Title

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Authors

Nguyen, T D

Gronsky, R

Kortright, J B

Publication Date

1990-03-01

UC411
LBL-28788 Abs.

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Materials & Chemical Sciences Division

To be presented at the XII International Congress for Electron Microscopy, Seattle, WA, August 12–18, 1990, and to be published in the Proceedings

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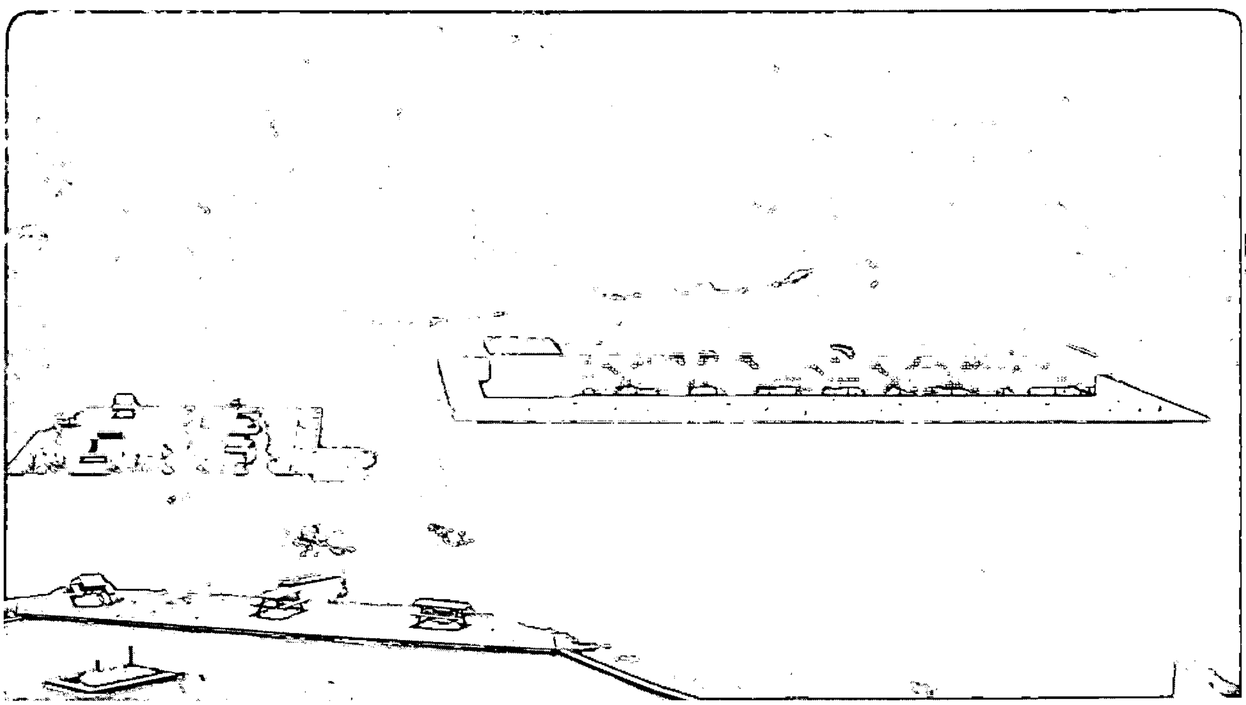
March 1990



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

LBL 28788-A

FRESNEL FRINGE EFFECTS AT INTERFACES OF THIN MULTILAYER STRUCTURES

Tai D. Nguyen*,† , Ronald Gronsky†, and Jeffrey B. Kortright*

*Center for X-Ray Optics, Accelerator and Fusion Research Division,
†National Center for Electron Microscopy, Materials and Chemical Sciences Division,
Lawrence Berkeley Laboratory,
University of California, Berkeley,
California 94720,
U.S.A.

This work was supported by the Director, Office of Energy Research, Office of Basic Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and by the Air Force Office of Scientific Research, of the U.S. Department of Defense under Contract No. F49620-87-K-0001.

FRESNEL FRINGE EFFECTS AT INTERFACES OF THIN MULTILAYER STRUCTURES

Recent developments in the TEM Fresnel-fringe technique have provided an alternative method to the determination of structures and morphology of interfaces in multilayer thin film structures. This method has been employed in the investigation of structures and defects in grain boundaries,[1,2] dislocations,[3] precipitate platelets,[4] twin boundaries,[5] metal interfaces,[6-8] and multilayer structures.[9] It has been demonstrated that the fringe spacing primarily relates to the layer thickness, while the fringe contrast as a function of defocus relates to the magnitude of the localized change in the scattering potential and thus to the interfacial composition.[2] The profile of the fringes is more closely related to the abruptness of the composition change at the interface.[7] Other factors affecting the Fresnel fringe intensity are the specimen thickness, aperture size, beam convergence, and degree of tilt of the interface from the incident electron beam.

Fresnel fringes result from the electrons experiencing an abrupt change in the inner scattering potential parallel to the electron beam path. Most previous calculations of the Fresnel contrast with defocus have simulated models based on one square or symmetrical trapezoid-shaped potential well,[7] which are applicable only to a single interface or grain boundary, or to a few layer pairs of the multilayer. To extend these models to the configuration of multilayer structures, the potential wells should be repeated to include a sufficient number of the layers, as shown in figure 1 for different potential well shapes, that closely resembles the multilayers in practice. In this figure, the potentials have been assumed to be uniform across each layer. Previous studies by Ness et al. have indicated that uniform potential models can provide a reasonable approximation as long as the layers are weakly diffracting and there are no strongly excited g-vectors normal to the interface.[2] The infinite slopes in the square potential wells in figure 1 a) represent perfectly sharp interfaces between the layers, while the finite slopes in figure 1 b)-d) represent the intermixing of the constituents in the layers, where in these figures a linear gradient in the composition of the mixing has been assumed. The true composition at the interfaces, however, can also be of a non-linear shape representing a non-uniform change in the constituents across the interface. The boundaries of each layer could be of any combination of perfectly sharp and intermixing interfaces as shown in figure 1 b), of symmetrical intermixing interfaces as in 1 c), and asymmetrical interfaces as in 1 d).

Modeling of the Fresnel fringes at different defoci from only one or few potential wells is only a gross approximation to those seen in a multilayer structure. The difference in the models could be seen, for instance, in the frequency representations of one potential well or of the convolution of the potential wells extending over a finite distance, and of the convolution of the potential wells over an infinite distance. The intensity and spacing of the fringes hence can be greatly different for models of different numbers of layers. A more realistic representation of the multilayer structures should probably contain a sufficient number of potential wells representing the layers such that the total multilayer length is appreciately greater than the potential well width.

Fresnel finges are observed in many TEM through-focus-series images of different multilayer systems such as W/C, WC/C, Ru/C, and Mo/Si. Figure 2 shows an overfocus cross-sectional TEM image of a 4 nm period tungsten/carbon multilayer prepared by dc magnetron sputtering.[10] The specimens were prepared for TEM cross-sectional observation by the conventional ion beam thinning method, and studied in a JEOL JEM 200CX electron microscope operating at 200kV.[11] The Fresnel fringes are clearly seen near the thin edge of the wedge-shaped sample. The visibility of these fringes hence is shown to depend on the thickness of the specimen, as reported in other studies,[2,8,12] and on the defocus value, where in this figure the layers near the edge were not in the same plane as those near the substrate when imaged and thus were at a different defocus. As imaged, the fringes appear symmetrical on the two interfaces of the W-rich layers, and the fringe spacing appears larger at thinner region of the specimen, although further digitizations are required to systematically measure the contrast and the spacing of the fringes.

Shown in figure 3 are three HRTEM images from a through-focus-series of a 6 nm WC/C multilayer. The Fresnel fringes at the interfaces have higher contrast with increasing defocus in both positive and negative values, as reported in other studies.[2,7-9] The top and bottom interfaces of the WC-rich layers do not show the same characteristics at opposite signs of defocus. The Fresnel fringes are observed at the top interfaces of the WC-rich layers at positive defocus (fig. 3 a)), while they are seen at the bottom at negative defocus (fig. 3 c)). At the interfaces where the Fresnel fringes are not present at both positive and negative defoci, smooth transitions in the image density are observed. This observation of Fresnel fringes at different interfaces of the layers at different defoci is not a result of misorientation of the interfaces from the electron beam, since previous simulated Fresnel fringe profile variation with defocus has indicated that tilted interface changes the shape of the fringes but does not diminish one of the fringes.[2] It has been shown that the contrast and profile of the Fresnel fringes differ for different interfacial composition profiles.[8] Since the scattering potential, specimen thickness, aperture, and beam convergence, are indentical for the two images, this observation is likely due to the different shapes of the potentials and hence of the chemistry or the composition at the interfaces. Further analysis and modeling of these fringes in multilayer configurations will give insight to the structures and morphology at interfaces.

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13. This work was supported by the Director, Office of Energy Research, Office of Basic Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and by the Air Force Office of Scientific Research, of the U.S. Department of Defense under Contract No. F49620-87-K-0001.

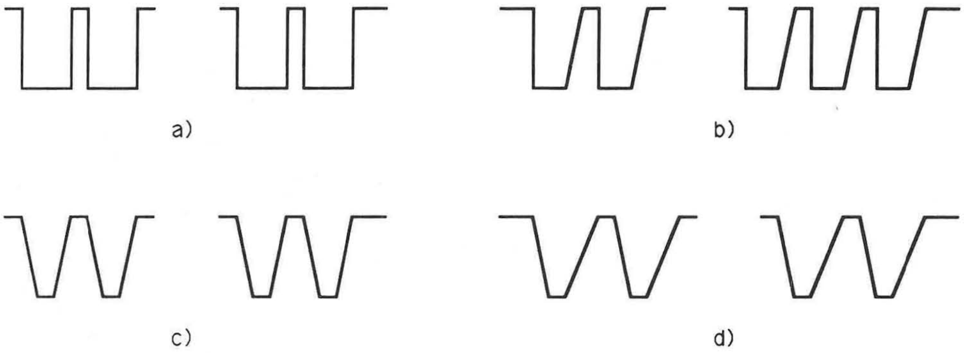

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FIG. 1.--Different potential well shapes for modeling of multilayer interfaces.

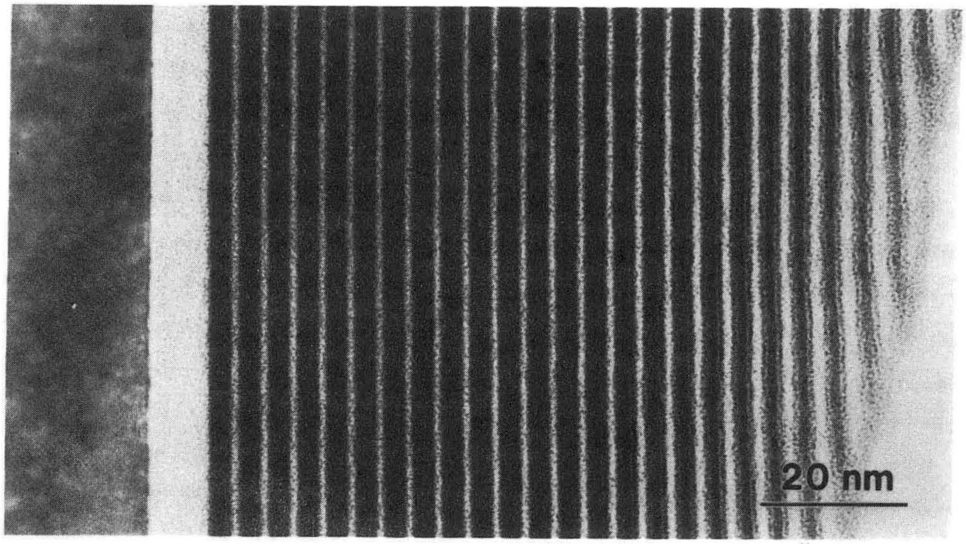

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FIG. 2.--Overfocus TEM image of W/C multilayer showing the Fresnel fringes at interfaces.

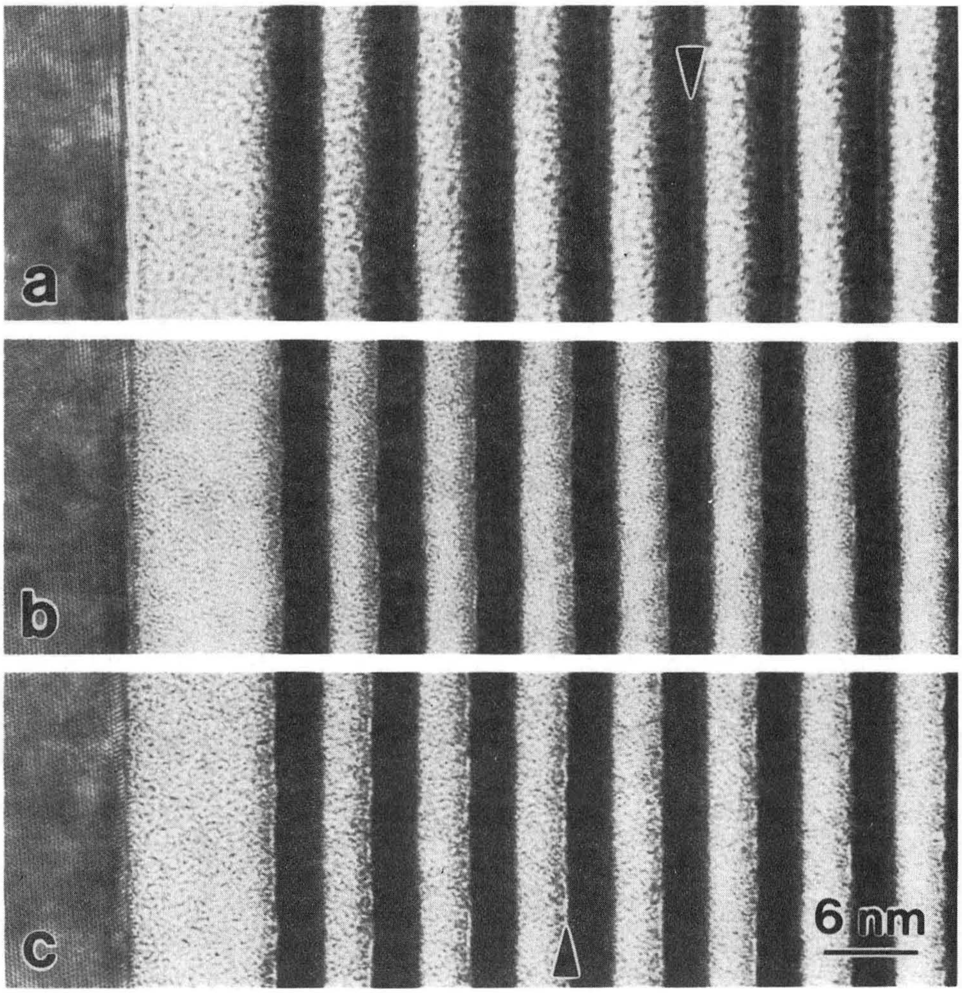

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FIG. 3.--Through-focus-series of a 6 nm period multilayer at defocus: a) +72 nm, b) -36 nm, c) -108 nm.