We describe the design of a facility for the batch production of large numbers of micro-channel-plate photomultipliers using the ``air-transfer'' photocathode process we have demonstrated on single LAPPD™ modules at the University of Chicago. The proposed facility uses dual nested low-vacuum (LV) and ultra-high-vacuum (UHV) systems in a rapid-cycling, small-footprint batch production system capable of producing 100 8” x 8” photodetectors per week, scalable to larger numbers. The system allows the use of O-rings or rubber gaskets rather than the usual UHV metal seals, full access for leak-checking before synthesizing the photocathode, and real-time photocathode optimization with feedback.
Applying Large-Area Fast Timing in the Field (<<10 psec for charged particles, < 50 psec for single photons)

INCOM TILE 41

NOW: Incom –6 (8)/ month, linearly expandable...

IN 10-20 YEARS: would like numbers comparable to current PMT use:
- TOF-PET: 10’s of thousands
- Colliders: 10’s of square meters;
- Neutrinos: JUNO has 18,000 20” and 25,000 3” (A. Giaz, arXiv1804.03575)

12/8/2019
Q: How are PMT’s made in batches?

LAPPD Collab purchase of Burle (RC) system (DOE funding)

- Batch of 30? tubes
- Pumped via a thin tubulation;
- Pinched off after cathode synthesis
- Simple oven (Low Vac=air)
- Low conductance manifold
- Low vacuum (LV) pump

Ans: UHV inside tube; cathode synthesized in situ
Prior Unsolved Problems with Large-area Flat Panel Packages

The aspect ratio of a flat-panel large-area package makes the PMT-like photocathode evaporation process difficult.

Micro-channel PMTs (MCP-PMT) are made via “vacuum transfer”, in which the photocathode is evaporated separately on the inside of the entrance window, and then transferred in UHV to the detector body, where it is sealed. This requires: a large UHV volume, relatively large thermal mass cycled through bake-out. The hermiticity of the seal and the cathode quality (QE, uniformity, lifetime) are difficult to access.
The four historical show-stoppers” have been proven viable:

- **Ceramic/glass hermetic seal** in batch production style chamber (solved, US Provisional patent 15/468,371)
  Challenges: indium oxide, metallization quality, surface quality

- **Air-transfer photocathode growth**
  Demonstrated photocurrent spreads across full area; industry to optimize process for QE from 4% to 25-35% *(see Baroisi quote slide 7)*
  Challenges: quality and thickness of antimony precursor, temperature uniformity during formation

- **MCPs recover after multiple cesiations**, are HV stable at fields with reasonable gain
  Challenges: explore in multiple trials, in progress

- **Consistent production of ceramic inside-out bodies**
  We have a full supply chain for LAPPD materials, have made a Gen-II LAPPD and used at the test-beam – top right

R&D for industrialization of in-situ method is done
FINALLY, we have a solution to the window-body seal problems.

Problem is— the oxide in the gap
Soln: gap defined by hard-stop
Soln: No oxide initially in gap
Soln: essential X-ray diagnostics

US Provisional patent 15/468,371

Indium wire— molten In is wick’d into gap (E.S.)
The Air Transfer Photocathode Process

Emulate PMT process:
1. LV outer, UHV inside tube due to high-temp baking, getter, alkali vapors
2. Photocathode synthesized inside volume
3. Low conductance UHV to LV through thin tubulation

Differences from PMT process:
1. Antimony layer pre-deposited on window; seal before alkali
2. Work in LV instead of air
3. Heat only the tube- no outer oven (reason for LV)

Margherita UHV outer vessel
MCP inside tile base
Conflat 16.5” metal seal
Air Transfer Is Not New

Eric Spieglan found these (obscure) papers:

1. B. Tanguy, J. M. Barois and M. Onillon; Experimental Study of the Equilibria of Cesium Potassium Antimonides with Alkali Vapours; Materials Chemistry and Physics, 30 (1991) 7-12
2. Jean Marc Barois, Claude Fouassier, Marc Onillon. and Bernard Tanguy; Experimental Study of the Non-Stoichiometry of Cesium Antimonide: $\text{Cs}_3\text{Sb}$; Materials Chemistry and Physics, 24 (1989) 189-197

Last sentence of Ref. 1 above:

“Manufacturing photoemissive layers by equilibrating the antimonides with binary alkali vapours would lead to a product with better definition than those obtained through the dynamic process used at present.”
Air Transfer Is Not New-cont.

Andrey Elagin found a Russian PMT manufacturer who sent us PMT’s made by air-transfer.

Naixin Liang and Vasily Soloview (Chicago undergrads) measured the QE- not great (~15%), but this was a one-off tube made just for us (gratis).

See PSEC Document Library #345 “Testing the Quantum Efficiency of MELZ Photo-Multiplier Tubes”, at lappddocs.uchicago.edu
In-Situ Cathode Synthesis

Start with a 10nm predeposited layer of Sb; bring in Cs through two tubulations on lower side (marked).

QE is below expected ~4% rather than 15-20%; most likely due to Sb layer too thick. Non-uniformity probably largely due to thermal non-uniformity (open to room air, heated in the middle below).

However: Cs transports over whole face; plates recover; Tile31 now at Fermilab Test Beam Facility with Evan. Leave to industry to optimize.
We realized that all the current steps can be straightforwardly parallelized as in the Photonis PMT stand.

Stack modules 3-high on one fixture, separately valved.
We realized that our dual UHV system is overkill - one needs only LV for the sealing process and thermal insulation. Means we can use gaskets or O-rings - not restricted to 16.5” Conflat metal seals – can have multiple stacks on one system; i.e. a faster batch cycle and a larger batch.

US Provisional Patent 62928598
A Multi-cart Batch Facility

The small footprint (cart or table) allows multiple units on a common vacuum, slow-control, and system.

US Provisional Patent 62928598

3 modules /manifold x 6 manifolds/cart x 6 carts = 108 8” modules/week, scalable
We believe that the R&D for industrialization of the in-situ method is done at UC Tile 31 at the Fermilab test-beam (Evan Angelico).

Conclusions – such as they are

We believe that the hermetic seal is in good shape, the mechanical stack-up also. Thermal cycle also works as expected, but needs optimization (Sb thickness, temperature control). Photocathode synthesis method is well-founded and acts as expected, but needs optimization (Sb thickness, temperature control). Leave to industry as it’s going to be tied into their own process.
Acknowledgements

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We thank those listed below for essential technical contributions and good company. Apologies for those I’ve inadvertently left off...

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• Michael Foley, Alexey Lyashenko, Camden Ertley, Mark Popecki (Incom)
• Jeff Elam and Anil Mane (ANL ALD group)
• The LAPPD Collaboration
• The many Chicago undergraduates and high school students
• Sergei Belyanchenko (MELZ), Giles Humpston (seal expert), and Bob Jarrett (Indium Corp.)
Reference Bibliography

1. PSEC papers, internal notes, and student reports are available from the PSEC Document Library: lappddocs.uchicago.edu

2. The PSEC archive of papers on photocathodes, anodes, micro-channel plates, etc. is available at https://psec.uchicago.edu/library/index.php
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