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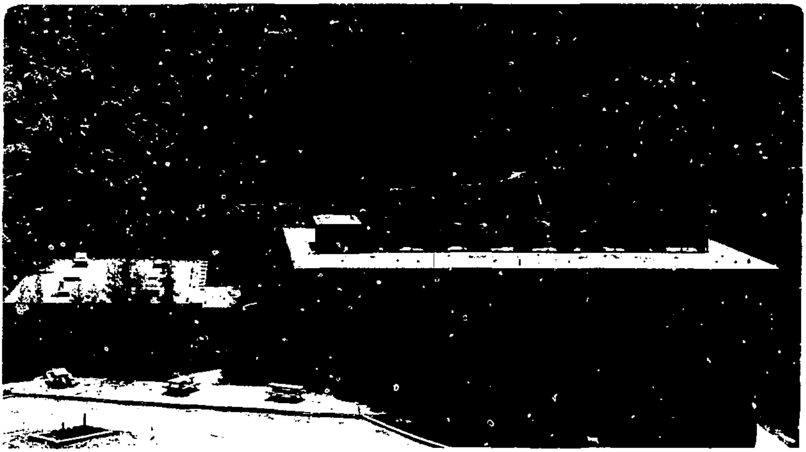

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THE U.S. ATOM-RESOLVING MICROSCOPE PROJECT

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Introduction - The largest project in transmission electron microscopy ever to be undertaken in this country has recently been initiated within the Materials and Molecular Research Division of the Lawrence Berkeley Laboratory due to the support of the Division of Materials Research, Office of Basic Energy Sciences, U.S. Department of Energy. This project has been given the name "Atomic Resolution Microscopy" and its goal is to provide the instrumentation and expertise necessary to conduct materials research directly at the atomic level. Taking advantage of the best available technology in electron-optical design, its core instrumentation is a unique machine, the Atomic Resolution Microscope (ARM), which is to be built by commercial manufacturers to the specifications of LBL and used in basic research programs requiring atomic imaging capabilities. The project will also include an in-house instrument development effort to maintain state-of-the-art performance from the ARM. Details of history, organization and performance specifications are outlined below.

Background - The nucleus of this project might be traced to informal discussions between Professors J. M. Cowley (Arizona State), R. M. Glaeser (Berkeley) and G. Thomas (Berkeley), who collectively formulated a plan for a "national center for electron optics" and went so far as to eventually submit a proposal to one of the major funding agencies in 1974. Although initially thwarted, the idea remained intact for two more years, undergoing a major (positive) fluctuation during the Berkeley Workshop on High Resolution Electron Microscopy[1] in late 1976. Within the next year, a series of workshops[2] on energy-related basic materials research sponsored by DOE (then ERDA) identified the "critical need" for more sophisticated high resolution electron microscopy facilities, and in response to this need the present proposal was initiated and extensively refined over the subsequent two years to its present form. At the time of this writing, Atomic Resolution Microscopy is a line item in the FY1980 budget cycle of DOE.

Project Organization - The schematic in Fig. 1 represents both the operational procedures and instrumentation planned for Atomic Resolution Microscopy, as they pertain to space needs and building design for the total project. Four "feeder" microscopes are scheduled to support and insure the most efficient use of the ARM. These would serve to "screen" specimens, identifying at reasonably high levels of resolution themselves the most appropriate specimen areas and experimental conditions for atomic resolution imaging. Other support microscopes would be used for chemical analysis (EDS and ELS) and for implementation of instrument design changes before modifying the ARM, in order to prevent excessive down time. To ensure that they interface most precisely with the ARM, the experimental microscopes will be of the 200kV variety. It is also planned to equip one each of the experimental and analytical machines with field emission guns.

Ancillary instrumentation for specimen preparation, photographic developing and printing, image analysis and image processing is scheduled to occupy contiguous locations as shown by arrows in Figure 1. Ion milling machines, wet chemical polishing devices, a scanning microdensitometer a precision optical bench and a video analysis system are included in the support equipment list, and will be set up as new space becomes available (see below). Although the heavier computing burdens will be relegated to LBL's central hardware (a CDC 7600 backed by two CDC 6600 machines), an on-site minicomputer.

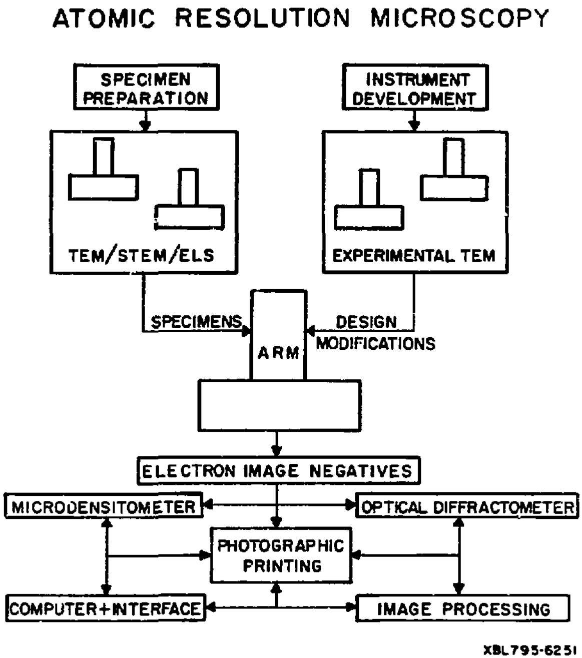

Figure 1 - Schematic diagram of the Atomic Resolution Microscopy project at LBL showing interrelationships of planned operations and equipment. Four feeder microscopes will support the ARM, two for specimen screening and chemical analysis, the remaining two for instrument development.

has been included to perform the more urgent computations in conjunction with an array processor, to drive the image analysis peripherals and to communicate with the central LBL machines.

The new building which will provide approximately 6500 sq. ft. of space for the equipment and personnel participating in this project is scheduled to occupy a site adjacent to both the original structure of the Materials and Molecular Research Division and its new high voltage electron microscopy facility which houses the 1.5 MeV electron microscope (see paper by Dr. K.H. Westmacott, these proceedings). The proposed location maximizes the potential for scientific interaction while minimizing duplication of equipment, technical support staff and transportation problems. Extensive measurements of ground stability, mechanical vibrations and magnetic disturbances were made previously for the 1.5MeV machine, and are therefore available for optimum siting of the ARM. In fact the precedent established by the 1.5 MeV electron microscope project has assisted in all facets of this effort from planning of the vibration isolation system to details of purchasing procedures, wherein LBL's administrative servies have been exceedingly helpful.

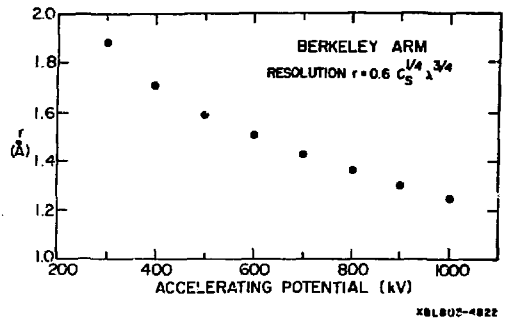

Figure 2 - Plot of theoretical resolution (r) as a function of accelerating potential for the Atomic Resolution Microscope. Values are determined by maintaining a constant $C_s\lambda$ product.

Staffing needs for the project within MMRD/LBL will become more clearly defined as it evolves into its planned ultimate configuration as a user-oriented shareable facility. Emphasis will obviously be placed on a highly qualified technical team for servicing and maintenance of the microscopes, for image interpretation and analysis and for development of electron-optical instrumentation. Facility operating policies will follow established DOE guidelines and will be administered through existing LBL structures. These policies will apply to all potential users of the facility. All present collaborative relationships with Arizona State University (Prof. J. M. Cowley, Prof. J. C. H. Spence and Dr. S. Iijima), Stanford University (Prof. R. Sinclair) and the Berkeley campus (Prof. R. M. Glaeser, Dr. O. L. Krivanek) will also be maintained.

Performance Specifications - A detailed list of performance specifications for the Atomic Resolution Microscope has been issued to potential manufacturers in subcontract form by the purchasing department of LBL. Highlights of this document are reproduced in the following.

(i) Vacuum - The accelerating tube and optical column shall have a pressure of 1×10^{-8} torr or less with hydrocarbon partial pressure at 1×10^{-9} torr or less.

(ii) Accelerating Voltage - The ARM shall be capable of operation at voltages between 200kV and 1000kV (continuously variable), with stabilities (including ripple) of 1×10^{-6} per minute or better.

(iii) Illumination System - The gun shall provide a brightness of at least 10^7 amps/cm^2 str. at the screen with an energy C_t $\frac{dE}{E}$ of not greater than 5×10^{-6} at all voltages.

(iv) Specimen Stage - A top-entry double tilt-lift stage shall be provided for the ARM to accommodate 3mm diameter grids with a tilt range of ± 45 degrees, biaxial. Specimen position within the objective shall be controlled via a lift mechanism to maintain a constant $C_s\lambda$ product over the entire range of operating voltages.

(v) Imaging System - The spherical aberration of the objective lens shall be such that the product $C_s\lambda$ does not exceed 0.025 mm-Å at all accelerating voltages. Objective lens current stability shall be 1×10^{-6} per minute or better, with sufficiently low C_c to permit imaging with higher order transfer intervals at large defocus values beyond the Scherzer limit. A high spatial resolution diffraction system shall also be incorporated in the ARM.

The obvious emphasis in these specifications has been on resolution, however operating efficiency has also been given considerable attention. A summary of the resolution capabilities of the ARM is presented in Fig. 2, using a generous definition of point resolution, for incremental voltages up to 1 MeV. The phase contrast transfer function corresponding to this maximum potential is also shown in Fig. 3.

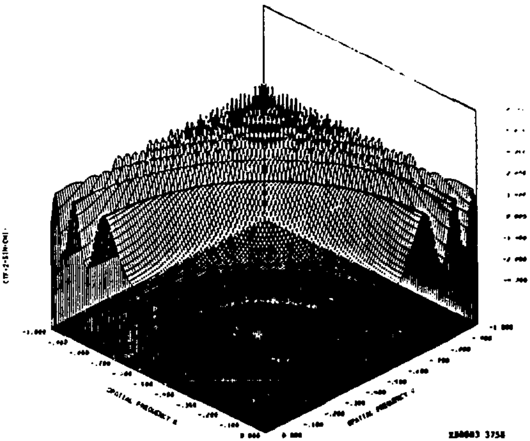

Figure 3 - Plot of the phase contrast transfer function (one quadrant) for the Atomic Resolution Microscope at 1 MeV accelerating voltage and Scherzer defocus.

Current Status - At present the architectural and engineering drawings for the new building are nearly complete and all relevant design criteria from air temperature variation to traffic flow patterns have been taken into account. An order has been placed for the first of the feeder microscopes which will operate in an ultrahigh resolution configuration to support the initial research programs in this project. Provisions are also being made to establish a proper computer library of image simulation routines, lens function routines, etc. These will precede the actual experimental results and assist in planning of all variations of high resolution imaging experiments, instrument development work and image processing schemes.

Finally, the manufacturer's bids for the Atomic Resolution Microscope are currently under intensive review and, barring any unanticipated delays, an award will have been made by the time of the meeting for which this paper is being submitted.

Acknowledgements - Appreciation is extended to Prof. G. Thomas, co-investigator on this project, and to all of the collaborators named in this article for their technical review of the ARM specifications. The assistance of Mr. J. Mazur with computer graphics and the financial support of the U.S. Department of Energy under contract No.W-7405-Eng-48 is also gratefully acknowledged.

1. Proceedings of the Workshop on High Resolution Electron Microscopy, G. Thomas, R. M. Glaeser, J. M. Cowley and R. Sinclair, (eds.), LBL Pub. No. 106, Lawrence Berkeley Laboratory, October, 1976.
2. Materials Sciences Overview I and II, ERDA 77-76/1 and 77-76/2, Division of Basic Energy Sciences, ERDA, August, 1977.