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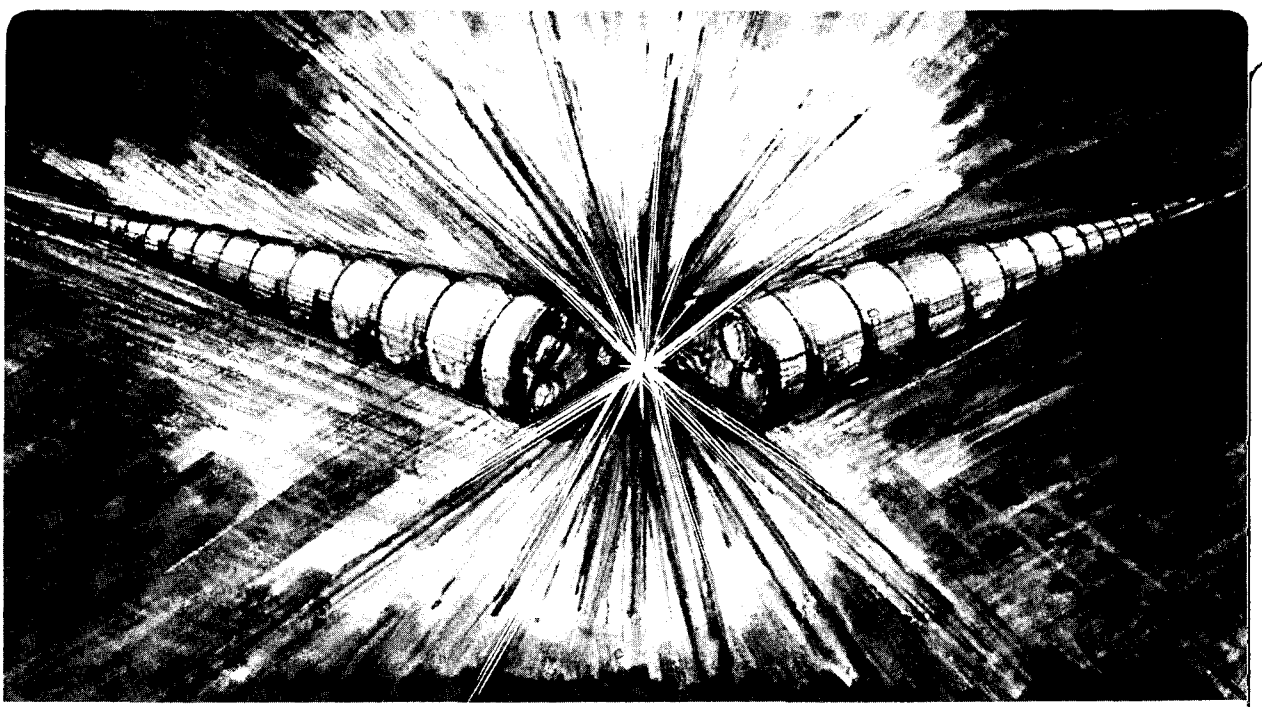

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DISCLAIMER

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BROAD-BEAM, HIGH CURRENT, METAL ION IMPLANTATION FACILITY

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ABSTRACT

We have developed a high current metal ion implantation facility with which high current beams of virtually all the solid metals of the Periodic Table can be produced. The facility makes use of a metal vapor vacuum arc ion source which is operated in a pulsed mode, with pulse width 0.25 ms and repetition rate up to 100 pps. Beam extraction voltage is up to 100 kV, corresponding to an ion energy of up to several hundred keV because of the ion charge state multiplicity; beam current is up to several Amperes peak and around 10 mA time averaged delivered onto target. Implantation is done in a broad-beam mode, with a direct line-of-sight from ion source to target. Here we describe the facility and some of the implants that have been carried out using it, including the 'seeding' of silicon wafers prior to CVD with titanium, palladium or tungsten, the formation of buried iridium silicide layers, and actinide (uranium and thorium) doping of III-V compounds.

1. INTRODUCTION

Metal ion beams of high intensity have traditionally been somewhat more difficult to produce than beams of gaseous ions, and this has been an experimental inconvenience and an impedance to the development of metal ion implantation applications. With the development of the MEVVA (metal vapor vacuum arc) ion source [1-6], however, metal ion beams of exceptionally high intensity have become available, providing a means for carrying out a wide range of metal ion implantations. A possible disadvantage for some applications is the presence in the metal beam of a small component of micron-sized solid cathode debris; however this can be removed by a magnetic filter or other means operating on the plasma within the ion source.

Several versions of MEVVA ion source have been developed and their operation and performance described previously [1-6]. The implanter makes use of the MEVVA V source version. This embodiment is a broad beam, multi-cathode ion source. The extractor grids are 10 cm in diameter, and this is thus also the beam maximum initial diameter. The multi-cathode assembly houses 18 separate cathode materials, between which one can switch simply and quickly. This source has been described in more detail in references [4,5]. A photograph of the partially-disassembled source showing the multicathode feature and the large area extractor is shown in Figure 1. In typical operation the source is pulsed at a rate of several tens of pulses per second. For our standard pulse length of 250 μsec, a repetition rate of 40 pps corresponds to a duty cycle of 1%, and the mean beam current is then 1% of the peak (pulse) beam current. The pulsed operation of the source described here is not inherent to the MEVVA technology, but is simply a legacy from its accelerator-based lineage; a version capable of delivering up to amperes of dc metal ion beam current has been tested and is in development.

2. DESCRIPTION OF THE FACILITY

Implantation is done in a broad-beam mode, without magnetic analysis of charge-to-mass beam components, and the ion trajectories are line-of-sight from ion source to target. The high ion beam charge density demands a very high degree of space charge neutralization of the beam, and any attempt at magnetic analysis would cause a major perturbation to the neutralizing electrons and disturb or destroy the neutralization, with consequent space charge blow-up and loss of beam. However, the MEVVA ion beam is particularly pure, containing a high fraction of just the wanted metal ion species; this is because the plasma is formed solely from the cathode material where the

cathode spots of the vacuum arc are active, and there is no carrier gas. Thus implantation in a non-mass-analyzed mode for many purposes (but not all) poses no problems.

The vacuum pressure during implantation is typically in the low-to-mid 10^{-6} Torr range. The target to be implanted is introduced into the vessel through an air lock and the turn-around time between target changes can be as short as a matter of minutes. The target is mounted on a water-cooled holder suspended from a vertically moving shaft; the source-to-target distance is 65 cm. A magnetically-suppressed Faraday cup with a 5 cm diameter entrance aperture can be inserted into the beam immediately in front of the target. The beam current can thus be adjusted prior to implantation and the number of beam pulses required to accumulate the required dose can be calculated. The overall set-up is shown in Figure 2. An example of the implanter beam current performance for the case of a titanium beam is shown in Figure 3. Here the beam pulse current density delivered onto target is plotted as a function of extraction voltage for a range of different arc currents. The peak ion beam current density is as high as 20 mA/cm^2, and the time-averaged current density up to approximately 1% of this.

The ion beam charge state distribution can be measured using a time-of-flight diagnostic. The detector measures the electrical current in the different Q/A states and provides a good measurement of the ion composition of the extracted ion beam. The time-of-flight system has been described in more detail in reference [7]. An oscillogram of the time-of-flight charge state spectrum for an Ir ion beam is shown in Figure 4.

Beam is extracted typically at 50 - 75 kV, and the maximum voltage at which we have operated is 110 kV. Since the ion charge state distribution contains multiply ionized species with charge state up to about Q = 5+ for some metals and with mean charge state of typically $\bar{Q}$ = 2+ to 3+, the mean energy of the beam ions produced can be 200 - 300 keV with components as high as 500 keV.

Cathode materials, and thus ion beams, with which we have operated include: Li, C, Mg, Al, Si, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ge, Sr, Y, Zr, Nb, Mo, Pd, Ag, Cd, In, Sn, Ba, La, Ce, Pr, Nd, Sm, Gd, Dy, Ho, Er, Yb, Hf, Ta, W, Ir, Pt, Au, Pb, Bi, Th and U [8,9]. Compound and alloy cathode materials have also been investigated [10] and mixed-composition beams can be produced.

3. SOME IMPLANTATIONS

The facility has been used for exploratory research for a variety of different ion implantation applications, including semiconductor, superconductor, and metallurgical applications. Although the fundamental characteristics of the MEVVA ion beam make the source not ideal for a simple retrofit to traditional semiconductor implanters, the MEVVA implanter can be a valuable tool for specialized or unique implants into semiconductors, especially in a research mode.

The requirements of future interconnect densities in VLSI devices have led to the development of new multilevel interconnect technologies. One such technique involves forming interconnects by selectively depositing tungsten into oxide channels which have been implanted with silicon. However, a high Si dose is required to initiate the selective deposition of W on oxide. In this work [11] the selective deposition of W on oxide that has been implanted with W was investigated. W implants were done at 137 keV. We found that a concentration of less than only 7.3×10^{20} cm^{-3} of implanted W is needed for the nucleation process, to be compared with a minimum Si concentration of 7.3×10^{21} cm^{-3} required to nucleate W on oxide when Si is the implanted species. We are indebted to Drs. Nathan Cheung and colleaques (U.C. Berkeley), Simon Wong (Stanford U.), and David Thomas (Cornell U.) for their lead collaboration in this research. This work is being continued using other implant species including Ti, Cu and Pd; see an accompanying paper [12] for more details.

Uranium and thorium impurities are known to be sources of soft errors in semiconductor memory devices, and this has motivated the implantation of U and Th into Si for some fundamental studies of diffusion. We are indebted to Dr. Fred Stevie and colleagues from ATT/Bell Laboratories for lead collaboration in this work; the results have been reported in detail in [13,14]. We implanted U and Th into Si wafers at a mean energy of 185 keV (U) and 205 keV (Th) and to doses of 1.2×10^{14} cm^{-2} (U) and 4.0×10^{14} cm^{-2} (Th). RBS and SIMS were used to obtain the depth profiles. The U and Th follow the anomalous diffusion behavior that is also seen for Al and Ag in Si at low temperatures, in that the implants migrate to two regions - the surface and the amorphous/ crystalline interface.

Actinides are good candidates for active ions in electro-optic materials due to the numerous sharp emissions covering a broad spectral range. Applications include non-silica-based fiber optics and light emitting junction diodes. We implanted uranium into the III-V semiconductors GaAs and InP at a mean ion energy of 131 keV and to a dose of approximately 4×10^{13} cm^{-2}; the implanted

samples were annealed at 640 - 850°C. Characteristics of the emission lines found are described fully in reference [15]. We are indebted to Dr. Gernot Pomrenke, of Wright Patterson AFB (present address AFOSR Washington), and colleagues, for their lead collaboration in this work.

We have investigated the formation of $IrSi_3$ layers buried in <111> silicon. The layers were formed by iridium ion implantation with a mean beam energy of 130 keV and at doses ranging from 2×10^{16} to 1.5×10^{17} cm^{-2}. The formation of the $IrSi_3$ phase was realized after annealing at temperatures as low as 500°C. A continuous $IrSi_3$ layer about 200A thick buried under 400A Si was formed. Radiation damage, and the effects of the implant dose on phase formation, interface morphology and implanted atom redistribution were investigated. It was determined that a critical minimum dose of 3.5×10^{16} cm^{-2} was necessary for the formation of a continuous buried layer after annealing, while implant doses over 8×10^{16} cm^{-2} resulted in the formation of an $IrSi_3$ layer on the surface due to excessive sputtering of Si by the Ir ions. Figure 5 shows the RBS spectra of samples implanted at a medium dose of 7×10^{16} cm^{-2}, before and after annealing at 750°C for 2 hours. Figure 6 shows a cross-sectional TEM micrograph of this sample; note the sharpness of the interfaces between the buried silicide layer and the surface and substrate Si. We are indebted to Dr. Kin Yu and colleagues at LBL for their lead collaboration in this work; this research has been reported in detail in [16].

4. CONCLUSIONS

The MEVVA implantation facility provides a unique tool for carrying out metal ion implantation experiments; a wide range of metallic ion species can be produced and delivered onto target. The implanter operates in a broad-beam, non-mass-analyzed mode, and the beam current is pulsed with a maximum beam current of about 1 amp and a mean current of about 10 mA. Ion energy can be varied up to several hundred keV.

The various implantations reported on here were carried out collaboratively and we are grateful to our colleagues as referred to in the text. This work was supported by the U.S. Army Research Office and the Office of Naval Research under Contract No. ARO 116-89 and by the Department of Energy under Contract No. DE-AC03-76SF00098.

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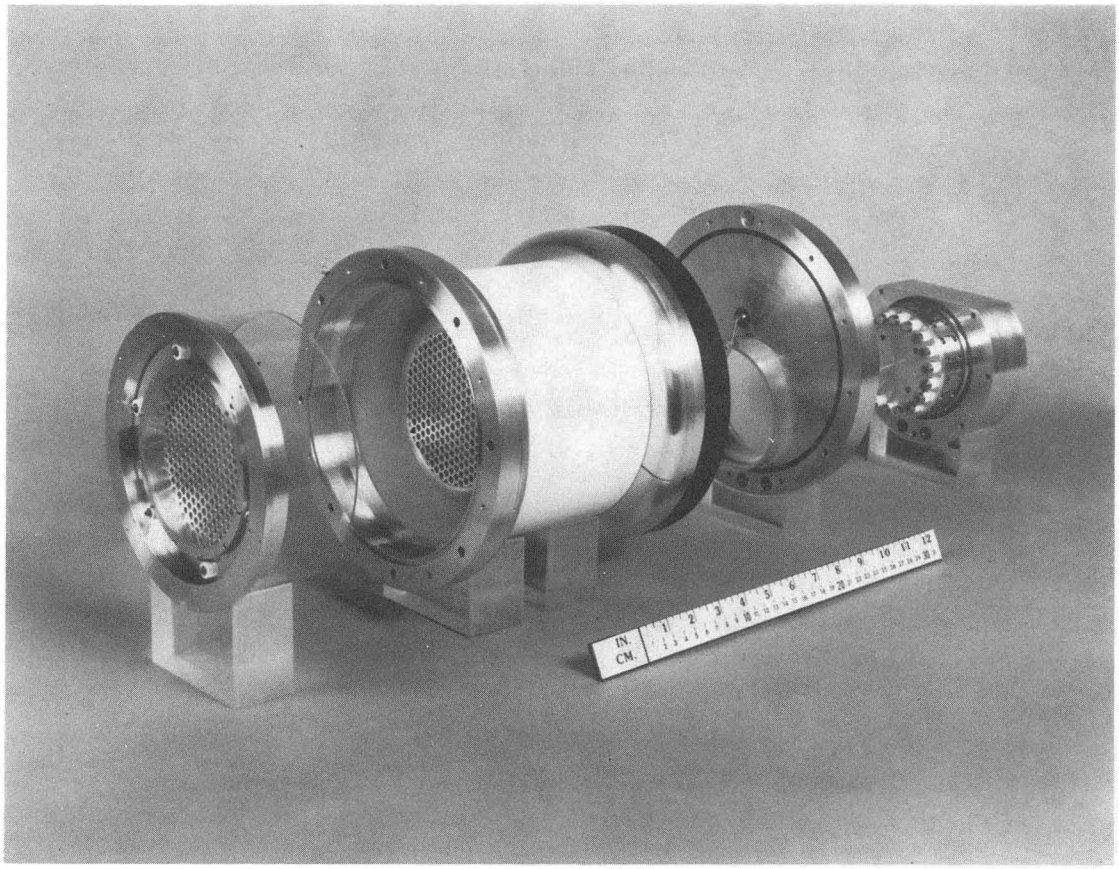


Fig. 1 The MEVVA V ion source, partially disassembled to show the multiple cathode feature (holds 18 separate cathodes) and the large beam formation electrodes. (XBB 892-1124)

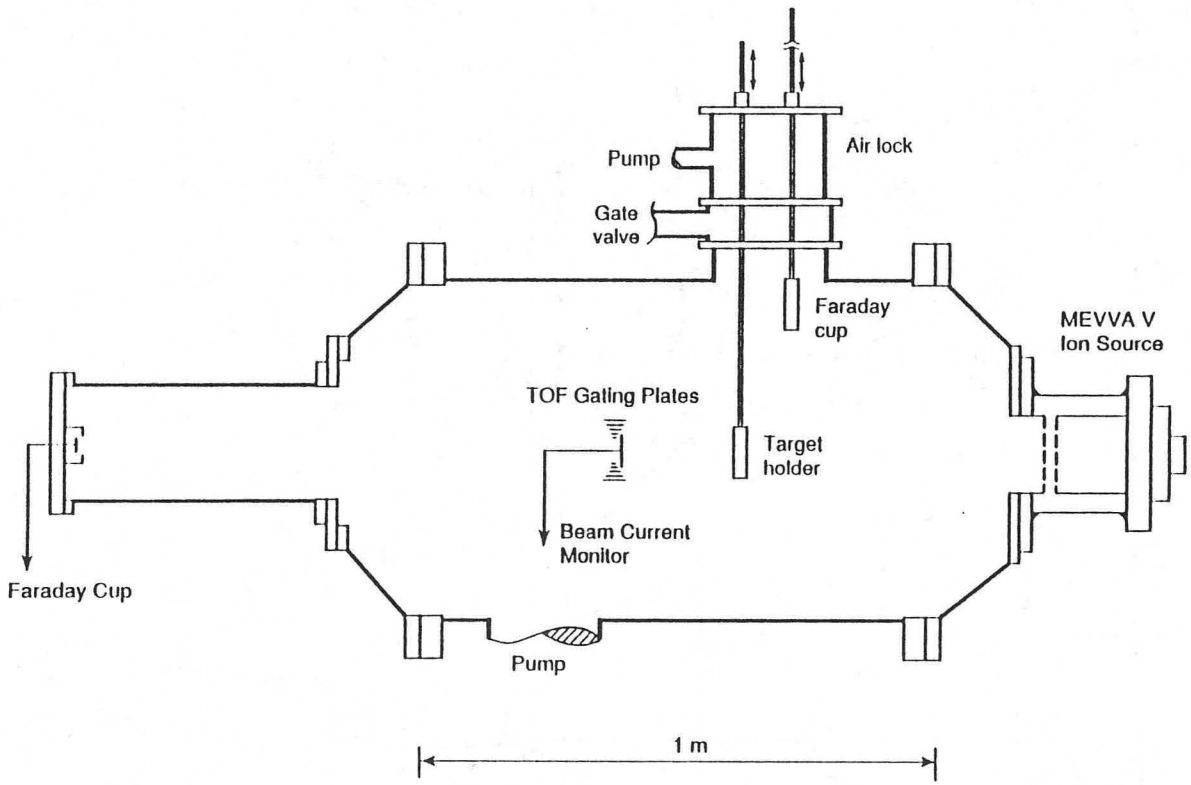
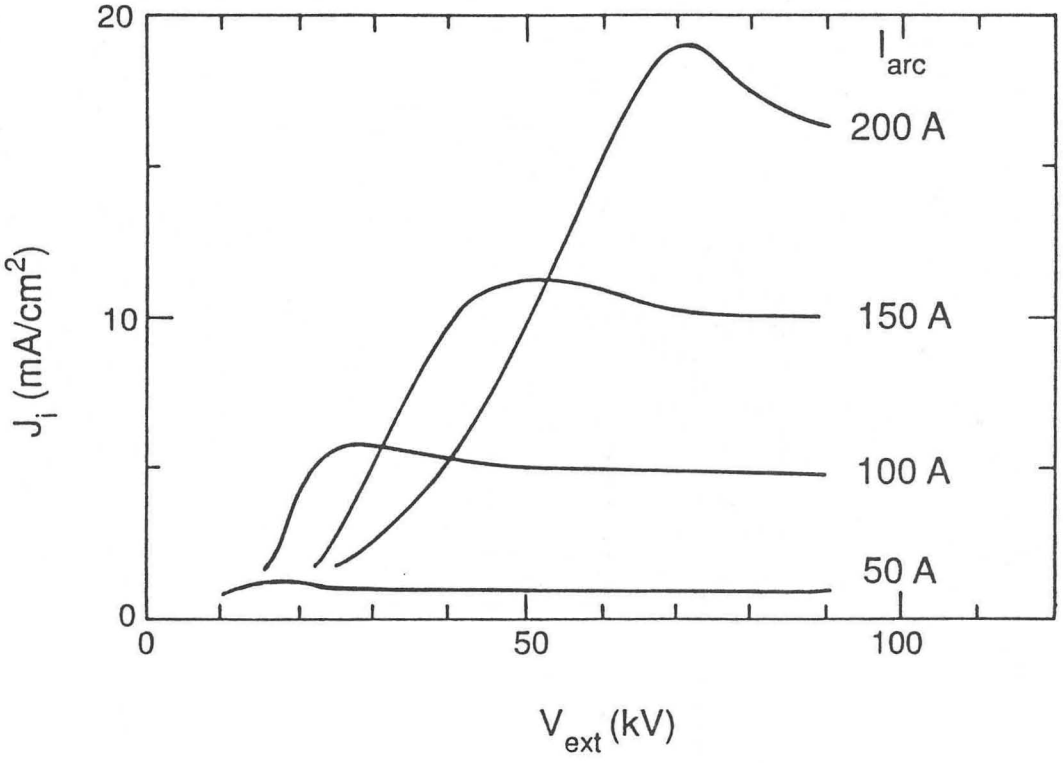


Fig. 2 Schematic of the experimental facility. (XBL 896-7641B)



XBL 904-6340

Fig. 3 Measured ion current density as a function of extraction voltage for several arc currents. Titanium beam. (XBL 904-6340)

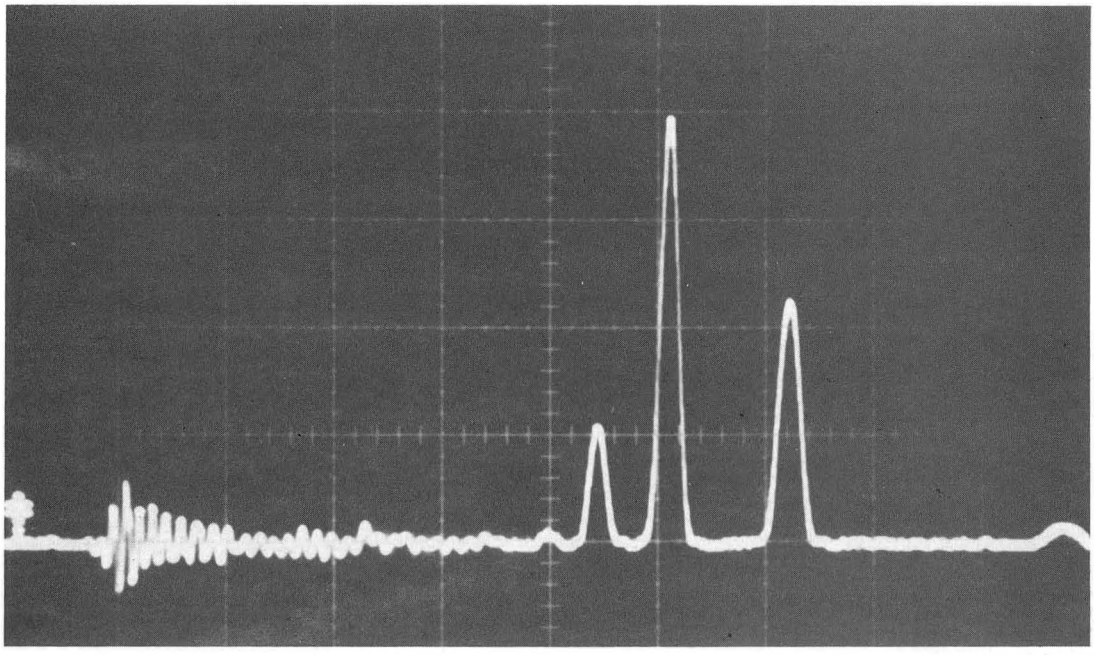


Fig. 4 Time-of-flight charge state spectrum for an iridium beam. The peaks correspond to Q = 1+ (far right), 2+, 3+ (maximum), 4+ and 5+, right to left. (XBB 907-5206)

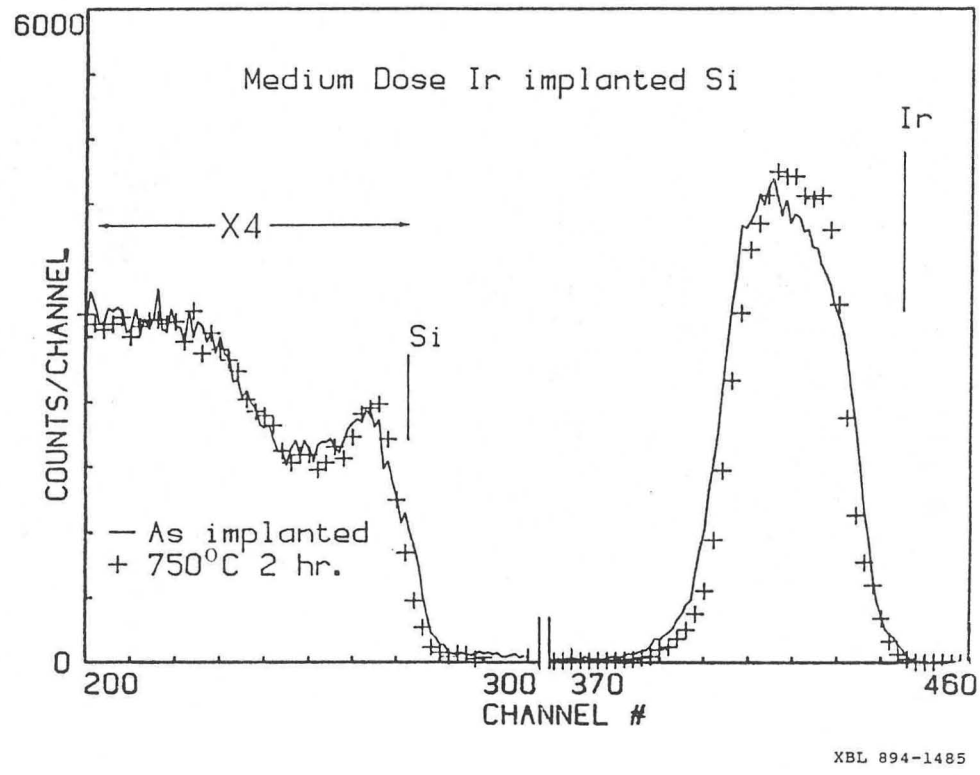


Fig. 5 Iridium implanted silicon. RBS spectra of the samples with medium dose, 7 x 10^{16} cm^{-2}, as-implanted and after annealing at 750°C for 2 hours. (XBL 894-1485)

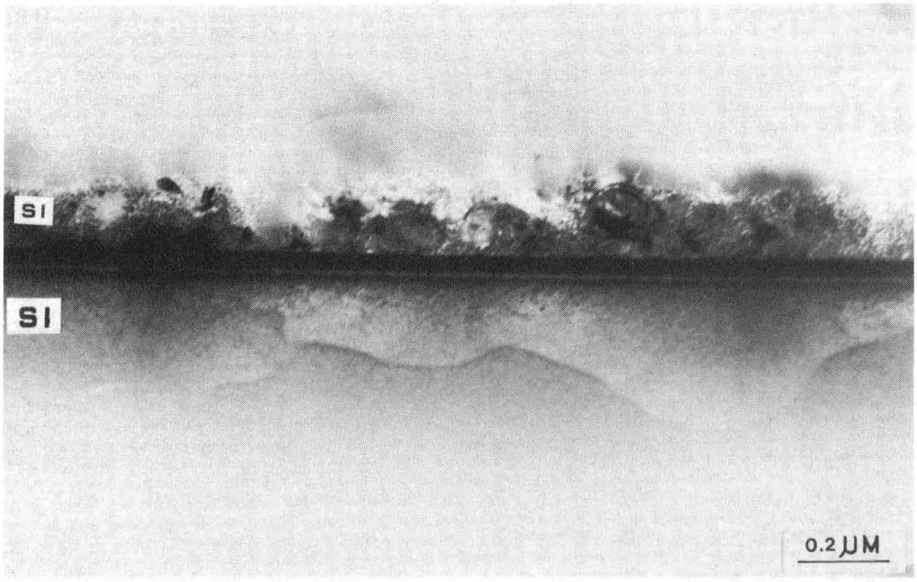


Fig. 6 Cross-sectional TEM micrograph of buried $IrSi_3$ layer. (XBB 893-2593)

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