SURFACE IONIZATION ION SOURCES

R. G. Wilson
Hughes Research Laboratories
Malibu, California

Recent achievements with iridium surface ionization ion sources are discussed. These sources can be used to produce ion beams of elements with ionization potentials from 5-1/2 to 6 V, e.g., the IIIA metals (Al, Ga, In and Tl), the rare earths, the heavier alkaline earths, and Li, in addition to the usual heavier alkalis. Ion beams of Li, Al, Ga, and In have been produced here. Ionization efficiencies, critical temperatures, current densities, and beam purities as measured by magnetic mass separation are discussed. An ion source design being employed for the IIIA metals is described briefly.

Ion implantation doping of semiconductors requires the use of ion beams of many elements with energies up to 100 or 150 keV. Normal doping is done with elements of the 2B, 3A, 5A, and 6A periods. The 1B metals, the rare earth metals and some transition metals are of interest for special solid state effects, e.g., lifetime reductions, color centers, deep levels, etc. (See Fig. 1). The III and V elements are put in Si and Ge; the II and VI elements in III-V compounds, etc. A low-energy ion accelerator is basic to such a program. Only moderate ion current densities are required to produce appropriate doping concentrations, but good uniformity over areas up to 1-1/2" in diameter requires the use of scanning techniques which reduce the current density of implanted ions. Good beam parallelism and alignment with single crystal targets are required for channeling effects. Beam purity is a consideration; an "isotope" separator is not needed, just an "element" separator. In surface ionization sources, pure enough ion beams may be produced directly from the source.

For the various desired ion species, several types of ion sources may be employed: Electron bombardment ionization sources are suitable for many; we are using them for B, P, As, S, Zn, etc; sputter ion sources are suitable for the 1B metals, Cu, Ag, Au; and surface ionization sources for the IIIA metals, Al, Ga, In, and Tl, plus the rare earths. Some investigators are using the alkali metals for ion implantation studies (interstitial effects) which are classically done by surface ionization. I will discuss surface ionization sources and their application to the ionization of Al, Ga, In, Tl, and rare earths.

The concept of surface ionization involves the ionization of a low ionization potential element (I) on a high work function surface (φ) hot enough to desorb the ions thermally; the electron is lost

$$\text{SURFACE IONIZATION EFFICIENCY} = \cfrac{1}{1 + \cfrac{\omega_o}{\omega_+} \exp\left(\cfrac{I-\phi}{kT}\right)}, T > T_c$$
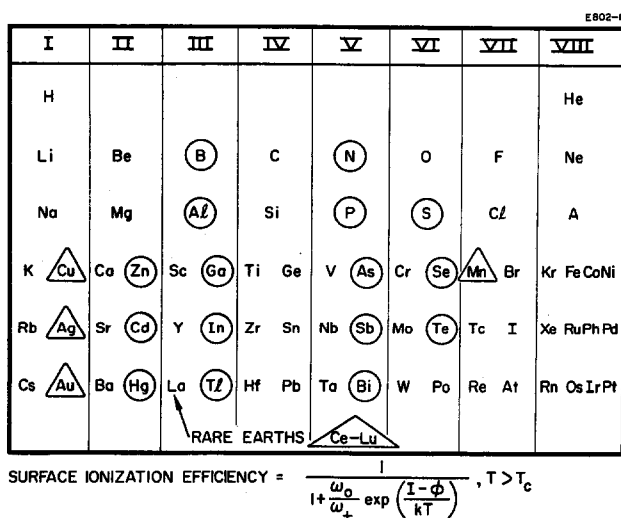
Fig. 1   Periodic Table of the Elements with implantation elements indicated and β equation at bottom.

to surface upon desorption. The ionization efficiency is the most important parameter

$$B = \cfrac{1}{1 + \cfrac{\omega_o}{\omega_+} \exp\left(\cfrac{I-\varphi}{kT}\right)} \quad T > T_c$$

in which the $(I-\varphi)$ difference is crucial. The critical temperature (T_c) is the temperature for maximum ionization (maximum current density). Al, Ga, In, Tl, and the rare earths have ionization potentials from about 5-1/2 to 6 eV, while the alkalis have from 4 to 5 eV. Refractory metals classically used for the alkalis are W, Mo, Ta, etc. Higher work function surfaces are required for the other ions. Concepts for higher work function surfaces are: (1) oxygenated surfaces, e.g., W. (2) higher work function metals, e.g., Re, Os, Ir, Pt, and (3) high work function faces of single crystals, e.g., the (110) of W, recently reported as 7 or 8 eV by Young and Clark at NBS. Oxygenated surfaces pose several problems: (a) enhancement of emission of inherent impurity ions from the ionizer surface, especially alkalis, (b) emission of other ion species from the ionizer surface in addition to the usual alkalis, (c) deterioration of the ionizer surface from attack by oxygen, (d) chemical reaction between oxygen and the element being ionized, e.g., Al or Ga at the surface, resulting in the gradual deposit of an oxide, e.g., Al_2O_3 on the ionizer surface and

possibly in ultimate failure of the ionizer, and (e) deleterious reaction of the oxygen introduced into the system, with other components of the ion source or with other materials in the system such as semiconductor targets. Single crystals pose problems of obtaining large area single crystal faces and maintaining them at the high surface ionization temperatures.

The remaining case is the one we have investigated - use of higher work function metals. We have studied Re, Os, Ir, and Pt, whose poly-crystalline ribbon work functions are 4.96, 4.83, 5.27 and 5.6 to 5.8 eV. The highest work function metal, Pt, has too low a melting point (below critical temperatures). The next highest work function metal, Ir, is suitable, so we have employed Ir surfaces. We have done some work on coating porous tungsten ionizers with layers of Ir and Os, but pure Ir with atoms incident from above the surface is the situation to be discussed here.

Figure 2 shows the ionization efficiencies which can be obtained for various elements on Ir; the alkalis are near 100% and others are seen down to $\sim 0.1\%$.
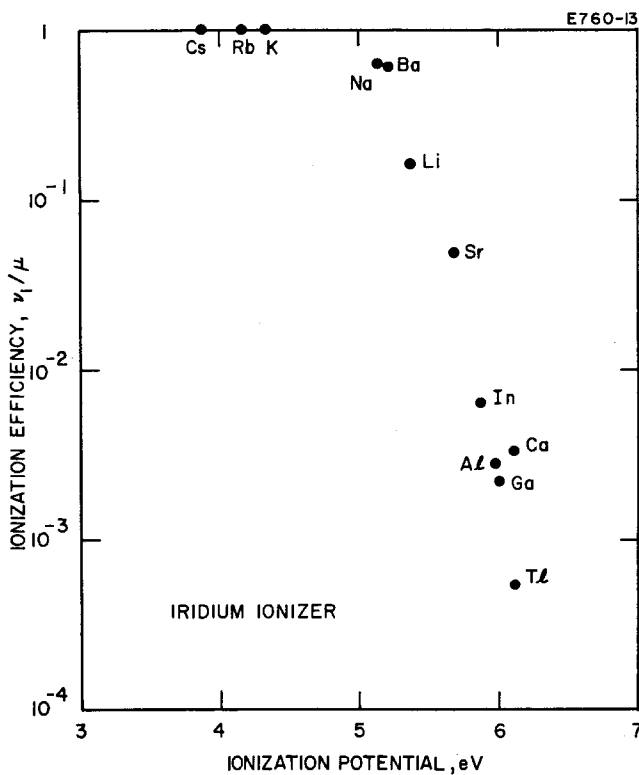

Fig. 2 Surface Ionization Efficiencies for Various Elements on Iridium.

Figure 3 shows the critical temperatures for surface ionization of several elements on Ir; they are seen to be low for the alkalis and higher
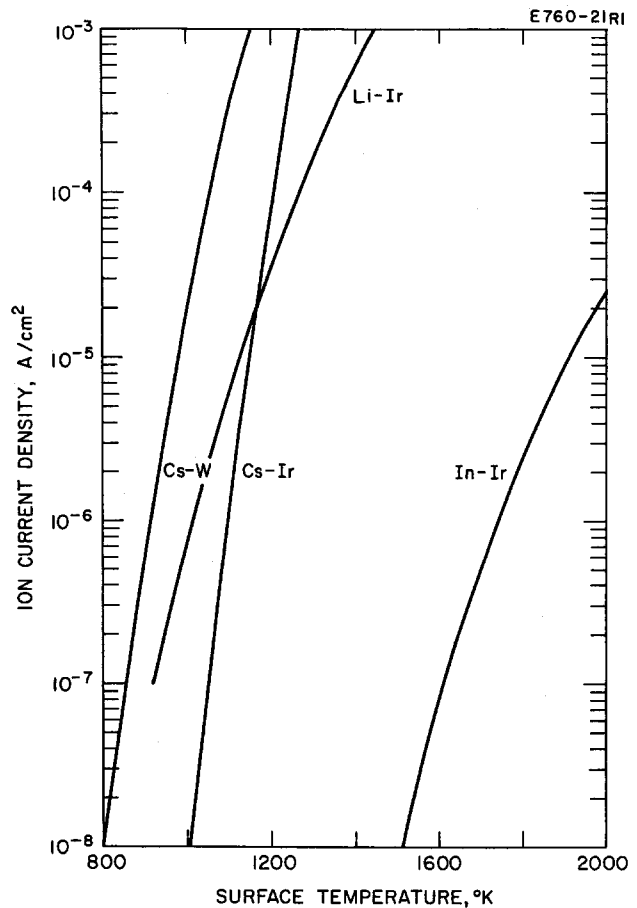

Fig. 3 Critical Temperature Envelopes for Surface Ionization of Several Elements on Iridium.

for others, e.g., $\sim 2000^\circ$K for Al vs $\sim 1000^\circ$K for Cs.

Our achievements with such ion sources are: current densities of 10 to 100 μA/cm^2 of In, Ga, and Al in 1 cm diameter beams, or 1 to 10 μA/cm^2 in 10 cm^2 beams. These compare to ~ 10 mA/cm^2 of Cs obtainable in surface ionization sources.

A problem was encountered with Al and solved. An Al surface ionization source must be operated in a clean, very high vacuum ($\sim 10^{-8}$ Torr) to prevent oxidation of the Al on the ionizer surface where a layer of Al$_2$O$_3$ building up on the surface eventually inhibits ionization. Another situation which must be prevented is the presence of bulk liquid of In, Ga, or Al on the Ir surface, which results in alloying at surface ionization temperatures and melting of the alloyed region.

Because the ionization process is not highly efficient for these elements, the resulting neutrals must be eliminated from the beam. This is automatically done when magnetic mass

separation is employed, but can also be done by electrostatic deflection of the beam or by the use of a curvilinear source (Fig. 4) designed to extract a parallel strip beam at an angle to the ionizing surface.
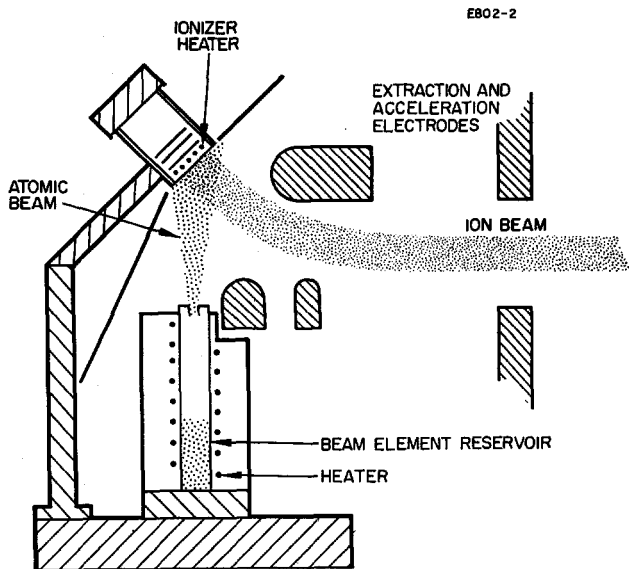

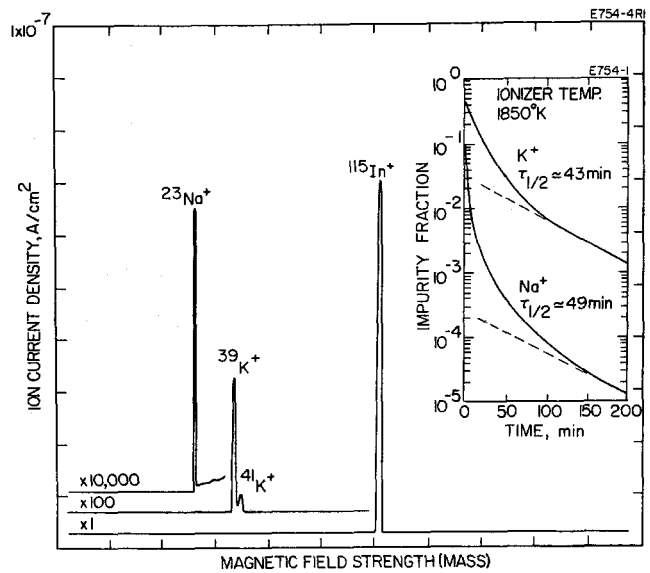Fig. 4   Curvilinear Surface Ionization Source.

Fig. 5   Mass Spectrum of Ion Beam From an Iridium Surface Ionization Source. Insert Shows Time Decay of Impurities.

    Ion beams from surface ionization sources have been magnetically mass analyzed here and found to contain impurities of K^+ and Na^+ which decay in time. Total impurity levels of 10^{-3} and 10^{-4} can be achieved after some hours of operation, and 10^{-5} after longer operation. The spectrum of an ion beam from an Ir source is shown in Fig. 5 early in its operation. The time decay of the K^+ and Na^+ impurity components is shown in the inset in Fig. 5.