Metal Photocathode Research at Daresbury Laboratory: From Surface Science Tools to Accelerator

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On behalf of the STFC ASTeC/Loughborough University EuCARD2 team

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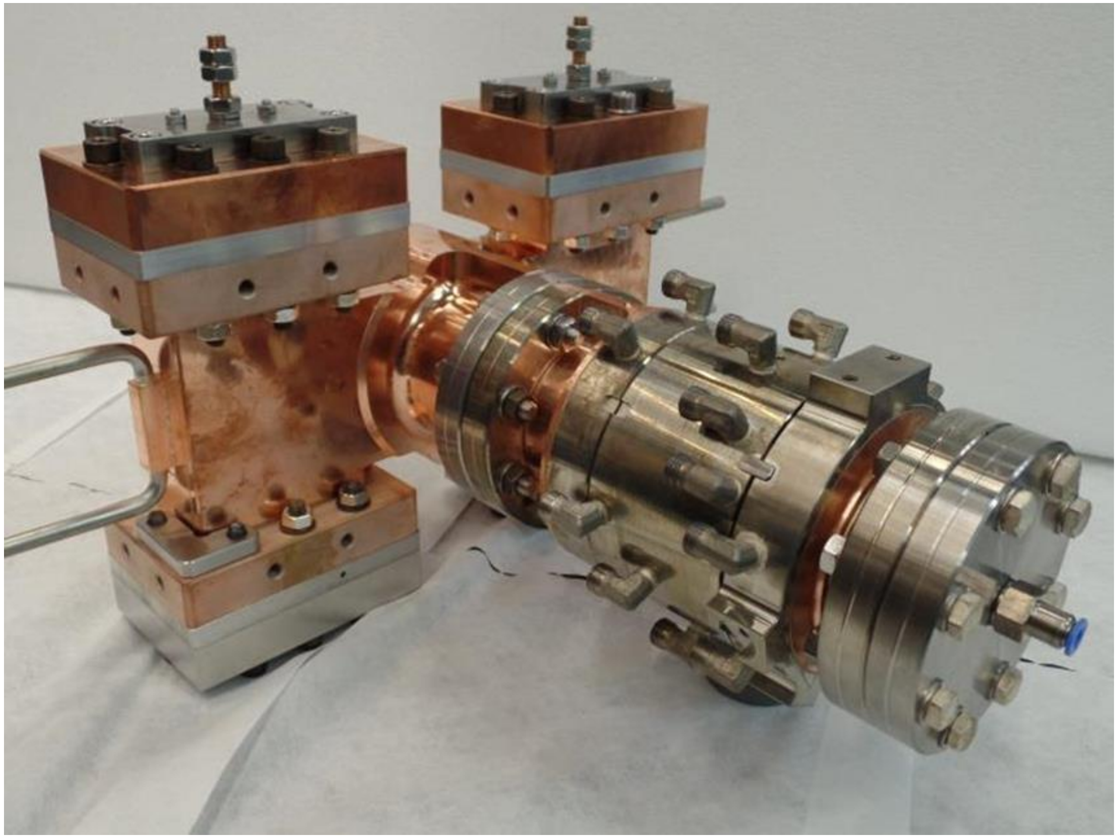
Outline

- Photocathode development activity at Daresbury – High Repetition Rate gun for CLARA/VELA FEL test facility
- Surface analysis for Photocathode Instrument
  - Analytical tools
  - Experiments
- Metal photocathode preparation facility
  - Tools
  - Results of the photocathode activation
- Current status of the CLARA photocathode infrastructure
- Future plans and perspectives

CLARA High Repetition Rate Gun



RF cavity of the CLARA High Repetition Rate Gun (HRRG)

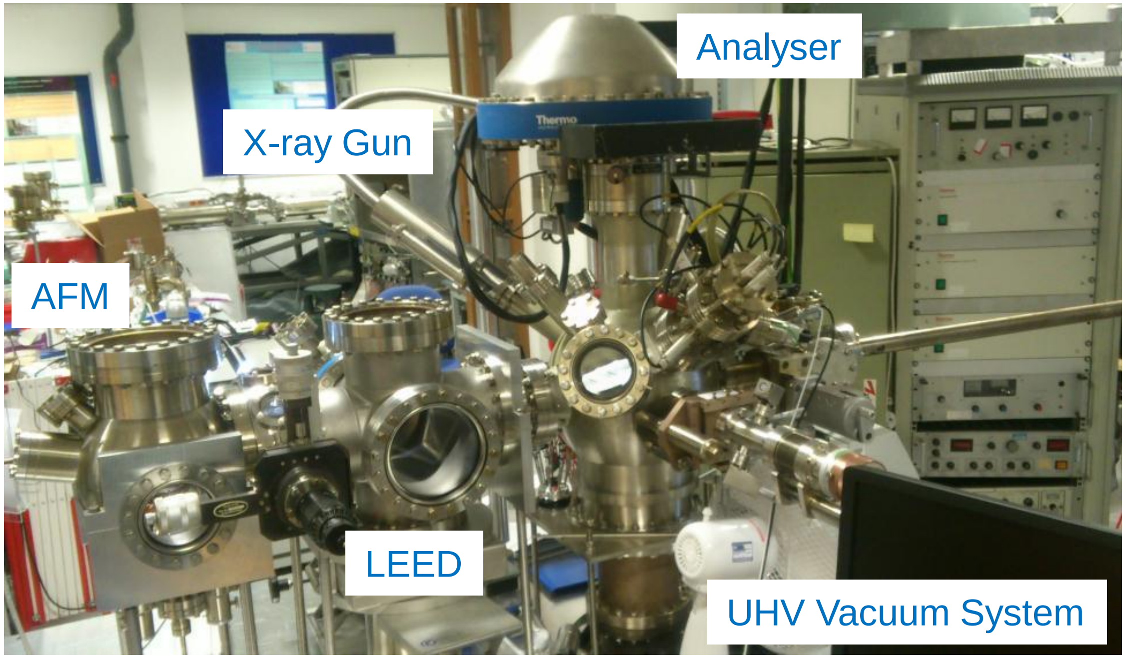
Mo photocathode plug of the HRRG

- May be used as electron source itself
- Different metal thin films can be deposited in search for minimum beam emittance
- Te- and Sb- based high *QE* semiconductor layers can be deposited

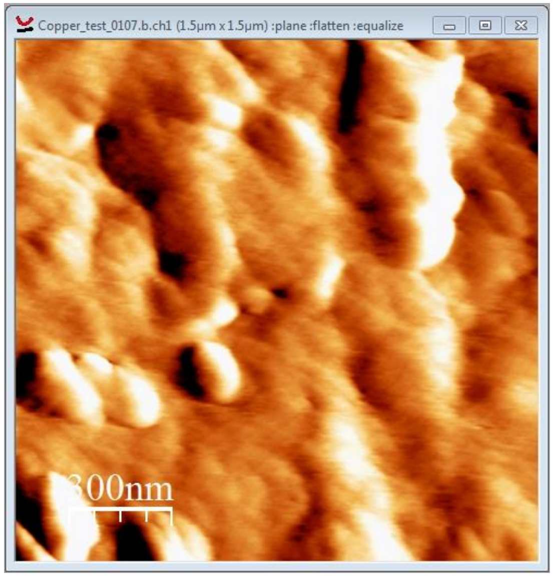
Surface Analysis for Photocathodes Instrument (SAPI)

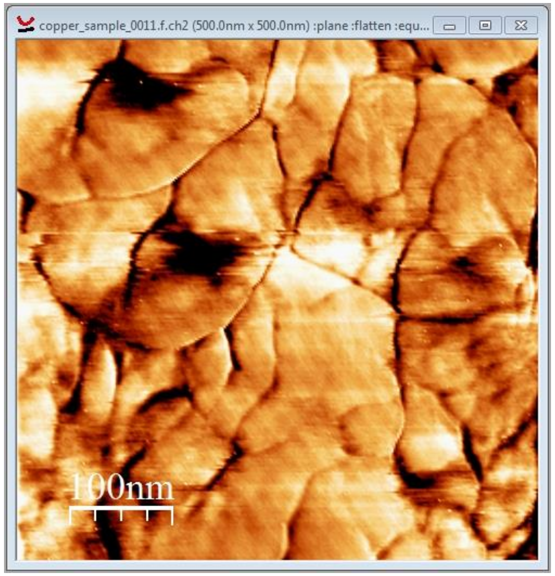
- **X-ray Photoelectron Spectroscopy (XPS)** - Compositional and chemical analysis
- **Atomic Force Microscopy (AFM)** - Surface roughness evaluation

- **Kelvin Probe** – Contact potential difference work function measurements
- **Low Energy Electron Diffraction (LEED)** – Crystalline ordering (single crystal only)
- **Quantum Efficiency measurements** – UV laser and calibrated photodiode



AFM Commissioning Data



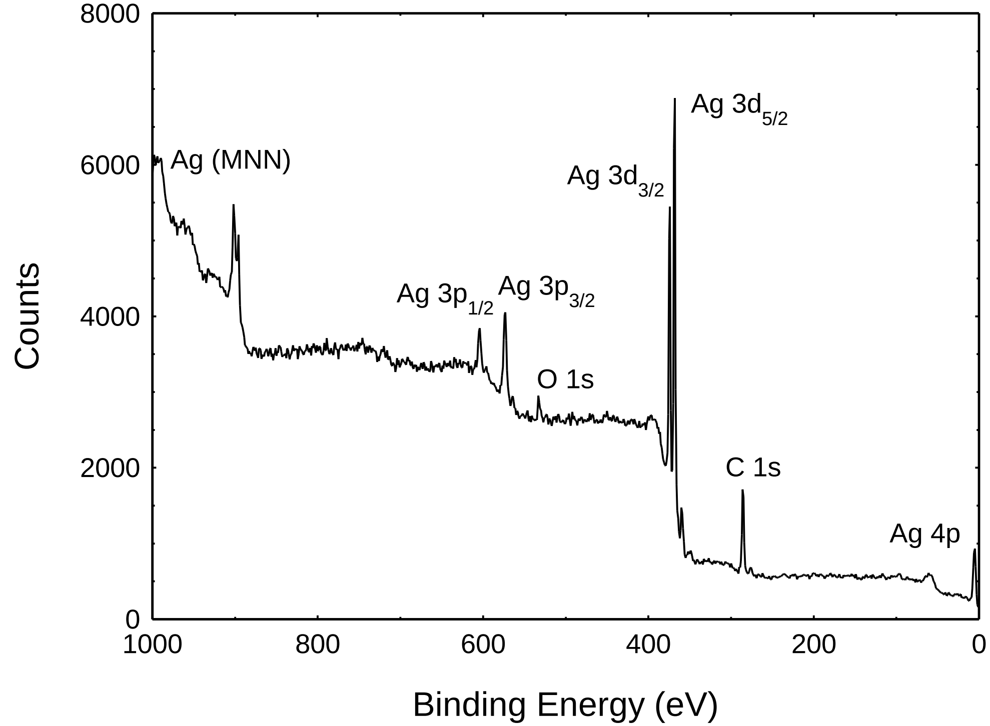


AFM images of polycrystalline Cu

- Line scans and RMS roughness values can be given by software
- Roughness likely to be a key parameter in determining transverse energy spread
- Further experiment are scheduled with the TESS energy spread spectrometer

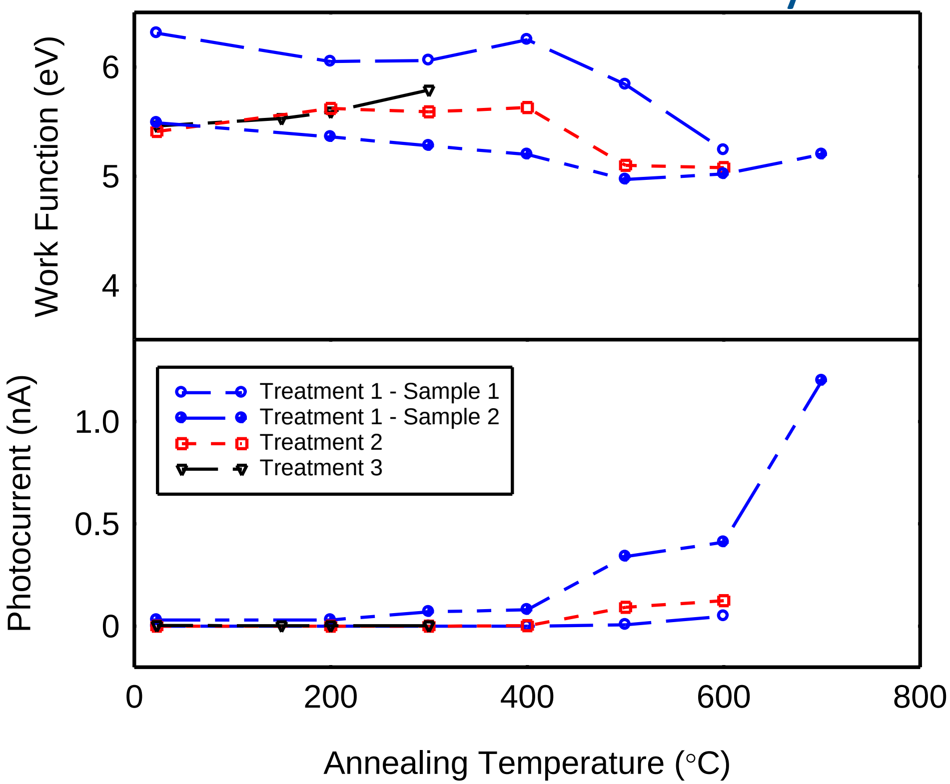
XPS data for 'clean' Ag

- Line positions provide surface composition
- Small shifts in position provide chemical state information



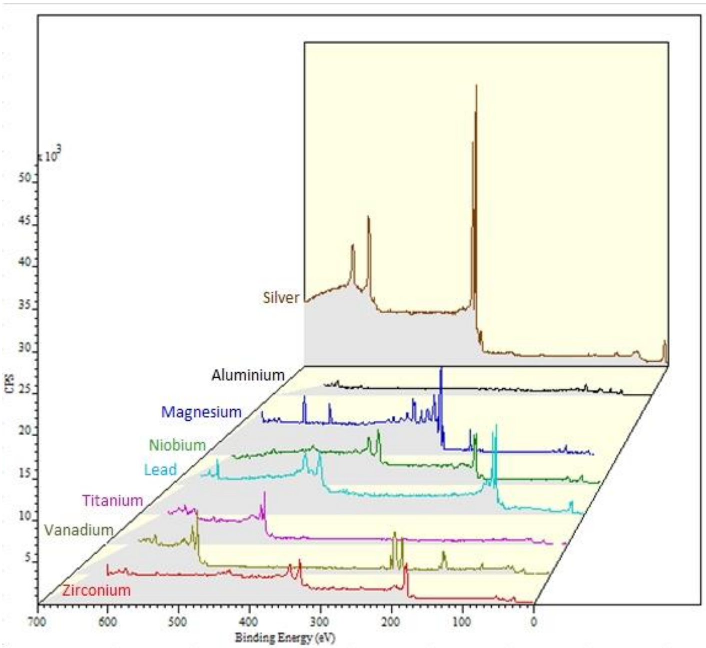
Kelvin Probe Commissioning

Kelvin probe work function measurements for Cu samples oxygen plasma treated with three alternative commercial systems



- Work function measurements will help to explain the effectiveness or other wise of a treatment or coating
- Currently being used on the MPPF instrument

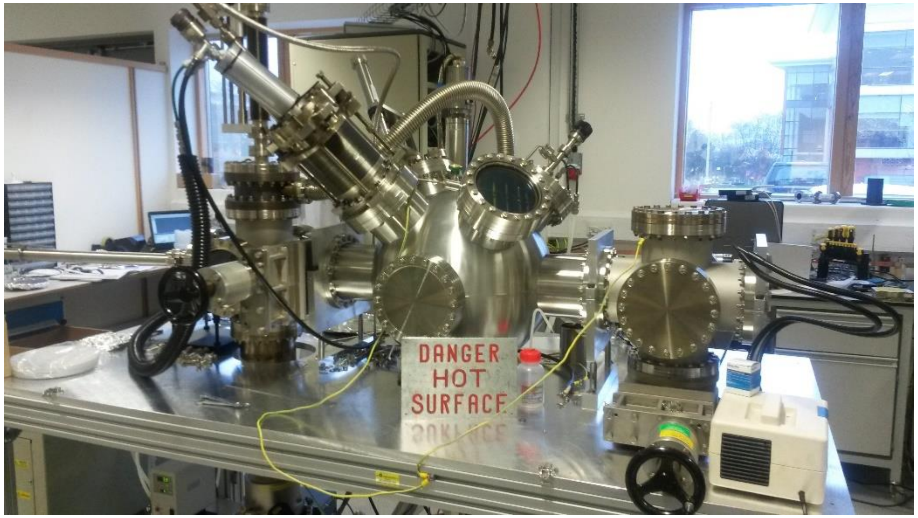
Comparison of Various Bulk Metal Samples



	ϕ (eV)	QE
Ag		
As received	5.09	9E-06
Ion bombarded	5.21	4E-05
After XPS	5.11	5E-05
Heated to 200°	5.06	8E-05
Al		
As received	4.02	1E-05
Ion bombarded	5.00	1E-05
	4.91	2E-05
Mg		
As received		2E-06
Ion bombarded		1E-03
Nb		
As received	5.30	4E-07
Ion bombarded	4.71	2E-04
After XPS	5.36	
Pb		
As received	4.63	2E-05
Ion bombarded		2E-04
Ti		
As received	4.75	0
Ion bombarded	4.47	3E-04
After XPS	4.96	
V		
As received	5.51	1E-06
Ion bombarded	5.00	1E-05
After XPS	5.57	2E-05
Heated to 200°	5.32	1E-05
Zr		
As received		6E-07
Ion bombarded		5E-04

- Bulk samples of various metals cleaned by Ar ion sputtering and annealing
- XPS data used to confirm surface cleanliness
- Along with Mg which gave the best result, Nb, Pb, Ti and Zr all demonstrated higher QE than Cu

Cu and Nb Thin Film Photocathodes



In place of (poly)crystalline metals, can consider also using film deposition

- Metal thin films deposited on silicon substrate by magnetron sputtering
- Cu and Nb thin films have been evaluated

Metal thin film	QE (%)	XPS for sample surfaces (%) O 1s	C 1s	Measured ϕ (eV)
Cu				
Received	1.47E-6	23.5	67.8	5.1435
Heated 250°C	1.14E-4	20.2	61.7	4.914
Repeat	1.17E-4	17.9	62.0	4.68
Nb				
Received	7.75E-7	63.1	25.3	4.3533
Heated 250°C	2.45E-5	61.5	4.3	4.8859
Heated 300°C	5.66E-6	55.8	15.9	5.1401
Ar^+ sputter	2.64E-4	9.6	0	4.7703

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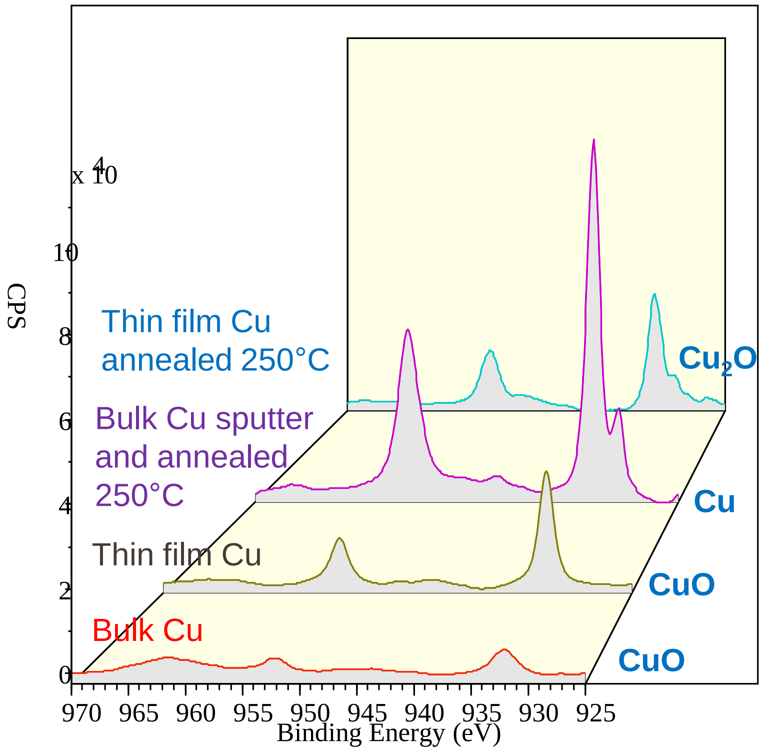
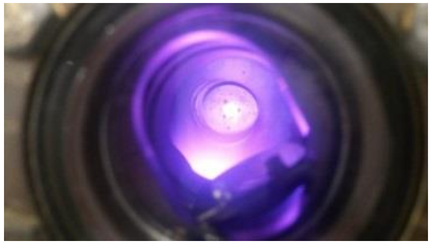
Bulk *versus* Thin Film Copper



Thin film Cu deposition



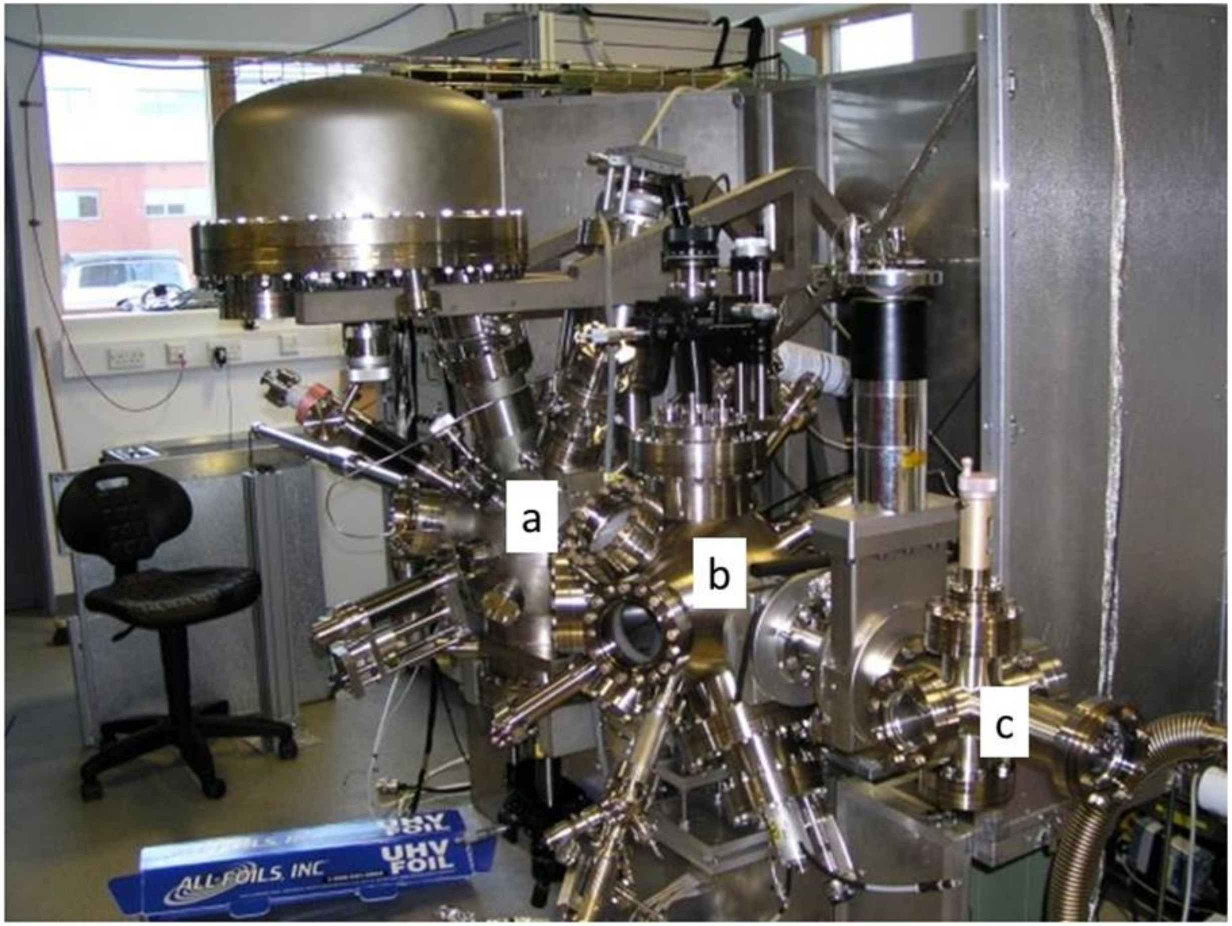
	QE as received	QE after treatment
Bulk	5×10^{-6}	1.7×10^{-5}
Thin Film	1.5×10^{-6}	1.2×10^{-4}

- Untreated bulk and thin film have low *QE*
- Sputtering and annealing bulk sample gives nominally clean Cu with good *QE*
- Annealed thin film has even higher *QE* despite residual Oxigen at the surface (Cu_2O film)

ESCALAB-II based Metal Photocathode Preparation Facility (MPPF)

Upgrade of the VG ESCALAB-II instrument:

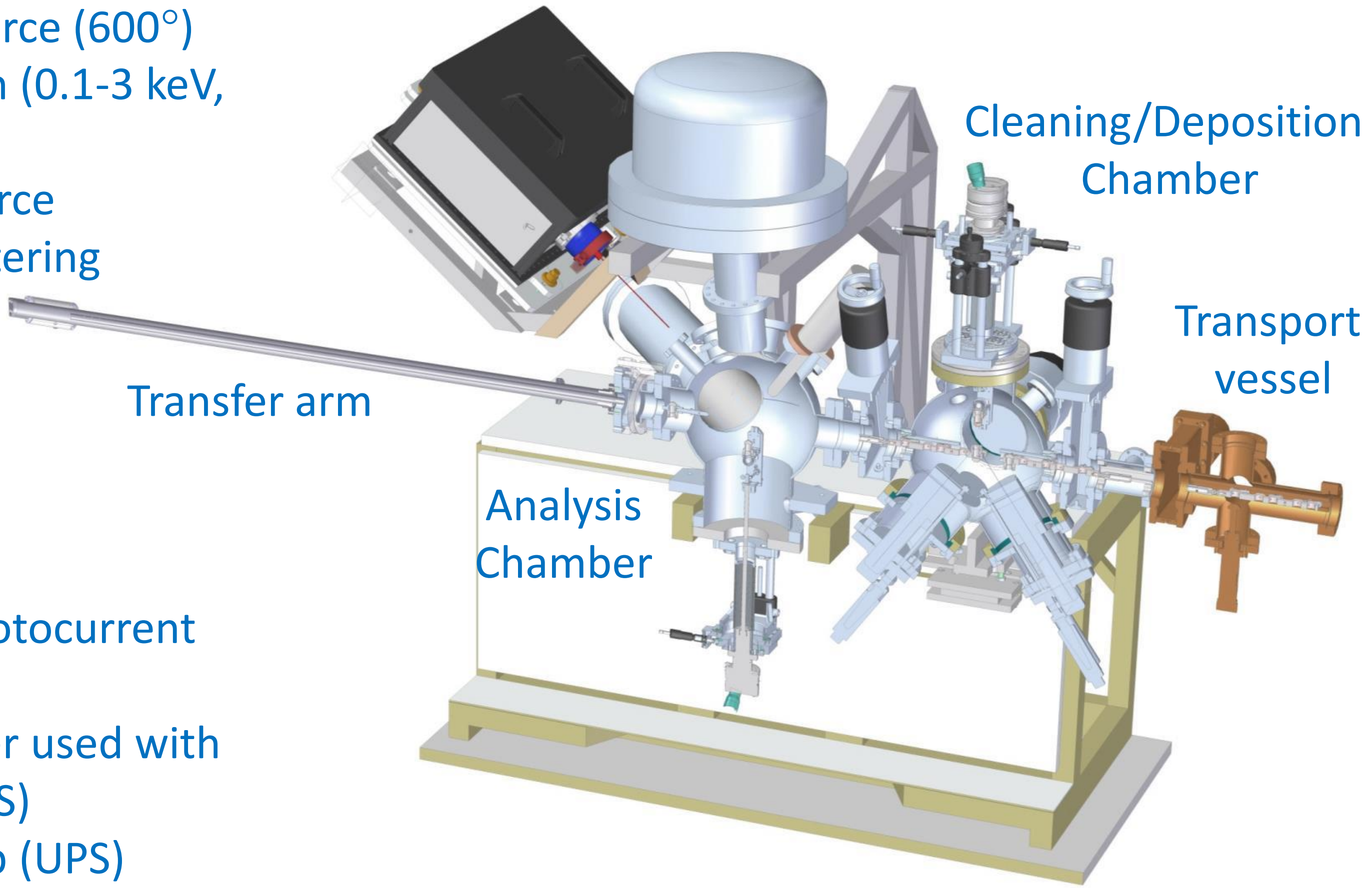
- Replaced vacuum seals to all metal to accommodate UHV requirements
- Replaced pumping system with high performance turbomolecular pumps to reach vacuum of 10^{-10} mbar
- Original loading chamber replaced with a new cleaning/deposition chamber
- UV laser installed for QE characterisation
- Numerous new instruments are installed



Metal Photoacthode Preparation Facility

Cleaning/Deposition Chamber:
- Radiative heating source (600°)
- Argon ion sputter gun (0.1-3 keV, 15 μA)
- Atomic hydrogen source
- Two magnetron sputtering
- sources

Analysis Chamber:
- UV 266 nm CW laser
- Pico-ammeter for photocurrent measurement
- Electron spectrometer used with
  - X-ray source (XPS)
  - Ultra-violet lamp (UPS)



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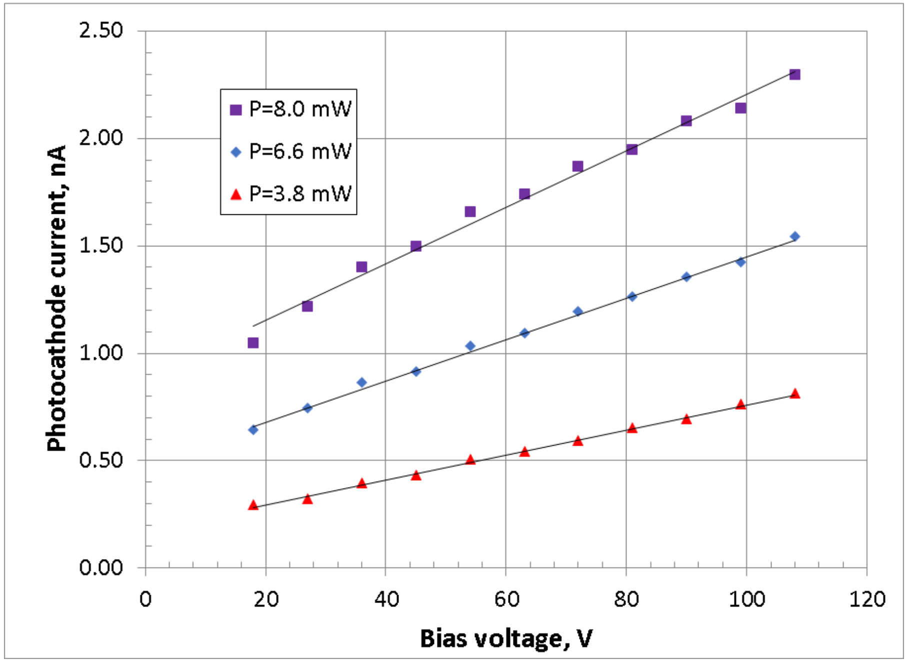
Activation of Mo sample in MPPF



Activation procedure:

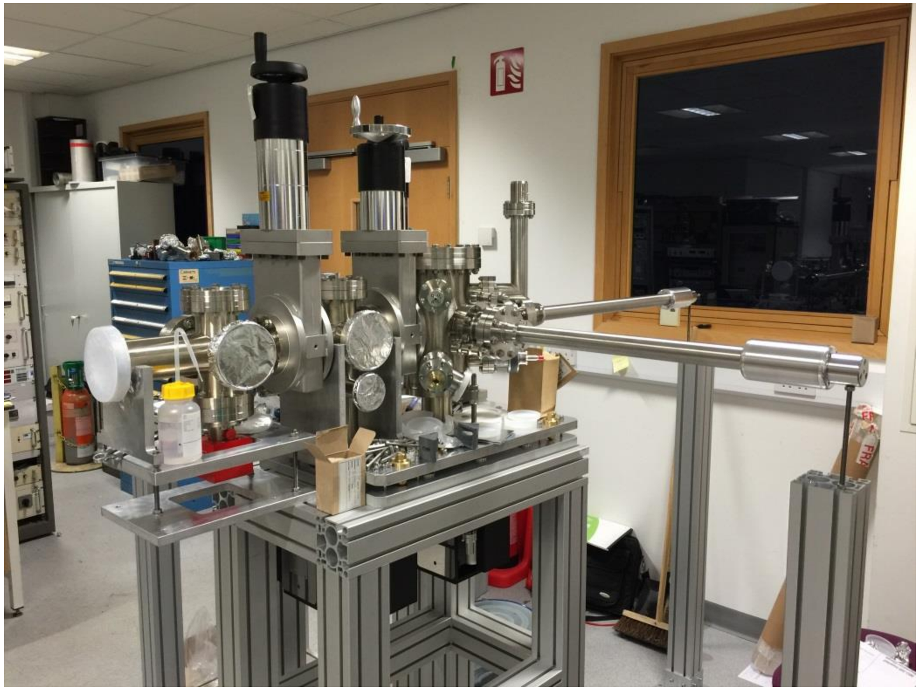
- Ar ion bombardment
- Annealing

$QE > 1.5 \cdot 10^{-6}$

Unknowns:

- Laser power calibration
- Linear current dependence on bias voltage

Photocathode transport to the electron source



In air Load-Lock system commissioning. Transport of the photocathode into the “mock” gun socket

First assembly of the Load-Lock system and the Transport Vessel

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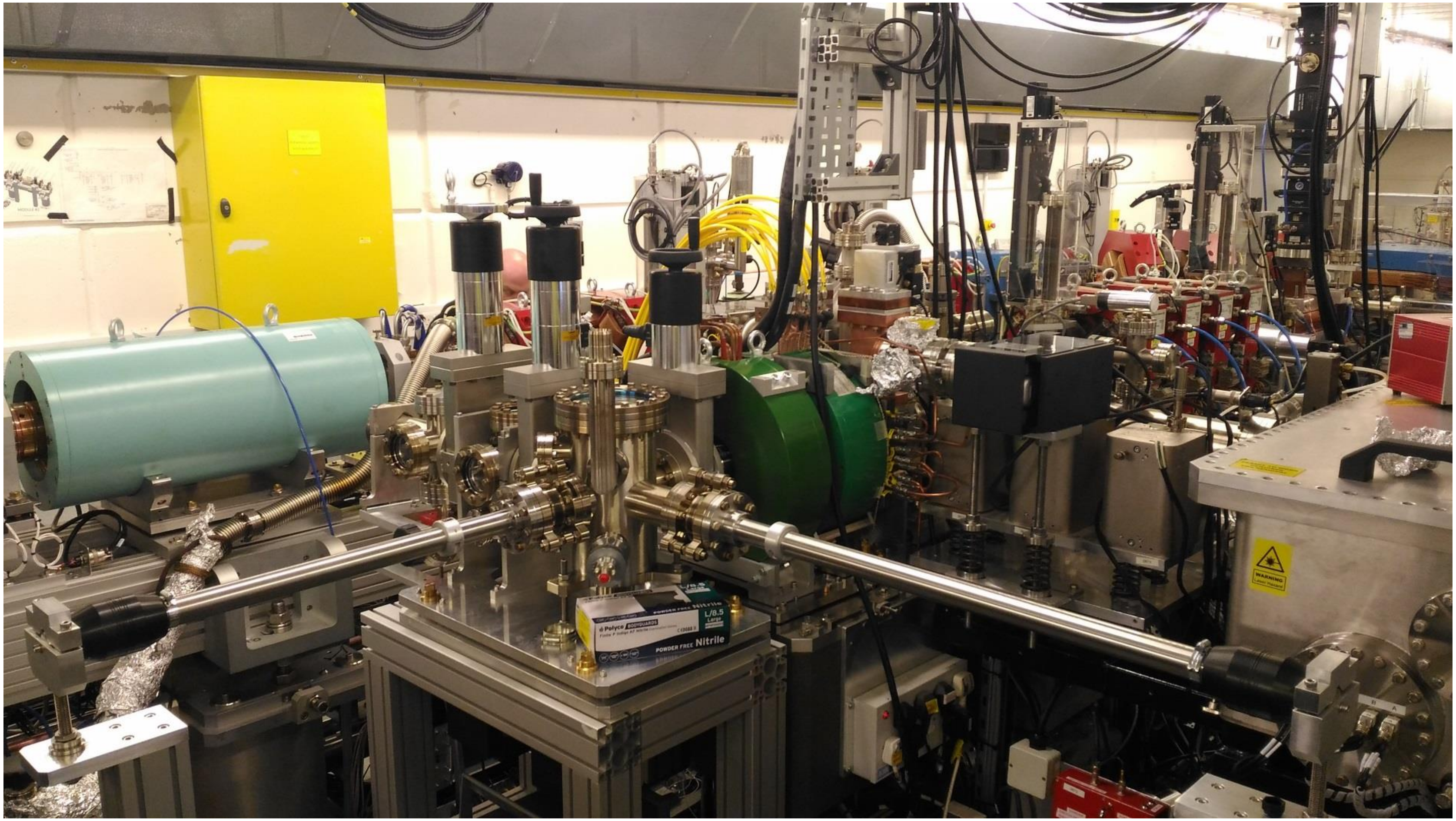
Photocathode Load-Lock system and HRRG in VELA beamline



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Major achievements in 2016-2017

- Surface Analysis for Photocathodes Instrument commissioned and first results are published
- Metal Photocathode Preparation System commissioned. First Mo photocathode prepared for HRRG first beam experiments
- Photocathode Transport Vessel commissioned and first photocathodes are ready for transfering to HRRG
- High Repetition Rate Gun commissioned and installed in VELA beam line
- Photocathode Load-Lock system commissioned and installed at HRRG
- Upgrade of the 2.5 cell gun is in progress to make it compatible with CLRA photocathode plugs in order to continue photocathode experiments in VELA beam line after migration of HRRG to CLARA

Future plans and perspectives

To evaluate different photocathode materials in Transverse Energy Spread Spectrometer and real accelerator environment in VELA beam line to characterise the following parameters:

- Quantum Efficiency
- Transverse Energy Spread on TESS
- Emittance and response time in VELA beamline

The following materials are planed to investigate:

- Metal single crystal and polycrystalline materials
- Metal thin films
- Oxide film coated metal photocathodes
- Alkali photocathodes (Te and Sb based)

Publications in 2015-2017

- S. Mistry, M. Cropper, R. Valizadeh, L.B. Jones, K.J. Middleman, A.N. Hannah, B.L. Militsyn and T.C.Q Noakes, "A Comparison of Surface Properties of Metallic Thin Film Photocathodes", Proc. of IPAC2016,3691-3694(2016)
- S. Mistry, M. Cropper, R. Valizadeh, K.J. Middleman, A.N. Hannah, B.L. Militsyn and T.C.Q. Noakes, "Preparation of polycrystalline and thin film metal photocathodes for normal conducting RF guns", Proc. of IPAC2015, 1759-1761(2015)
- Sonal Mistry – PhD thesis in preparation

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