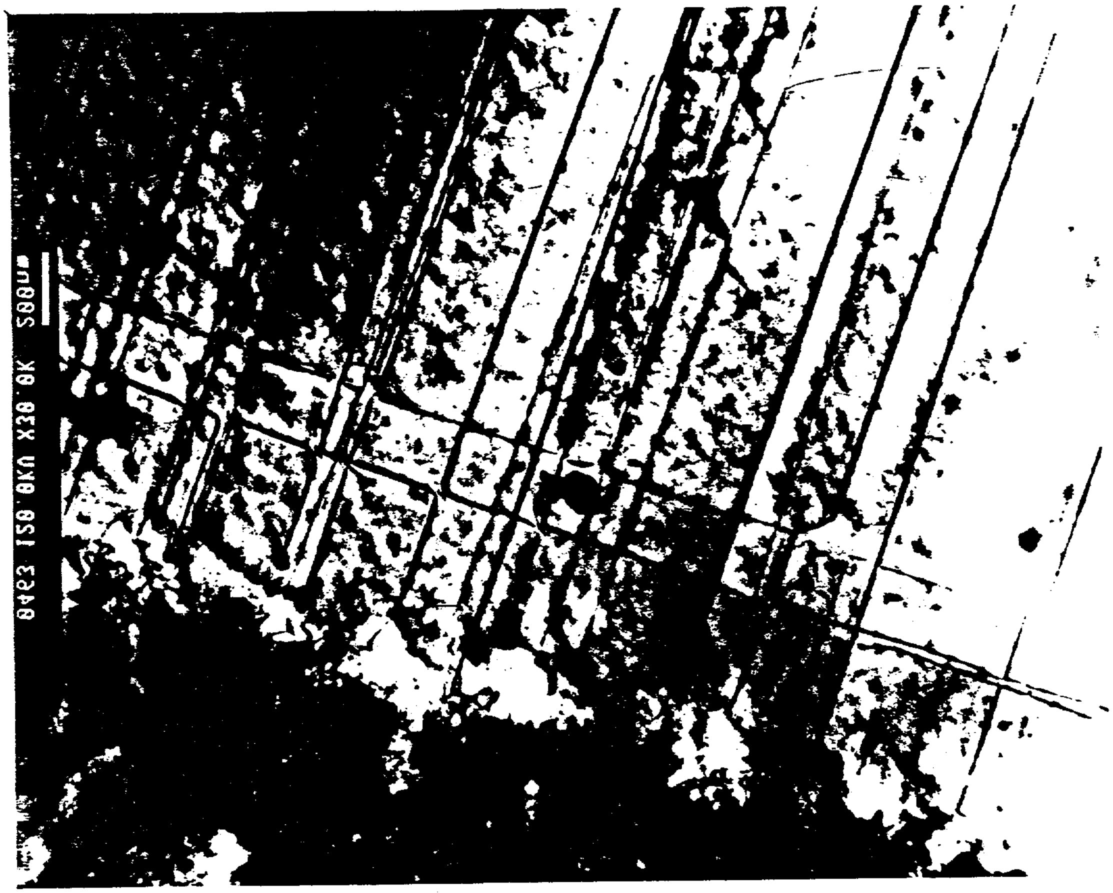
We have also studied how the misfit density varies with the size of isolated regions. Square substrate regions were patterned with sizes that varied from 100 to 800 $\mu$m to a side. Figure 3 is a plot of how the dislocation density was found to vary with square size. The relationship is linear at even large (almost 1 mm) square sizes which implies that dislocation multiplication mechanisms are not active in this material.

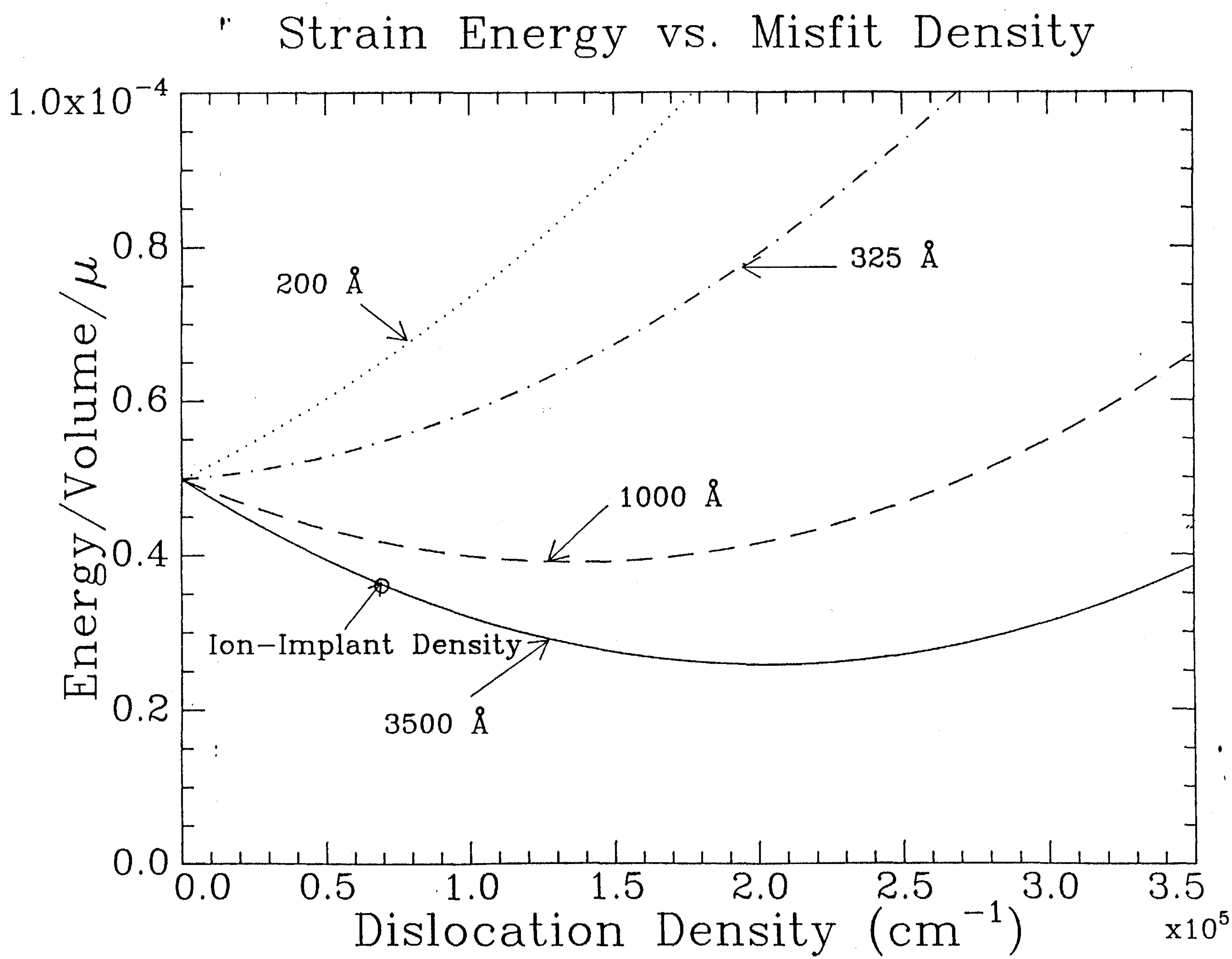
References

1 E .A .Fitzgerald, G .P .Watson, R .E .Proano, D .G .Ast, P .D .Kirchner, G .D .Pettit, J .M .Woodall, J .Appl .Phys. 65, 2220 (1989).

2 "The Isolation and Nucleation of Misfit Dislocations in Strained Epitaxial Layers Grown on Patterned, Ion-Damaged GaAs", G. P. Watson, A. Fischer-Colbrie, and J. Miller, presented at the TMS annual conference in Anaheim, CA, February 1990, and to be published in J. Electronic. Materials.

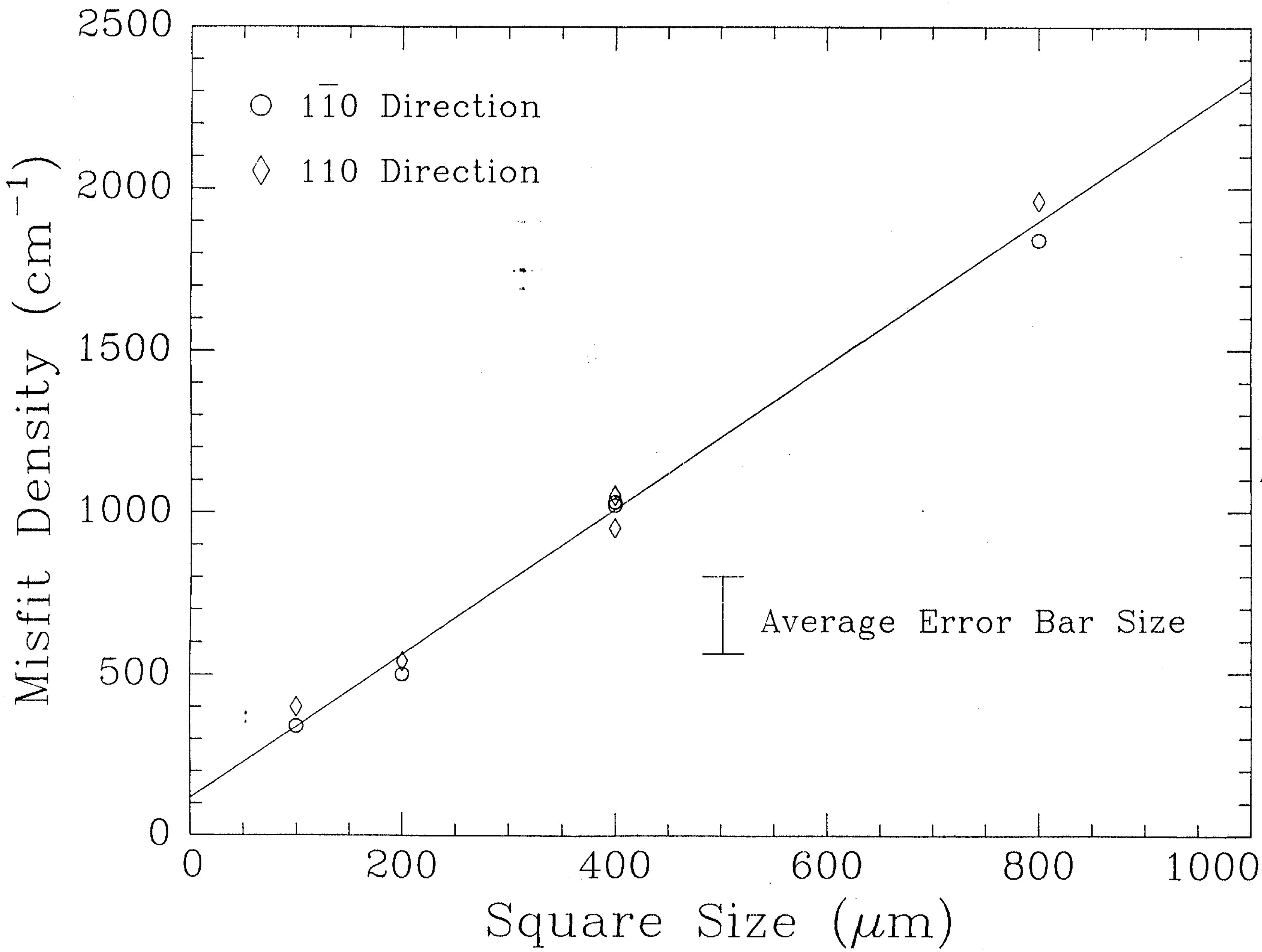
3 "The Control and Properties of Misfit Dislocations in OMCVD Grown Epitaxial Layers", G. P. Watson, D. G. Ast, T. J. Anderson, and Y. Hayakawa, to be presented at the CIM conference in Ontario Canada, August 1990 and to be published in the conference proceedings.





Strain Energy vs. Misfit Density
1.0x10^-4
0.8
0.6
0.4
0.2
0.0
Energy/Volume/μ
200 Å
325 Å
1000 Å
Ion-Implant Density
3500 Å
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
x10^5
Dislocation Density (cm^-1)


Fig 2



1$\bar{1}$0 Direction
110 Direction
Average Error Bar Size
Misfit Density (cm$^{-1}$)
Square Size ($\mu$m)
0
500
1000
1500
2000
2500
0
200
400
600
800
1000