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Preparation of GaAs Photocathodes at Low Temperature*

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Abstract

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ABSTRACT

A variety of cleaning techniques related to preparation of an atomically clean GaAs surface without heating to 600°C are discussed and evaluated.

The preparation of an atomically clean surface is a necessary step in the formation of negative electron affinity (NEA) GaAs. Traditional methods to this end include cleaving, heat cleaning and epitaxial growth. Cleaving has the advantage of yielding a fresh surface after each cleave, but is limited to small areas and is not suitable for specialized structures. Heat cleaning is both simple and highly successful, so it is used as a preparation method in virtually all laboratories employing a NEA source on a regular basis. Due to its high cost and complexity, epitaxial growth of GaAs with subsequent *in vacuo* transfer is not a practical solution for most end users of GaAs as a NEA electron source.

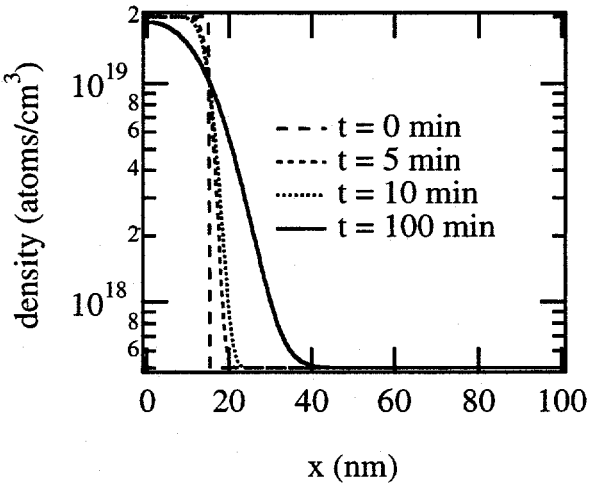

Figure 1: Diffusion profile of Zn dopant as a function of time at 600°C. Diffusion coefficients after [1].

While simple, the heat cleaning process has a number of disadvantages. High temperatures ($\geq$ 600°C) can lead to reliability problems when utilized in systems designed for other criteria, e.g., high potential gradient electron gun structures. In some systems high temperatures may not be attainable. However, the problem may lie with the GaAs photocathode itself, e.g., the quality of a GaAs crystal with a graded doping profile may deteriorate if the dopant possesses a high diffusivity at elevated temperatures such as illustrated in Fig. 1. Graded doping is desirable as it may lead to high electron polarization while mitigating the surface photovoltage effects seen in extraction of high current densities.

There are clear gains to be had in reliability, photocathode advances and ease of use when GaAs can be cleaned at low temperature. In general, we can divide these cleaning methods into two classes: those that are performed on the photocathode before insertion into vacuum and those that are applied after the photocathode is installed into the ultra-high vacuum chamber.

The purpose of cleaning the GaAs external to the vacuum system is to minimize the amount of cleaning necessary upon insertion into vacuum. For an *ex situ* tech-

nique to be successful, it is necessary after cleaning to transport the photocathode in a clean non-reactive atmosphere, e.g., nitrogen (see Fig. 2)[2]. In principle, it is possible to chemically strip all contaminants from the surface and immediately obtain a clean surface in vacuum. This is not achievable due to residual contamination from the treatment chemicals, the transport gas and the load vessel. Despite this limitation, *ex situ* techniques have a firm place in the preparation of GaAs photocathodes.

A standard technique for preparation of bulk GaAs is to etch the surface to remove damage induced by the polishing process. Typically this consists of a 4:1:1 solution of H_2SO_4, H_2O and H_2O_2. While this is an efficacious process, an oxide layer is typically left behind which must be removed either in another process or in vacuum. Also, the etch rate is too high for use in removing contaminants at the surface of thin GaAs emitters.

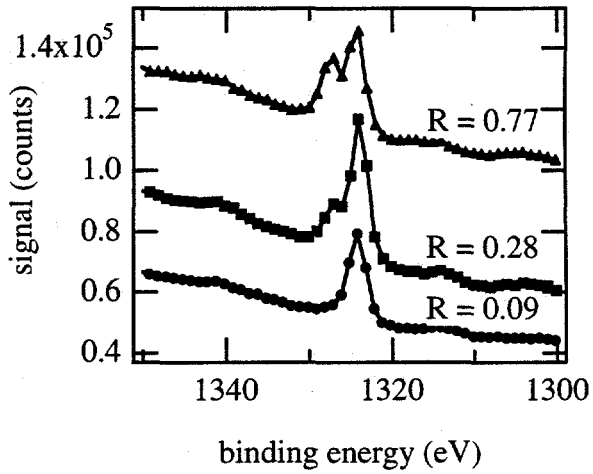

Figure 2: As $2p$ XPS from surfaces with varying oxide content. From top to bottom the curves correspond to: baked, etched air transported and ultra pure water rinsed nitrogen transported GaAs. R denotes the ratio of the oxide peak to the elemental As peak.

A variant of this technique is the acid-alcohol dip, where the acid is either HCl or HF at a concentration of 5% in ethyl alcohol[3]. This technique effectively removes surface oxides leaving behind an As rich surface mildly contaminated with carbon that is evaporable by heating to 400°C. It has also been shown that rinsing GaAs in ultra-pure deionized de-oxygenated water is an effective method for removing surface oxides. Like the HCl and HF dips, there is a tendency for the rinsing to leave loosely bound carbon on the surface. These methods are well suited to cleaning the surfaces of thin photocathode structures.

Another effective chemical etch of surface oxides is NH_4OH. This chemical is used at SLAC for removal of a deliberately grown surface oxide protection layer. Removal of this layer leaves behind a surface which may be cleaned at lower than normal temperatures, i.e., about 500°C .

In addition to the techniques mentioned above, it is also possible to *in situ* clean GaAs exclusively by ion sputtering. However, even if a very low energy is used, the collision of the ions and the crystal atoms results in near surface damage in the form of dislocations which have to be annealed away. Meaning of course that elevated temperatures are once again required; this is what we need to avoid.

If a thick As cap is deposited as the final step prior to removal from the growth chamber, this protective layer can be desorbed around 450°C. Thinner layers, e.g., 20 nm, do not have sufficient blocking to keep oxidation at bay. Additionally, the As cap is a one-shot process: if a photocathode protected by an As cap needs subsequent

cleaning for NEA activation, it once again becomes necessary to heat clean in the usual way.

A standard surface cleaning methodology is the application of a reactive gas at a surface to bond with contaminants and subsequently desorb them at a temperature lower than they would do otherwise. With GaAs this can be accomplished through the use of atomic hydrogen as the catalytic agent. Sources of atomic hydrogen include electron cyclotron plasma, DC glow discharge and thermal. The plasma and glow discharge systems are bulky. The thermal source is compact, but presents a high heat load to the vacuum vessel. All systems require exposures of more than 10^{-6} Torr at the GaAs surface. Another drawback of this technique is the need to mildly anneal the GaAs in order to desorb the remnant hydrogen which will combine with some types of acceptors in p-type GaAs[4]. However, bulk GaAs has been successfully activated at temperatures as low as 350°C using a thermal atomic hydrogen source at SLAC[5]. The action of the atomic hydrogen on the activated (Cs and F covered) surface is still under investigation.

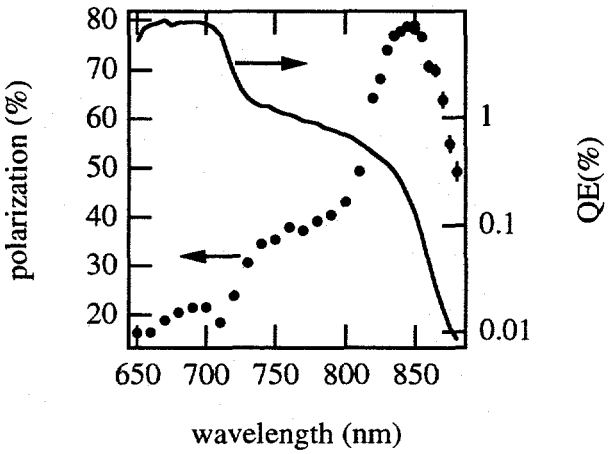

Figure 3: Photoemission data from a cathode having the doping profile shown in Fig. 1. The cathode was heat cleaned to 500°C for 1 hour.

It is also possible to etch GaAs *in situ* using, for example, Cl_2[6]. Acceptable etch rates (a few nm/min) have been achieved at 250°C. However, Cl remains on the GaAs surface after etching. The effect on NEA activation has not been tested.

We have seen that there are several methods applicable to the creation of a clean GaAs surface suitable for activation into the NEA state. These methods have been applied at SLAC to create a clean surface on a graded dopant strained GaAs photocathode (See Fig. 3). Other promising techniques need further development with regards to their application to NEA GaAs.

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