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DISLOCATION CONTRAST AT HIGH VOLTAGES

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Some results of up to 12 beam contrast calculations for systematic orientations[1] have indicated that high order reflections at high voltages may provide improved dislocation resolution. For example the contrast profiles for dislocations show a decrease in image width for increasing order of reflection (i.e. increasing $\bar{g}.\bar{b}$), thus enabling improved resolution of narrow dislocation dissociations and closely spaced dipoles or superdislocations.[2]

This paper provides experimental confirmation that high order systematic reflections do indeed result in an improvement in bright field image resolution e.g. image widths of dislocations can be reduced by a factor of ~3. The results have been obtained from [001] foils of GaAs semiconducting devices in which dislocations are associated with surface and interfacial defects. In each case the crystal is set at the exact Bragg condition for each reflection along the systematic row being used. The work was done on the Berkeley Hitachi microscope operated at 650 kV.

Figure 1 shows a single dislocation in gallium arsenide and its projection under various operating reflections. In A and B, the operating reflections 040 and 080, because they have relatively large Bragg angles, even at high voltages (650 kV), approximate the low voltage two-beam conditions, i.e. no strong systematic influences are present. It can be seen that there is little change in image width by using the higher order reflection. The smaller Bragg angle of the [220]

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reflections allows many beams of the systematic set to operate. Figure 1C-G show that the use of these systematic reflections leads to a marked decrease in dislocation image width, especially in C-E, which correspond to imaging of primarily the edge components of the dislocations. In F and G the contrast is primarily due to the screw components of the dislocation and, although not as marked as in C-E, there is again some decrease in image width with increasing $\bar{g}$. Figure 2 shows inclined arrays of dislocations imaged using various systematic <$\bar{2}$20> conditions. The confusion due to oscillatory contrast which is present in A, especially where the dislocations intersect the surface or where they lie above one another, is sharply reduced as the order of the reflection at the Bragg condition increases. For example, the double dislocation images which are readily apparent in the lower portion of B and C are extremely difficult to resolve in A. Also, the image width decreases with increasing order of reflection, as expected. Not only is resolution improved, but the "noise" in the image due to contrast phenomena (e.g. oscillations in intensity) is largely reduced, i.e.,image confusion is reduced.

These results seem to have broad application to studies of lattice defects and small coherent particles at high voltages and can be applied more generally than the "weak beam" method of Whelan et al.[3]

Dislocation image characteristics under systematic diffracting conditions have also been found useful for determining the magnitude of the product g_1b where g_1 is the first order reflection of the systematic set and thus can be of tremendous help when it is necessary to choose between a number of different possibilities. For example,

in the fcc system, for an undissociated dislocation with Burgers vector of the type a/2<110>, when a 220 reflection is used the only three possibilities are $g_1.b$ equal to 0, 1, or 2. Figure 3 shows the image of a dislocation image profile and multiple beam bright-field profiles obtained by computer methods for the possibilities $g_1.b = 1$ and 2. Comparing the trace of the image with the theoretical profiles it is clear that there is excellent correspondence for the width of the central minima and the positions of all extrema for the $g_1.b = 2$ case. Variations in relative intensities in the experimental image are most likely due to thickness variations and discrepancies in dislocation depth. An illustration that the $g_1.b = 1$ dislocation exhibits only an observable central minimum is given in Figures 1d and g. Thus, there exists confirmation of the applicability of images obtained using higher-order reflections to determine Burgers vectors in a system where the Burgers vector is well characterized. The method can then be applied to a system where the Burgers vector has not been characterized and there is even extensive debate and confusion about the possible allowable Burgers vectors. In the cobalt-ferrite spinels it is possible to determine which is the correct possibility. Figure 4 illustrates how the possibility of a $g_1.b = 1$ dislocation is ruled out by comparing higher-order bright field images to theoretical profiles and comparing the number and spacing of primary extrema. More details of this work will be published elsewhere.

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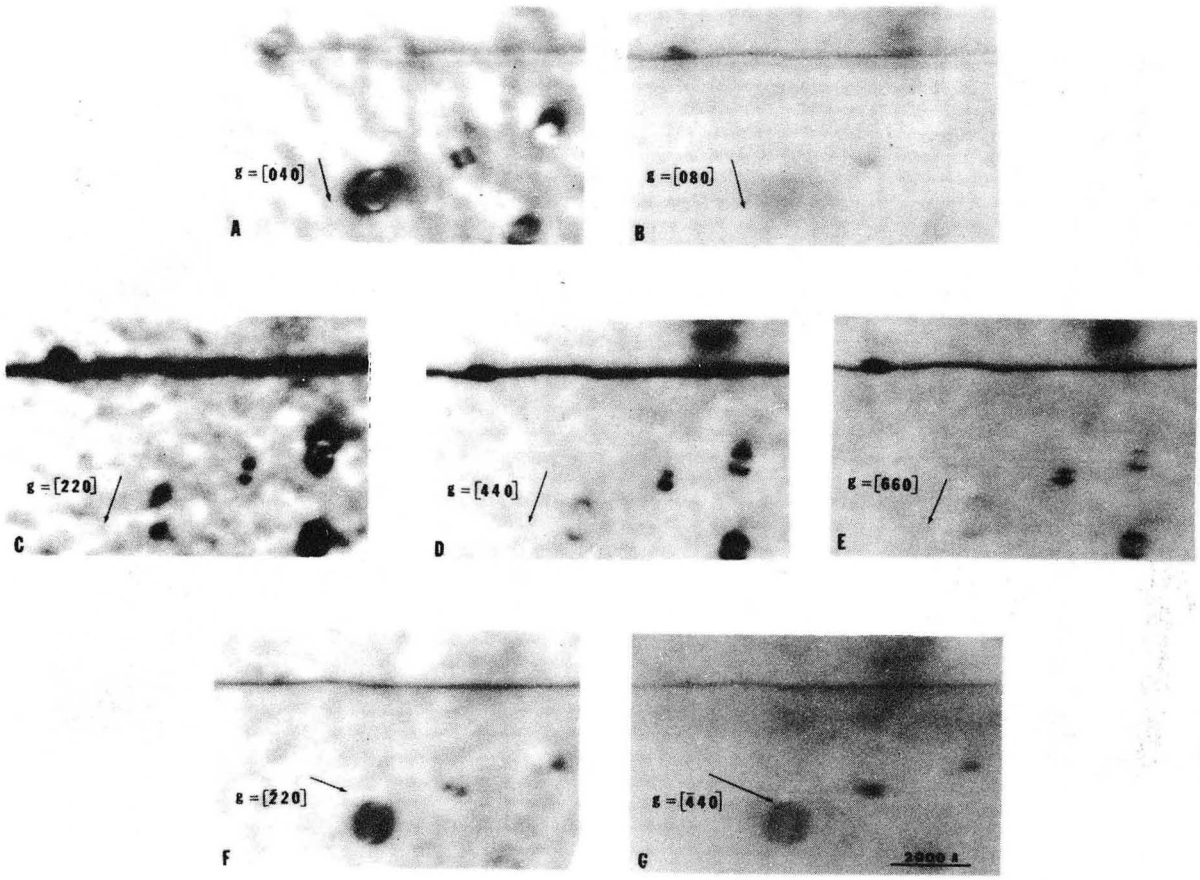

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Fig. 1

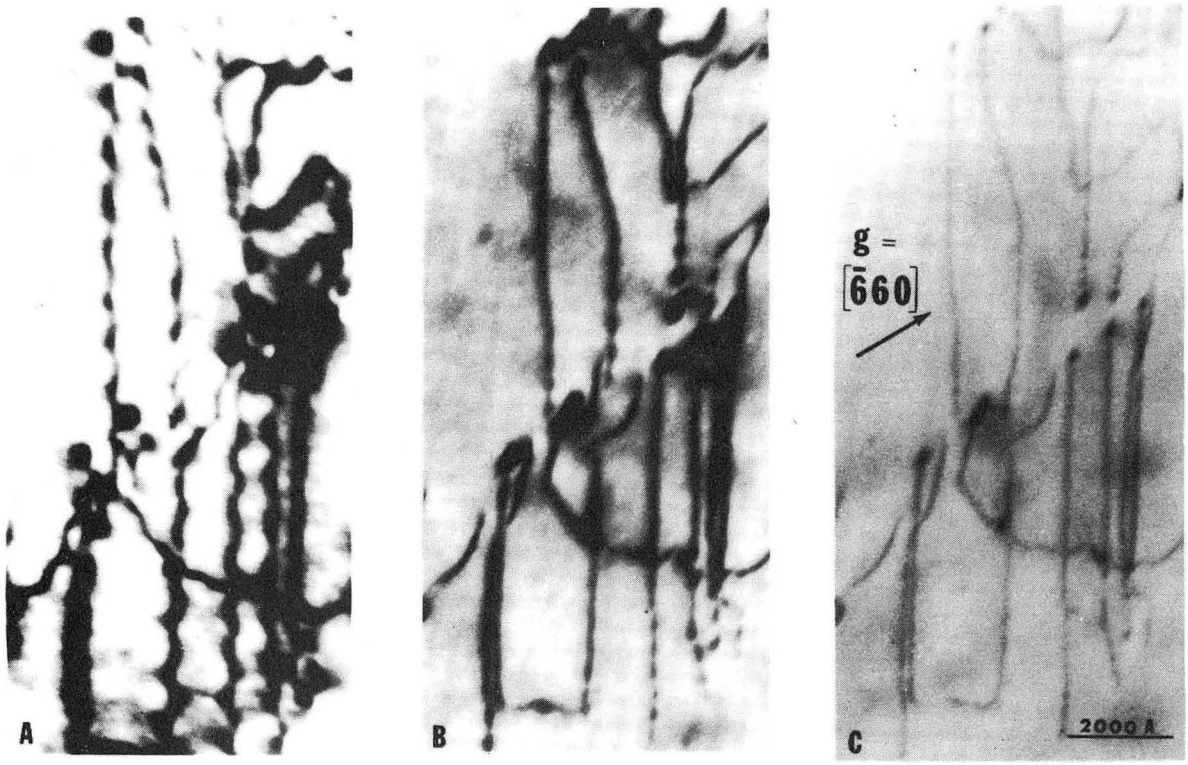

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Fig. 2

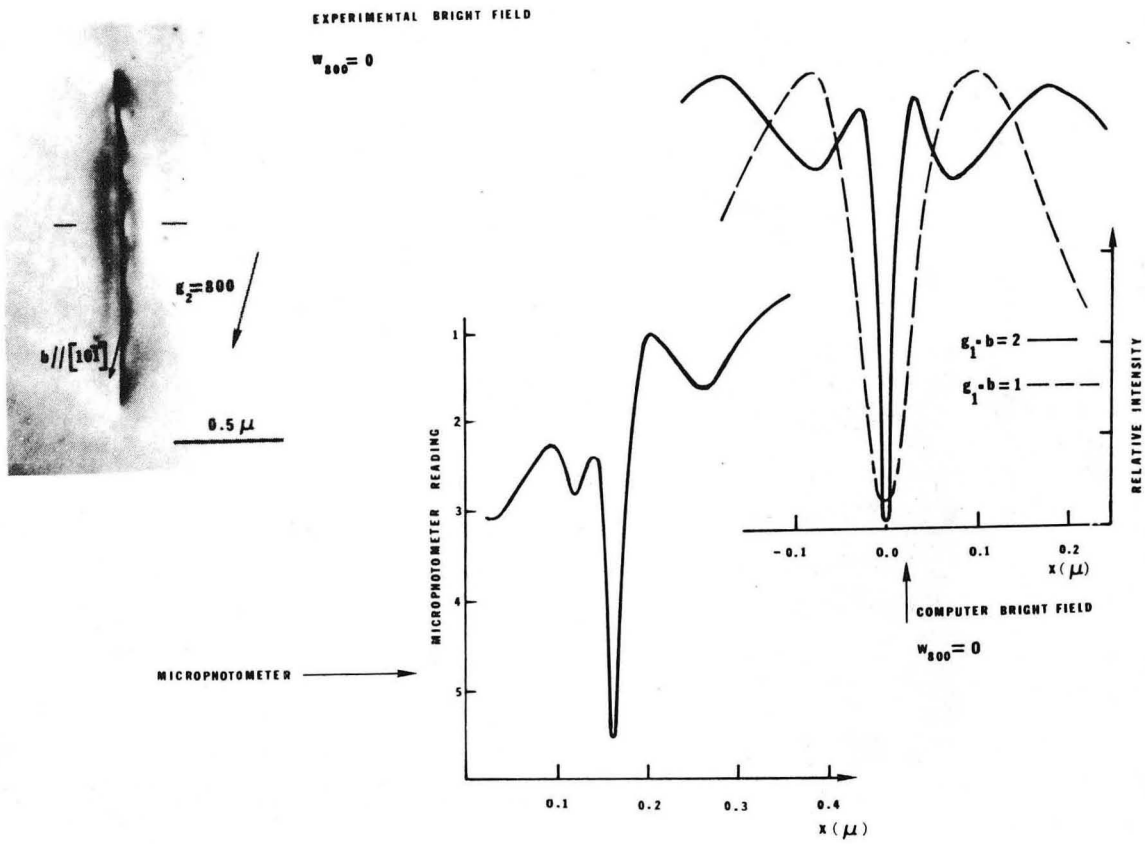

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Fig. 3

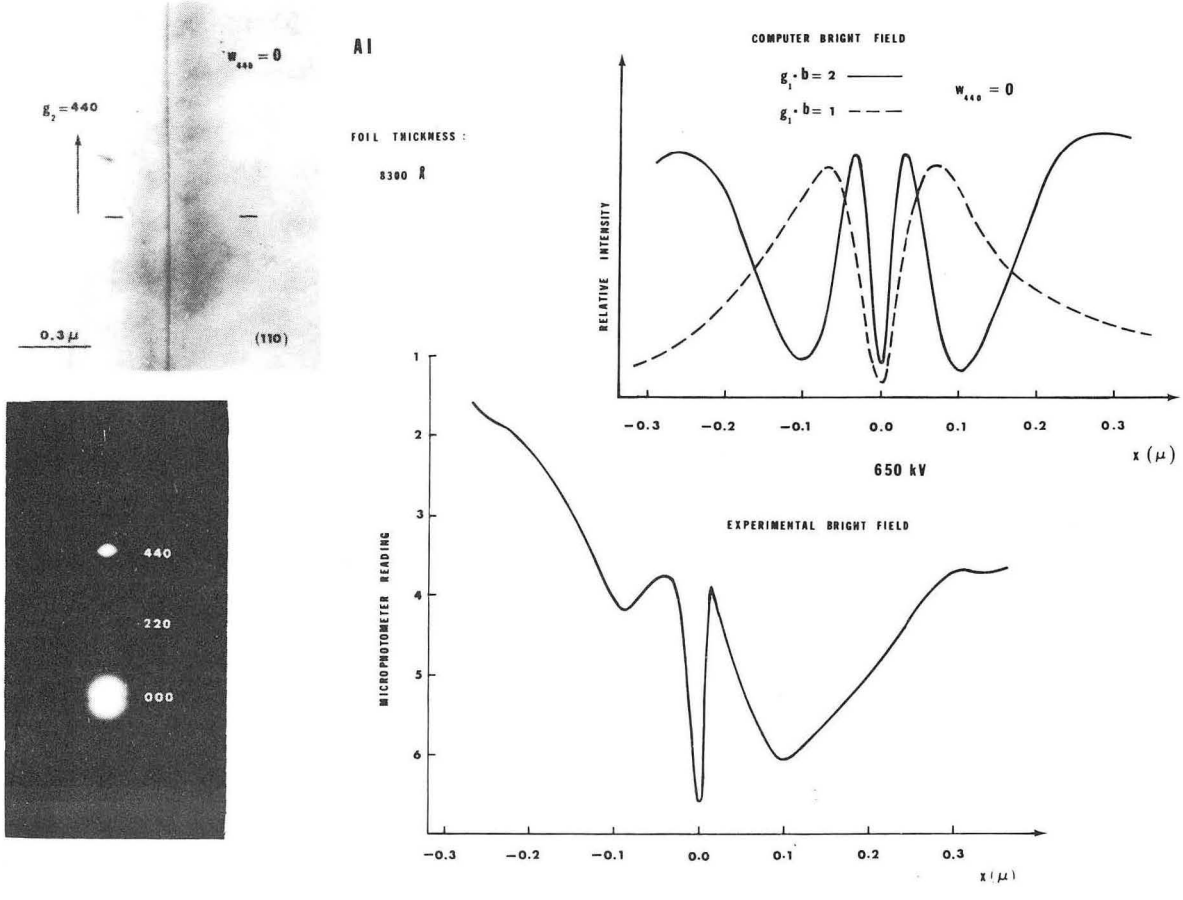

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Fig. 4

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