**BAPVC Annual Project Report**

**Project Title:** Advanced Evaporation Source Design
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**Summary:**

A pilot-scale evaporation source prototype incorporating an *in-situ* nozzle heater and concentric In-Ga crucibles has been designed, fabricated, installed, and operated. The nozzle heater exhibits the required power dissipation equivalent to 1500ºC blackbody radiation to compensate for nozzle heat losses, and a mixed Ga-In vapor has been generated to deposit an In-Ga film on Mo/soda-lime glass substrates. These achievements meet the Year One milestones.

**Key Accomplishments:**

Figure 1 shows the prototype evaporation source as installed in the vacuum system. The body of the source is heated by a large graphite cylindrical serpentine heater, while the nozzle is heated by a wound tantalum filament on a boron nitride support form inserted into the nozzle of the graphite source. Later generations of the nozzle heater are anticipated to utilize a miniaturized version of the graphite body heater to improve longevity.

Two milestones were specified for year 1:

1) Operation of the nozzle heater at power equivalent to blackbody radiation at 1500 ºC, the anticipated operating temperature of the Cu source, and
2) Generation of a mixed Ga-In vapor.

Figure 2 documents the maximum power generated by the nozzle heater – 865 W at 32V/27A. This meets the requirement of 874 W for a 4.46cm diameter blackbody disk radiating at 1500 ºC. The electrical power output is presently voltage-limited by the power supply, so the Ta filament diameter will be increased from 0.040 in to 0.050 in to reduce operating voltage and enable operation at ~1200W.

Figure 3 shows a scanning electron micrograph of a Ga-In film deposited over 60 minutes at an estimated source temperature of 1200 ºC. The mass of indium evaporated from the source over ~2.5 hours at temperature was 4.5g, measured by the utilization of a removable pBN liner within the In crucible. The film thickness indicated by gravimetric mass gain was 10 μm. The composition measured by energy dispersive spectroscopy is 55% Ga, 45% In, while that measured by x-ray fluorescence is 75% In/25% Ga. These composition measurements indicate that the film is not homogeneous and that Ga has segregated to the film surface. This is not surprising given that the film was likely in a molten state due to heating from the source, and that segregation could occur during cooldown/solidification. In the future, film thicknesses < 1μm will be deposited to more closely approximate the thicknesses required in $Cu(InGa)Se_2$ device fabrication.

Figure 1.  Photograph of installed source with insulation removed.  Cylindrical main body heater and leads to nozzle heater(underneath) are visible.


Figure 2.  Photograph of 865W achieved by the nozzle heater, meeting the 874W milestone requirement.

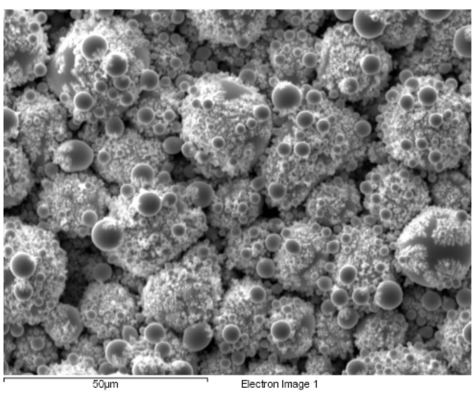


Figure 3.  Micrograph of 10µm-thick Ga-In film deposited on Mo/soda-lime glass.

**Future Work:**

In the coming year, the source performance will be more thoroughly characterized for simulated operating stability over long deposition runs, and source design and operating parameters will be refined to achieve spit-free Cu evaporation of 15 g/hr.  Internal rate restricting orifice dimensions will be determined to achieve Ga/(In+Ga) ~ 0.5 vapor composition.  Additional minor design issues have been identified related to the high current assembly and will be addressed.  Improved process instrumentation also will be implemented to characterize source operating stability and power consumption.