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ATOMIC AND ELECTRONIC STRUCTURE OF DEFECTS IN  
SEMICONDUCTORS(U) ARIZONA STATE UNIV TEMPE DEPT OF  
PHYSICS J C SPENCE AUG 83 ARO-16885.19-MS

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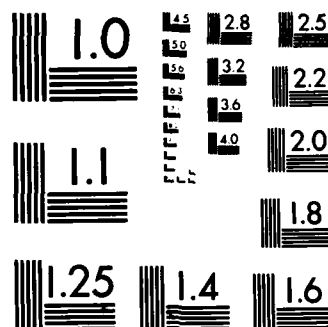
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| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>semiconductors                      gallium aluminum arsenides<br>crystal defects                      interfaces<br>silicon                                  surface properties<br>band structure                          |                                     |                                                                      |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>This research was aimed at developing new techniques for the characterization of sub-micron defects in semiconductors by electron beam methods. A brief summary of the main results and a list of publications are included. |                                     |                                                                      |

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Final report of A.R.O. Contract No. DAAG-29-80-C-0080

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Arizona State University  
Tempe, AZ 85287

Period Covered 4/1/80 - 6/30/83

1. Problem studied

This research is aimed at developing new techniques for the characterisation of sub-micron defects in semiconductors by electron beam methods.

2. Summary of main results

2.1 In collaboration with the Berkeley Physics Department, calculations for the electronic band structure of dislocations in silicon have been published ( 8 ). These line defects degrade the performance of many real semiconductor devices.

2.2 The degree of atomic roughness at interfaces between  $\text{Ga}_x\text{Al}_{1-x}\text{As}$  multilayer films has been determined by atomic resolution transmission electron microscopy ( 1 ).

2.3 The "EXELFS" (Extended Electron Energy Loss Fine Structure) technique has been developed and a new technique, in which the local environment of a particular atomic species is probed in a particular crystallographic direction ( 5 ). This technique provides similar capabilities to the synchrotron EXAFS method (with similar count rates), but can be applied to submicron regions and recorded in conjunction with an atomic resolution image.

2.4 High resolution images of semiconductor surfaces have been recorded for the first time by reflection electron imaging at 100kV (10). This new technique provides information unobtainable by any other method.

2.5 Incommensurate lattice modulations have been observed by direct atomic resolution imaging in Strontium Niobate. The phase of the modulation

with respect to the host has been determined - this is not possible by any other method (4).

2.6 Microanalysis by electron energy loss spectroscopy has been applied to crystals using an electron probe which is smaller than a single unit cell. A variation of composition was detected within one unit cell (6).

2.7 A Cathodoluminescence system has been built for a transmission electron microscope. This device obtains the optical emission spectrum from isolated defects in semiconductors in correlation with a high resolution transmission electron image. Defects have now been analysed in GaP, GaAs, MgO and diamond (12). Spectra and scanning monochromatic CL images are obtainable at  $-170^{\circ}\text{C}$  with submicron spatial resolution.

2.8 A full analysis of the electronic structure of dislocations in diamond is in progress, and will be continued on ARO contract No. DAAG29-83-K-0087. This study involves both visible CL and, high resolution imaging and optical polarization studies.

2.9 A Fourier Transform Infrared Spectrometer has been designed for CL studies in TEM (10). This work will be continued on the new grant, and allow CL studies on silicon and III-V's to be performed at submicron spatial resolution.

### 3. List of publications

See attached list.

### 4. Scientific Personnel

|      |                 |                         |
|------|-----------------|-------------------------|
| P.I. | J.C.H. Spence   | Assoc. Prof.            |
|      | Dr. J. Lynch    | Post Doc.               |
|      | Dr. N. Yamamoto | Post Doc.               |
|      | M. Disko        | Ph D. Student (Physics) |



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5. Degrees

During the course of this contract, M. Disko was awarded a Master's Degree in Physics. He will complete a Ph D. in Physics in Sept. 1984 under the new contract.

A.R.O. Journal Articles of J.C.H. Spence funded by A.R.O.  
Contract DAAG29-80-C-0080

(May 1980 - May 1983)

1. "The Use of Characteristic Loss Energy Selected Electron Diffraction Patterns for Site Symmetry Determination" Optik, (1980) Vo. 57, p. 451-456.
2. "The Crystallographic Information in Localised Characteristic Loss Electron Images and Diffraction patterns" J.C.H. Spence, Ultramicroscopy, (1981) Vol 7, p. 59-64.
3. "Electron Energy Loss Spectroscopy as a probe of the Local Atomic Environment" O.L. Krivanek, M.M. Disko, J. Taftø and J.C.H. Spence, Ultramicroscopy, 1982 Vol 9, p. .
4. "High Resolution Electron Microscopy of the Incommensurate Structure in SR2NB207, N. Yamamoto, Acta Cryst (1982) A38, p. 780.
5. "an EXELFS Analysis System and preliminary Orientation Dependence of EXELFS in Graphite" M.M. Disko, in "Analytical Electron Microscopy-1981, R. Geiss Ed. San Francisco Press, 1981, pp. 214-220.
6. "STEM Microanalysis by Transmission Electron Energy Loss Spectroscopy in Crystals" J.C.H. Spence and J. Lynch, Ultramicroscopy, 91982) Vol. 9. p. 267-276.
7. "Orientation-Dependent Extended Fine Structure in Electron Energy-Loss Spectra, M.M. Disko, O.L. Krivanek and P. Rez, Phys. Rev. B15, #6, p. 4252 (1982).
8. "Electronic Structure of the Unreconstructed 30 Partial Dislocation in Silicon" J.E. Northrop, M.L. Cohen, J.R. Chelikowsky, J.C.H. Spence and A. Olsen, Phys Rev. B24, #8, pp. 4623-4628 (1980).
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10. "Surface Imaging of III-IV Semiconductors by REM and Inner Potential Measurements", N. Yamamoto and J.C.H. Spence, Thin Solid Films (1983) Vol. 104, p. 43-55.
11. "Electron Microscopy and Diffraction of Phases in the Al2O3-BAAL2O4 System" N. Yamamoto and M. O'Keefe, J. Appl. Cryst. (1983) In press.
12. "Cathodoluminescence and Polarization Studies of Dislocations in Diamond" N. Yamamoto and J.C.H. Spence. Phil. Mag. (1983).

A.R.O Conference Publications of J.C.H. Spence funded by  
A.R.O. Contract DAAG29-80-C-0080

(May 1980 to May 1983)

1. "High Resolution TEM of Semiconductor Defects" J.C.H. Spence, Proc. EMSA, 1980. p. 282.
2. "An EXELFS System and Preliminary Orientation Dependence Results" M. Disko, O. Krivanek and J.C.H. Spence, Proc. EMSA, 1981. G.W. Bailey, Ed, Claitors Publishing Division, Baton Rouge, LA, p. 192.
3. "High Resolution Electron Microscopy of Semiconductor Defects" J.C.H. Spence, Proc EMSA 1981. p. 120.
4. "The Crystallographic Information in Electron Energy Loss Spectra" J.C.H. Spence, O. Krivanek, J. Taftø and M. Disko, Inst. Phys. Conf. Ser. No. 61, Chapter 6, p. 253.
5. "Vacancy Ordering in Vanadium Carbide" N. Yamamoto and Y. Kumashiro, Proc Fortieth Annual EMSA Meeting (Washington) p. 726, 1982.
6. "A Digital on-line Diffractometer and Image Processor for HREM" J.C.H. Spence, M. Disko, A. Higgs, J. Wheatley and H. Hashimoto, Proc. Tenth Int. Congr. on Electr. Micros., Hamburg, (1982) p. 519-520.
7. "TEM/STEM on Line Image Processing Techniques", M.M. Disko, A. Higgs, B. Monosmith, T.M.S. Annual Meeting, March, 1983.
8. "Incommensurate Lattice modulation in SR2NB207" N. Yamamoto, Proc Int. Congr. on Electr. Micros., Hamburg, 1982. In Press.
9. "A Cathodoluminescence Apparatus for TEM" N. Yamamoto, J.C.H. Spence, D. Hazeltine and M. Bergh. EMSA 1983
10. "A Fourier Transform Spectrometer for I.R. CL. in TEM" J.C.H. Spence and J. Isenman, Proc EMSA 1983.
11. "New Techniques in Electron Microscopy" Proc. Iowa Symposium on Electron Microscopy, 1983. J.C.H. Spence.



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