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Final Technical Report for Contract No. AFOSR-86-0347

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ABSTRACT

This report describes work conducted under Contract AFOSR-86-0347, "Laboratory for X-Ray Optics." A "silicon/metals" molecular beam epitaxy (MBE) apparatus, purchased with this support, arrived at the University of Arizona on March 7, 1988, and is now fully operational.

INTRODUCTION

This x-ray optics research program received a significant boost in 1986 with the funding of the "Laboratory for X-Ray Optics" by the AFOSR/University Research Initiative Program (URIP). In addition, an extremely fortunate combination of circumstances enabled us to negotiate the purchase of a state-of-the-art "silicon/metals" molecular beam epitaxy (MBE) apparatus, with a total replacement value of \$990,000, for only \$400,000 (\$325,000 of URIP support and \$75,000 from the University of Arizona).

This capability for producing MBE multilayer coatings for use in the 10-Å to 300-Å wavelength range (i.e., between soft x rays and the extended ultraviolet, referred to here as *X-UV*) is unique at laboratories conducting research in the field of x-ray optics. The University of Arizona now has a complete program, with capabilities for design, fabrication, characterization, and testing of multilayer coatings for the XUV; for development of state-of-the-art instrumentation to produce and characterize these materials; and for training graduate students and visiting scientists in this important field.

FINAL REPORT

The Perkin-Elmer 433-S MBE machine arrived on Monday, March 7, 1988. The assembly, installation, and acceptance process was completed by the end of April. The MBE machine is now fully functional, having produced its first epitaxial, single-crystal film of silicon in July. The machine is located in a Class 1000 clean room, with the introduction chamber in a Class 100 environment.

The 433-S is a new machine, which is scheduled to be introduced officially by Perkin-Elmer at the annual meeting of the American Vacuum Society this fall. Although the total list price of the machine as configured for us will be almost exactly \$1 million, a very significant discount was obtained for this purchase.

For a three-month period during the summer of 1986, Perkin-Elmer offered a 50% discount to universities for their standard gallium arsenide (GaAs) MBE systems. (This discount was withdrawn after three months, and has not been re-introduced.) Unfortunately, the design of the GaAs machine would not have been suitable for our x-ray optics research. However, during this three-month period, Perkin-Elmer became convinced of the potential impact of our x-ray optics research program on

future sales of their new "silicon MBE machine," then only in design stages. Because of this potential impact, Perkin-Elmer was persuaded to allow us to order one of these machines at the discount price.

Hughes-Malibu took delivery of the first of these new machines at the end of February 1988; the University of Arizona is the first university group to receive one. The remainder of the initial production run of five will be shipped to Caltech, UCLA, and Illinois-Urbana by the end of the year. These other groups will use their machines to study silicon; we are the only group exploiting this new machine to investigate the epitaxy of metals and metallic superlattices for x-ray optics.

The 433-S has a number of capabilities not found on previous MBE machines. It was specifically designed for epitaxy of refractory materials, such as Si, without giving up the ability to grow lower-melting-point substances. Thus the 433-S has cryoshrouded electron-beam guns, as well as a "GaAs flange" for a full complement of eight Knudsen cells. Also, the substrate manipulator goes to 1200°C (while rotating at 120 rpm, with up to a 1-kV bias, if desired), rather than the 800°C of a GaAs machine. Because of the heat generated by the electron-beam guns, the entire chamber is water cooled, and contains extensive internal LN₂ cryoshrouds. The machine has many other capabilities as well (e.g., laser ports for in situ inelastic light scattering or Kerr rotation studies, a port for a multi-hearth electron-beam gun or UHV sputtering gun, and ports for ion sources).

Ours is a four-chamber machine, with rapid load lock (20 minutes to the mid-10⁻⁷ Torr range), a substrate preparation chamber (<1x10⁻¹⁰ Torr), a deposition chamber (<5x10⁻¹¹ Torr), and an analysis chamber (<1x10⁻¹⁰ Torr). In addition to reflection high-energy electron diffraction (RHEED) and low-energy electron diffraction (LEED) systems on the deposition chamber, we are installing Auger electron spectroscopy, x-ray photoelectron spectroscopy (XPS), and ion-scattering spectroscopy (ISS) facilities on the analysis chamber, which also has a port for later addition of an ultraviolet photoelectron spectrometer (UPS). A 4-keV gun allows ion milling of samples, and a heated (800°C) substrate goniometer enables angle-resolved XPS studies as a function of temperature. The four chambers of the MBE system are configured in a "T," which allows externally-grown samples (e.g., sputtered multilayer X-UV coatings) to be introduced into the analysis chamber for study, completely bypassing the growth chamber.

In summary, a state-of-the-art MBE system for producing multilayer soft x-ray optics has been purchased under contract AFOSR-86-0357. This machine arrived in March 1988, and was made fully operational within four months.