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Atomic Hydrogen Cleaning of GaAs Photocathodes

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It is well known that surface contaminants on semiconductors can be removed when samples are exposed to atomic hydrogen [1]. Atomic H reacts with oxides and carbides on the surface, forming compounds that are liberated and subsequently pumped away. Experiments at Jefferson Lab with bulk GaAs in a low-voltage ultra-high vacuum H cleaning chamber have resulted in the production of photocathodes with high photoelectron yield (i.e., quantum efficiency) and long lifetime [2]. A small, portable H cleaning apparatus also has been constructed to successfully clean GaAs samples that are later removed from the vacuum apparatus, transported through air and installed in a high-voltage laser-driven spin-polarized electron source. These results indicate that this method is a versatile and robust alternative to conventional wet chemical etching procedures usually employed to clean bulk GaAs.

Initial efforts at Jefferson Lab involved immersing GaAs samples in an atomic H environment created with a DC glow discharge. There was evidence of cleaning but results were inconclusive. Unequivocal cleaning results were obtained when an rf discharge was employed to produce an atomic H flux [3]. This method provides high atomic H flow rates and does not inadvertently heat other portions of the vacuum chamber as is often the case when thermal crackers are used. The H source is shown in Fig. 1. Research-grade molecular H flows through a leak valve into a Pyrex glass dissociator (2.5 cm dia.). The molecular H is dissociated with an rf inductive discharge created by a 12 turn coil 3.5 cm in diameter, which is part of an LC tuned circuit. The LC circuit resonates at ≈ 100 MHz and 40 Watts of rf power is absorbed by the hydrogen when the dissociator-region pressure is 20 mTorr. Atomic H exits the dissociator through a 1 mm dia. hole and travels through an aluminum tube [4] toward a GaAs sample approximately 15 cm away, which is located within a photocathode activation chamber. A nonevaporable getter pump and an ion pump are used to maintain a pressure of $\approx 10^{-6}$ Torr near the GaAs sample during H cleaning corresponding to a mean free path > 1 m. With the

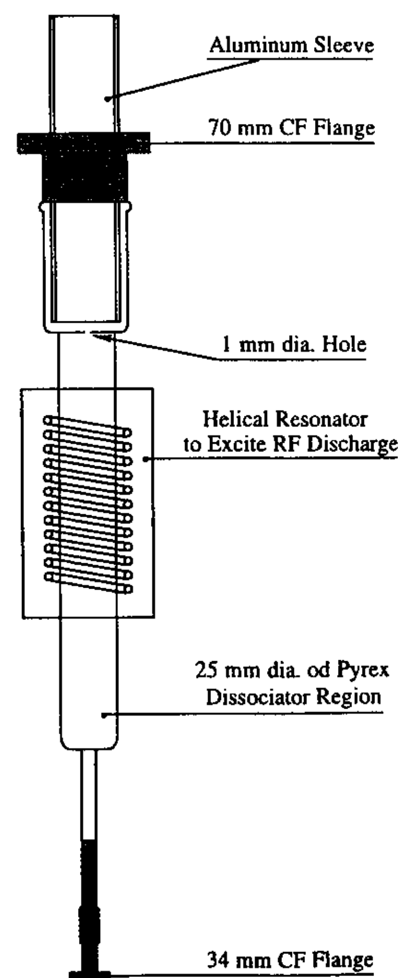

Fig. 1 Atomic H source

present system geometry, Monte Carlo simulations predict that approximately 2.5% of the total H flux hits the wafer. Under these conditions, the atomic H flux at the wafer is estimated to be 10^{17} atoms/cm^2/s, assuming a 50% degree of dissociation.

To quantify the effectiveness of the H cleaning method, quantum efficiency (QE) and lifetime of activated photocathodes is measured after cleaning. The procedure is as follows. A degreased, bulk GaAs sample (p-doped with Zn at 2 to 3×10^{18}/cm^3) is installed in the vacuum chamber. The entire chamber, including the H cleaning apparatus, is baked at 250°C for 36 hours and allowed to cool to room temperature. The GaAs sample is then heated to 300°C and exposed to atomic H for 45 minutes. After H cleaning, the GaAs sample is heated to 600°C for 12 hours to liberate H infused in the sample surface. After cooling again to room temperature, a photocathode is made in the usual way; approximately a monolayer of cesium is applied to the GaAs surface and oxidized with NF_3 while photocurrent yield is measured during illumination with white light. Relative QE measurements as a function of wavelength are made using a monochrometer with a tungsten halogen white light source. This data is cross-calibrated with absolute QE measurements using diode lasers with wavelengths 780 and 860 nm. Very high QE values over a broad range of wavelengths (>10%) have been recorded for a number of different samples. The H cleaned photocathodes also exhibit very long lifetimes (> 1000 hours under constant diode laser illumination).

In conclusion, we have demonstrated that bulk GaAs photocathodes can be manufactured that have very high QE's and lifetimes when samples are cleaned with atomic H. It will be particularly interesting to use this method to clean other photocathode materials, for example, strained layer GaAs and chalcopyrites, for which no effective cleaning procedures presently exist. The effectiveness of this technique may also simplify material-growth procedures, making arsenic-capping of photocathodes unnecessary. Finally, it may also be possible to attach an H cleaning apparatus to a load-lock gun, where photocathodes may be removed from the gun chamber and recleaned for potentially indefinite use.

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1) E.J. Petit et al., J. Vac. Sci. Technol. A 10 (1992), 2172.; E.J. Petit and F. Houzay, J. Vac. Sci. Technol. A 12 (1994), 547., and references within.

2) C.K. Sinclair et al., Workshop on Polarized Electron Sources and Low Energy Polarimeters, Amsterdam, May 1996.

3) W.W. MacAlpine and R.O. Schildknecht, Proc. IRE, (1959), 2099.; J. Slevin and W. Stirling, Rev. Sci. Instrum., 52 (1981), 1780.

4) Aluminum was chosen because of its low molecular H recombination coefficient compared with stainless steel or Pyrex. See for example, J.S. Price and W. Haeberli, Nucl. Instr. and Meth. A 349 (1994) 321.