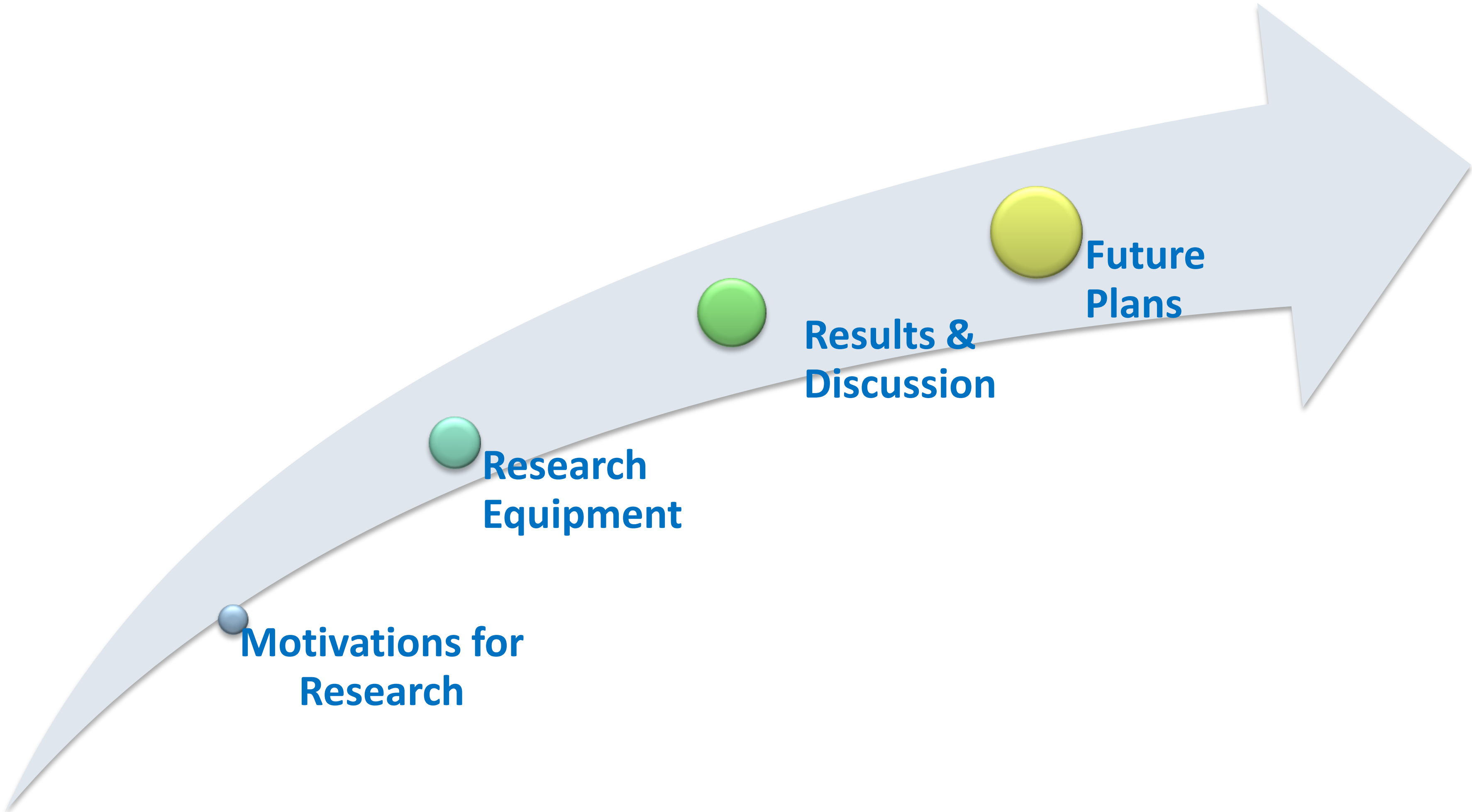
Photocathode Research using Facilities at Daresbury Laboratory: Progress Report

Sonal Mistry

Loughborough University, STFC ASTeC

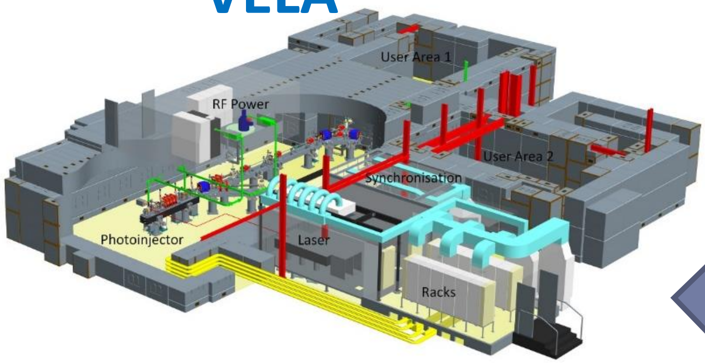
EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

Overview


Motivations for Research
Research Equipment
Results & Discussion
Future Plans

Motivations

VELA

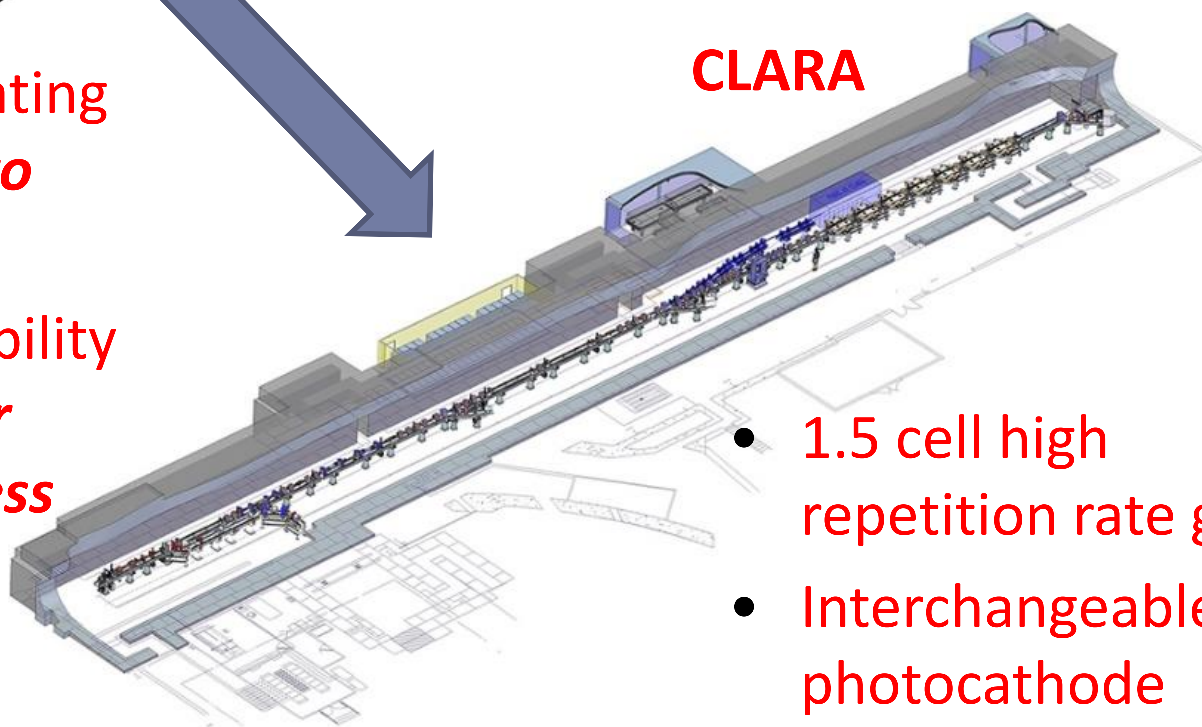


- Photoinjector consists of 2.5 cell S-band RF gun
- Cu photocathode:

Quantum Efficiency = 1 x 10^{-5}

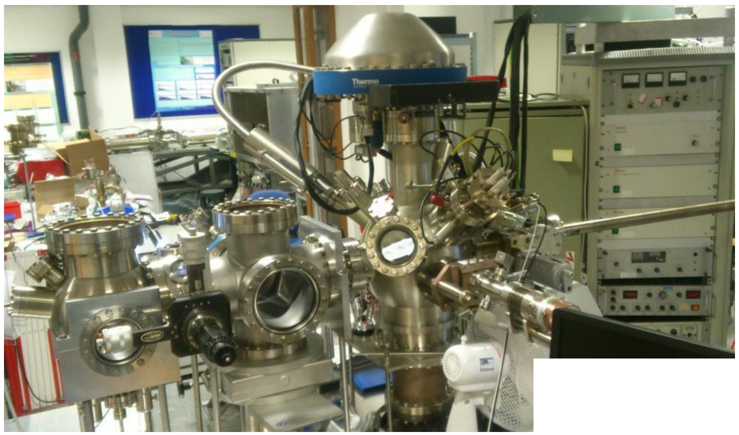
- Interest in investigating ***alternative metal to copper***
- Investigate applicability of metals to ***deliver ultra high brightness beams***

CLARA

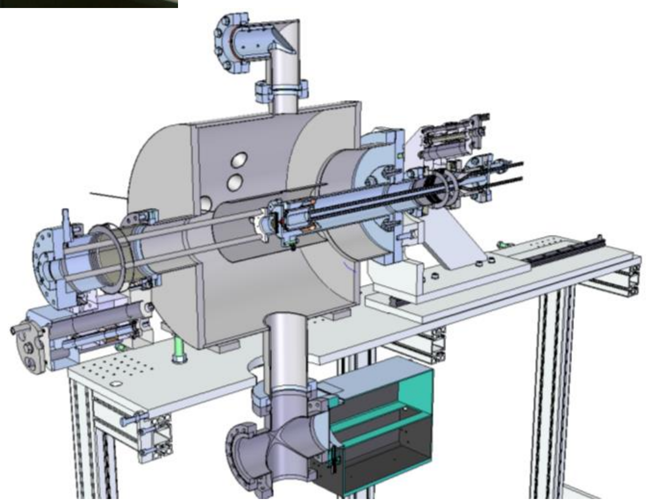


- 1.5 cell high repetition rate gun
- Interchangeable photocathode

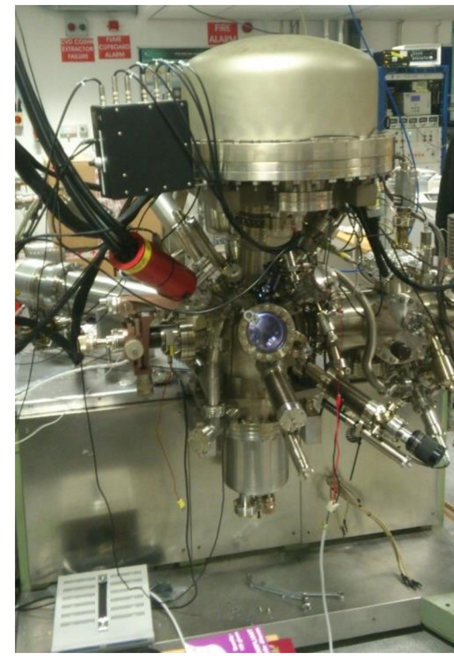
Photocathode Research Equipment



SAPI - Surface Analysis/Preparation Installation



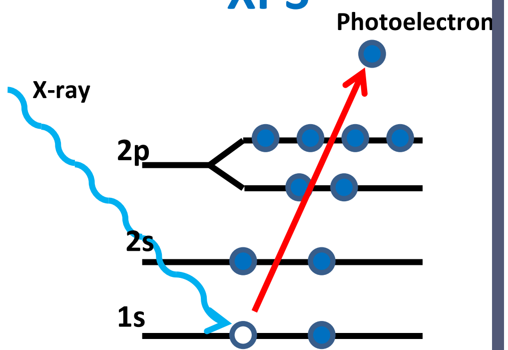
TESS – Transverse Electron Energy Spread spectrometer

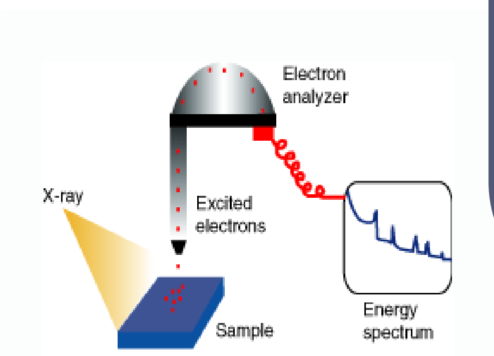


ESCALAB-II – Surface analysis facility

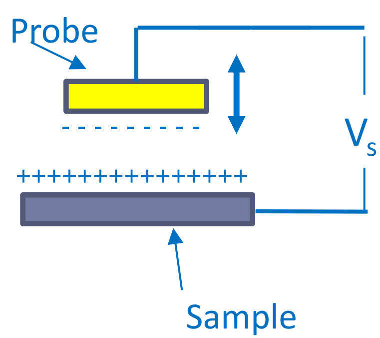
Photocathode Research Techniques

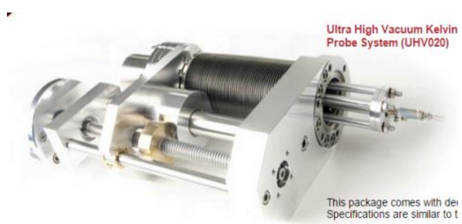
XPS



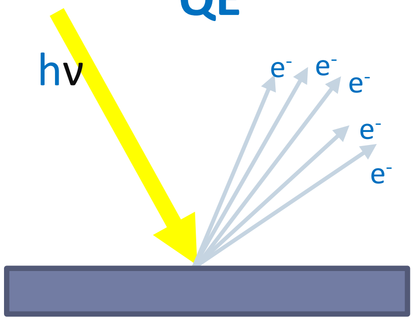


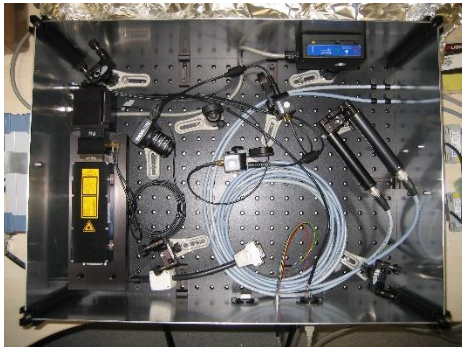
Kelvin Probe





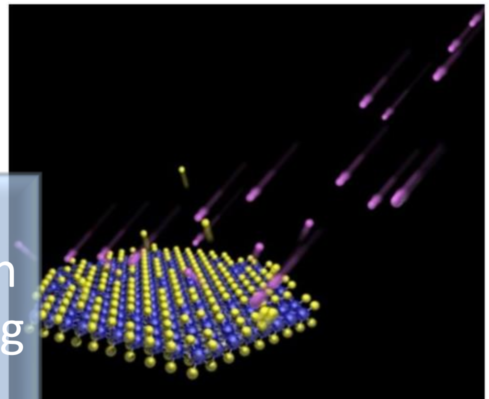
QE



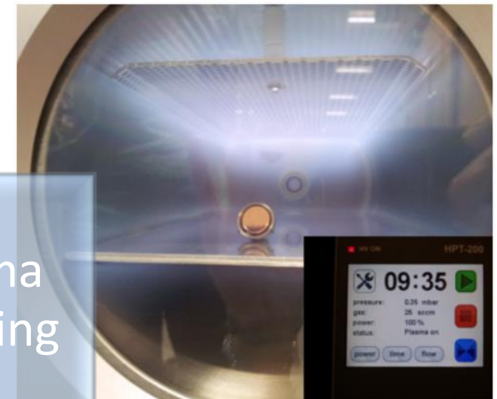


Photocathode Research Techniques

Argon Ion Sputtering



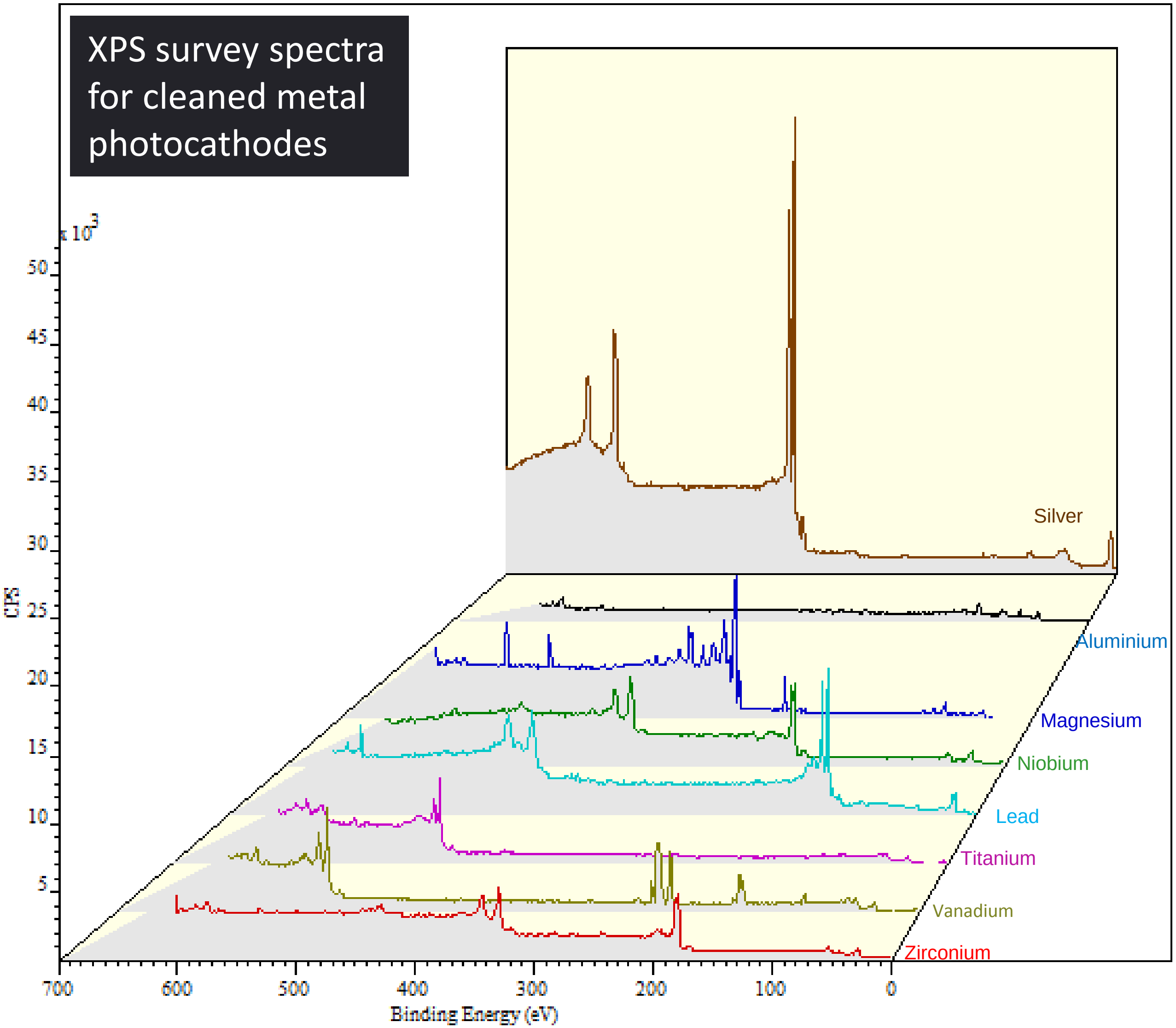
Plasma Cleaning



Annealing

Experimental Procedure

XPS survey spectra for cleaned metal photocathodes



1st Experiment Aim:
To identify metal photocathodes with reasonable QE

A survey of a 10 bulk metals, chosen because:

- **Widely used in photoinjectors**
- **Low work function**
- **Vacuum compatibility**

Results: Ar^+ sputter

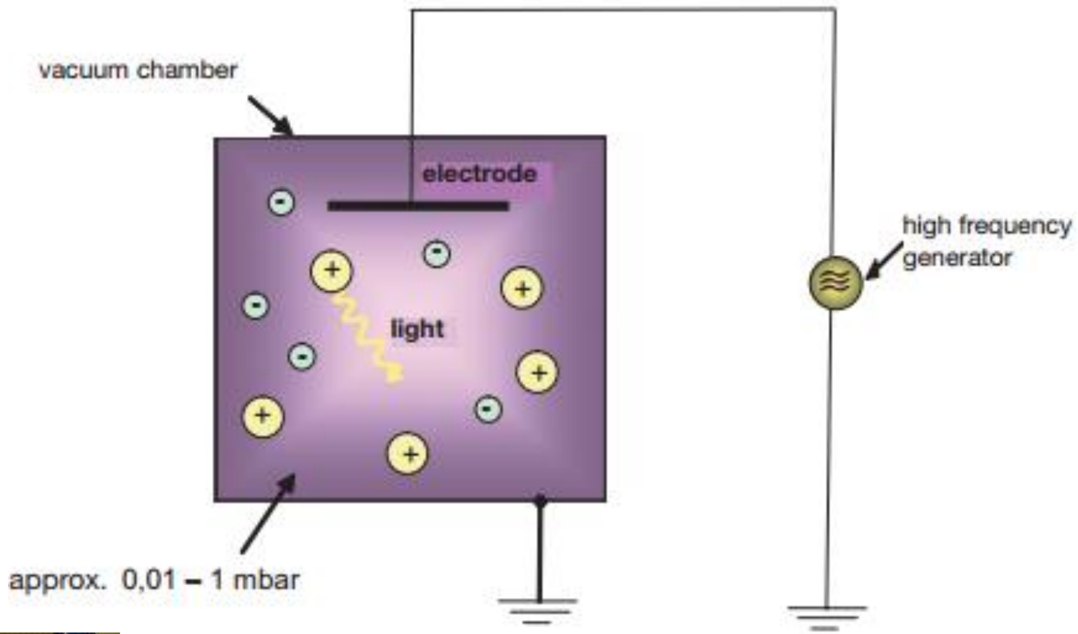
Metal	QE (%)	XPS for sample surface(%) O 1s	C 1s	Work Function (eV)
Al				
Received	9.5E-6	36.8	38.3	4.0
Ar^+ sputter	2.2E-5	13.4	17.4	4.9
Ag				
Received	8.5E-6	0	59.4	5.1
Ar^+ sputter	5.1E-5	0	0	5.1
Cu				
Received	5.0E-6	32.9	66.2	5.4
Ar^+ sputter	1.1E-5	0	0	5.3
Mg				
Received	6.0E-6	35.2	52.3	3.4
Ar^+ sputter	**1.7E-3**	40.0	0	3.4
Mo				
Received	1.47E-7	24.2	64.9	5.1
Ar^+ sputter	2.48E-6	7.8	17.8	5.2

Metal	QE (%)	XPS for sample surface (%) O 1s	C 1s	Work Function (eV)
Nb				
Received	3.9E-7	47.8	48.6	5.3
Ar^+ sputter	**1.9E-4**	16.2	21.0	4.7
Pb				
Received	2.9E-5	43.9	34.8	4.6
Ar^+ sputter	**2.4E-4**	0	0	4.7
Ti				
Received	0	39.2	53.6	4.7
Ar^+ sputter	**3.3E-4**	14.6	16.8	4.5
V				
Received	1.4E-6	45.7	45.9	5.5
Ar^+ sputter	2.2E-5	25.0	0	5.0
Zr				
Received	3.88E-6	48.4	44.1	4.4
Ar^+ sputter	**2.89E-4**	14.4	0	4.3

O_2 plasma cleaning and post annealing

VELA Cu photocathode prepared by:

- **O_2 plasma cleaning**
  - Removes carbon
  - Leaves thin oxygen layer
- **Annealing**
  - Oxygen dissolves into bulk



Second experiment applies this cleaning procedure to the metals identified in the first experiment.

Results: O_2 plasma cleaning

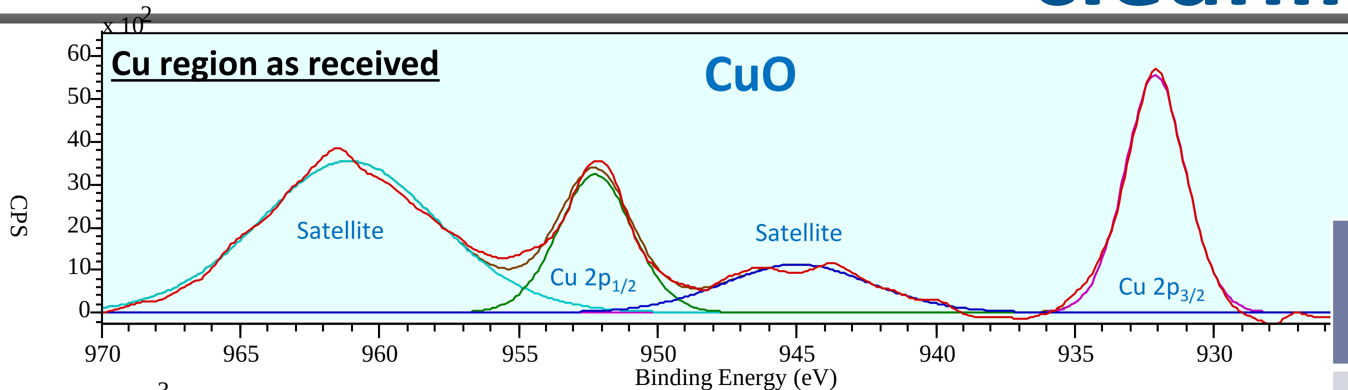
Measurements for Ti, Zr, Mg, Cu, Nb, Pb:

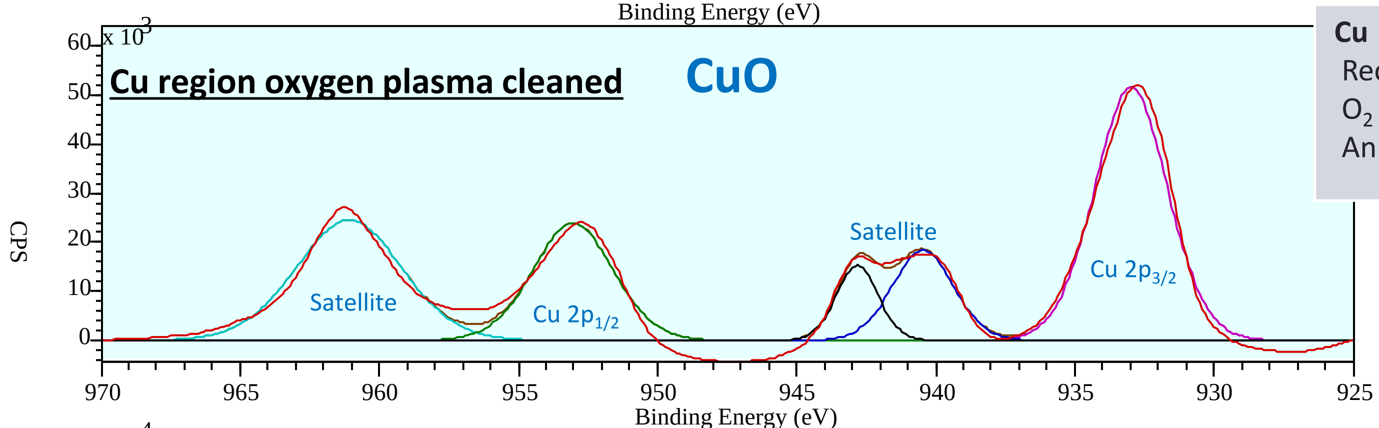
- O_2 Plasma Cleaned for 20 minutes
- Annealed

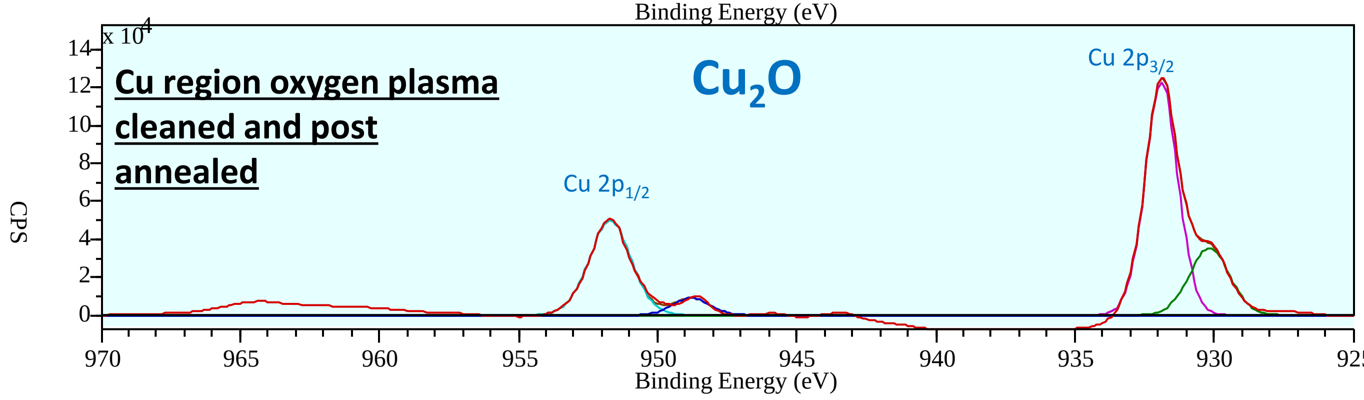
Metal	QE (%)	XPS for sample surfaces (%) O 1s	XPS for sample surfaces (%) C 1s	Work Function (eV)
Ti				
O_2 plasma	0	87.1	5.1	5.8
Anneal 250°C (0.5 hr)	6.32E-5	88.3	4.5	4.5
Anneal 250C (24 hr)	1.16E-4	79.9	9.0	4.3
Zr				
O_2 plasma	3.82E-7	78.4	12.4	4.9
Anneal 250°C (0.5 hr)	6.94E-5	83.5	3.9	4.3
Anneal 250°C (24 hr)	1.35E-4	74.6	9.8	4.8
Mg				
O_2 plasma	3.82E-7	83.5	3.2	4.4
Anneal 200°C (0.5 hr)	2.40E-5	76.8	3.5	3.9
Anneal 200°C (4 hr)	4.90E-5	67.8	9.4	3.7
Anneal 200°C (24 hr)	7.09E-5	66.7	3.8	3.6

Metal	QE	XPS for sample surfaces (%) O 1s	XPS for sample surfaces (%) C 1s	Work Function (eV)
Cu				
O_2 plasma	0	80.1	3.1	5.7
Anneal 250°C (0.5 hr)	1.6E-4	76.7	6.5	5.7
Nb				
O_2 plasma	5.21E-7	87.5	5.7	5.7
Anneal 300°C (0.5 hr)	1.34E-4	80.2	6.3	4.5
Pb				
O_2 plasma	3.47E-7	82.1	7.1	5.6
Anneal 160°C (0.5 hr)	6.94E-6	77.9	10.9	4.3
Anneal 200°C (0.5 hr)	1.67E-5	77.8	9.9	4.5

Results: O_2 plasma cleaning







Metal	QE	XPS (%) O 1s	XPS (%) C 1s
Cu			
Received	4.2E-6	40.4	59.0
O_2 plasma	0	80.1	3.1
Anneal 250°C	1.6E-4	76.7	6.5

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Results: Ar plasma cleaned

- Argon plasma treatment is **just as effective in removing C 1s** from the sample surfaces
- QE obtained for oxygen plasma treatment and post anneal is greater than that obtained with argon plasma treatment for all samples

Argon Plasma

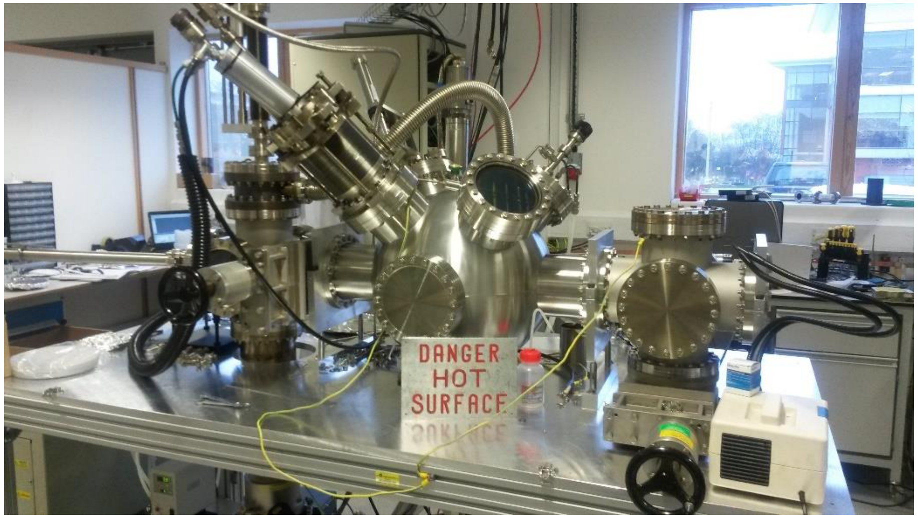
Metal	QE	XPS (%) O 1s	XPS (%) C 1s	Work Function (eV)
Cu				
Received	4.2E-6	40.4	59.0	5.1
Ar plasma	2.1E-7	84.0	4.0	5.4
Anneal 250°C ½ hrs	5.6E-5	78.9	4.4	4.7
Nb				
Received	5.9E-7	39.9	55.2	4.8
Ar plasma	3.5E-8	89.3	3.3	5.3
Anneal 300°C ½ hrs	5.9E-5	80.8	5.0	4.3

Oxygen Plasma

Metal	QE	XPS (%) O 1s	XPS (%) C 1s	Work Function (eV)
Cu				
Received	4.2E-6	40.4	59.0	5.1
O_2 plasma	0	80.1	3.1	5.7
Anneal 250°C ½ hrs	1.6E-4	76.7	6.5	5.7
Nb				
Received	5.9E-7	39.9	55.2	4.8
O_2 plasma	5.2E-7	87.5	5.7	5.7
Anneal 300°C ½ hrs	1.3E-4	80.2	6.3	4.5

EuCARD²

Thin Films Photocathodes



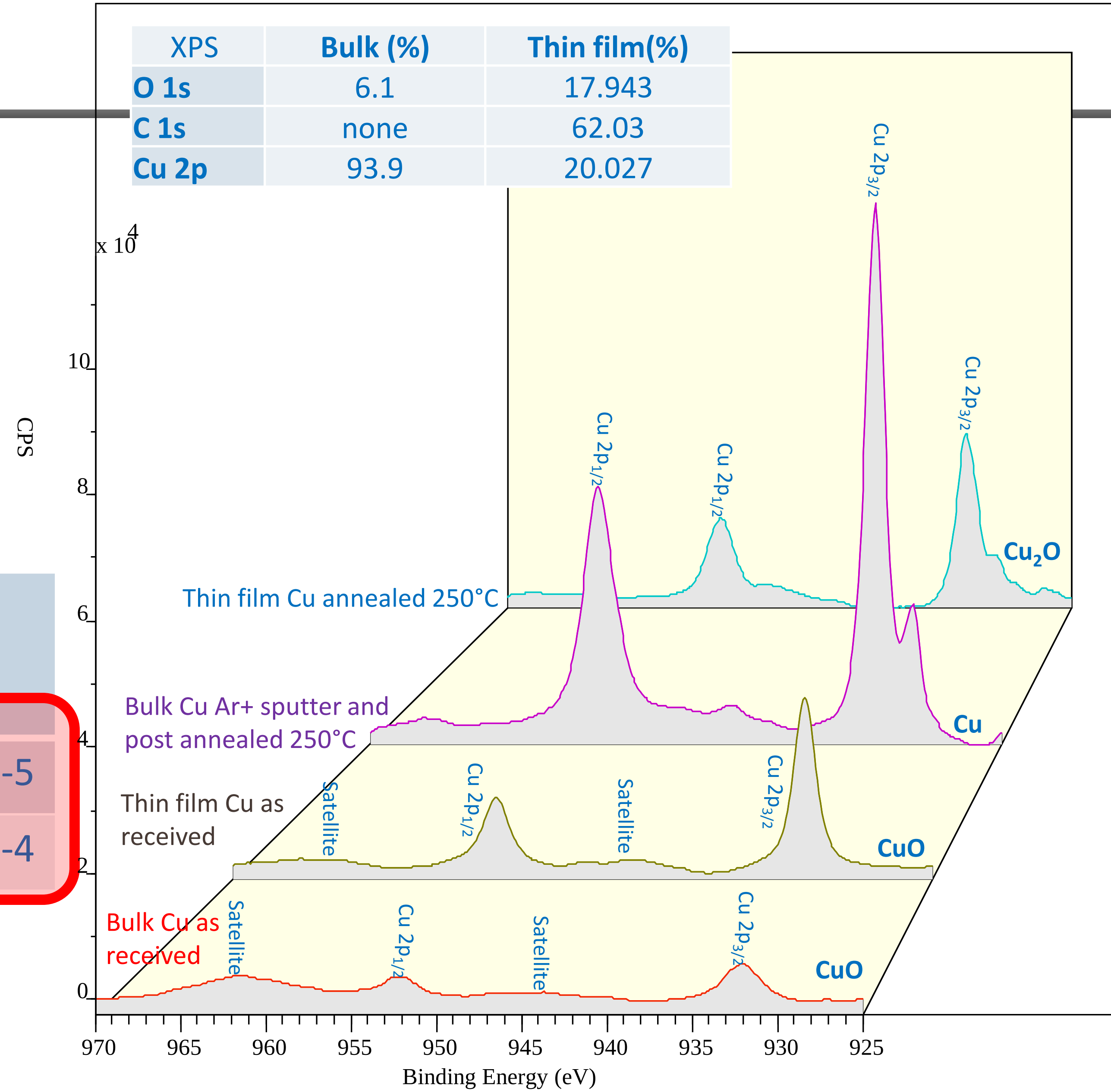
Along with polycrystalline metals, can consider also using film deposition

- Metal thin films deposited on silicon substrate by magnetron sputtering
- So far only Cu and Nb thin films have been produced (µm)

Metal thin film	QE (%)	XPS for sample surfaces (%)		Measured ϕ (eV)
		O 1s	C 1s	
Cu				
Received	1.47E-6	23.5	67.8	5.1
Heated 250°C	1.14E-4	20.2	61.7	4.9
Repeat	1.17E-4	17.9	62.0	4.7
Nb				
Received	7.75E-7	63.1	25.3	4.4
Heated 250°C	2.45E-5	61.5	4.3	4.9
Heated 300°C	5.66E-6	55.8	15.9	5.1
Ar^+ sputter	2.64E-4	9.6	0	4.8

Cu thin film compared with bulk

XPS	Bulk (%)	Thin film(%)
O 1s	6.1	17.943
C 1s	none	62.03
Cu 2p	93.9	20.027

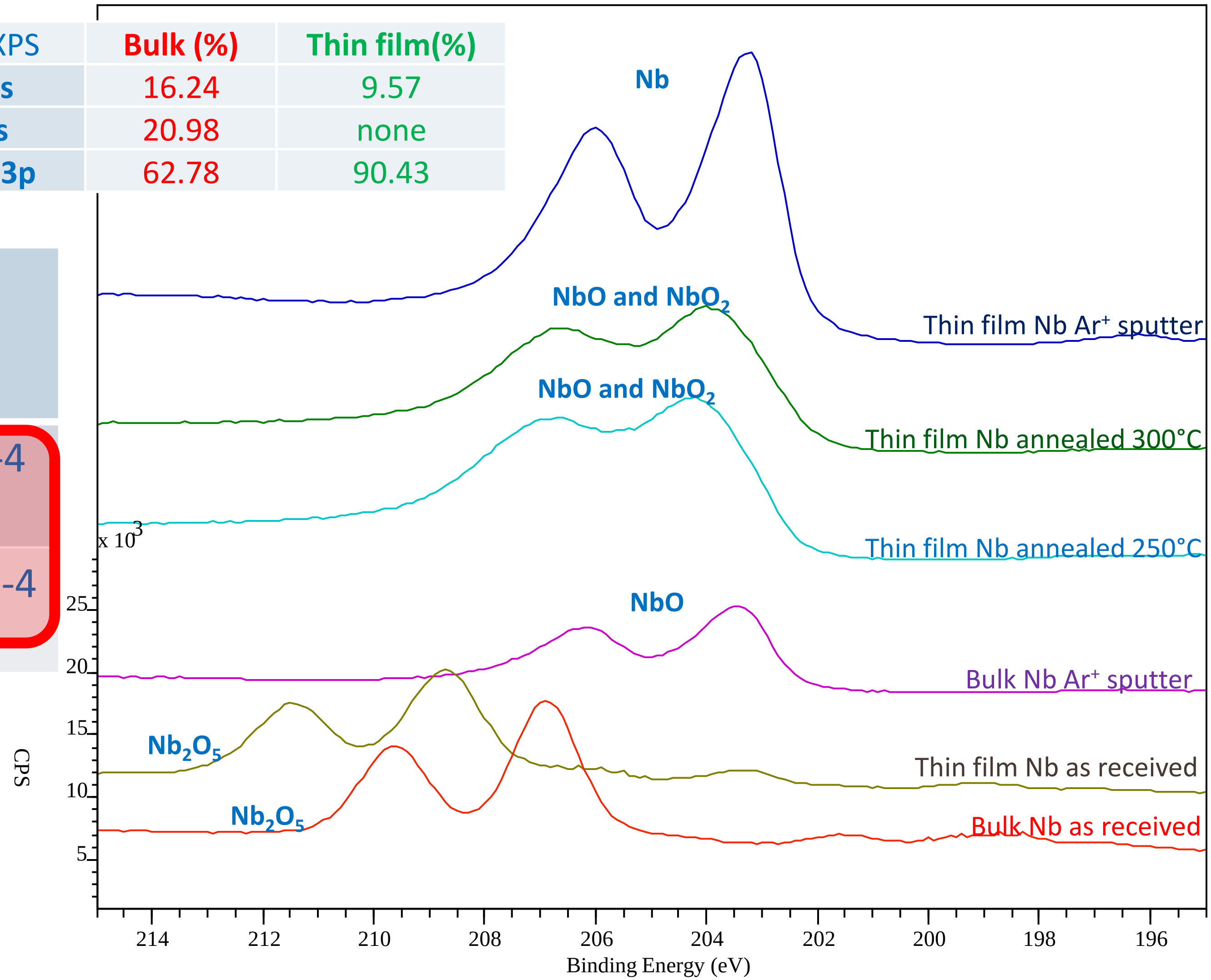


	Work function (eV)	QE
Bulk	5.234	1.70E-5
Thin Film	4.68	1.17E-4

Nb thin film compared with bulk

XPS	Bulk (%)	Thin film(%)
O 1s	16.24	9.57
C 1s	20.98	none
Nb 3p	62.78	90.43

	Work function (eV)	QE (%)
Bulk	4.7	1.9E-4
Thin Film	4.8	2.64E-4



EuCARD²

Future Plans

Produce and investigate **metal thin film** photocathodes

Investigate single crystal photocathodes (Cu and others**)**

Modify ESCALAB-II to accept **DESY/INFN** plug based photocathodes

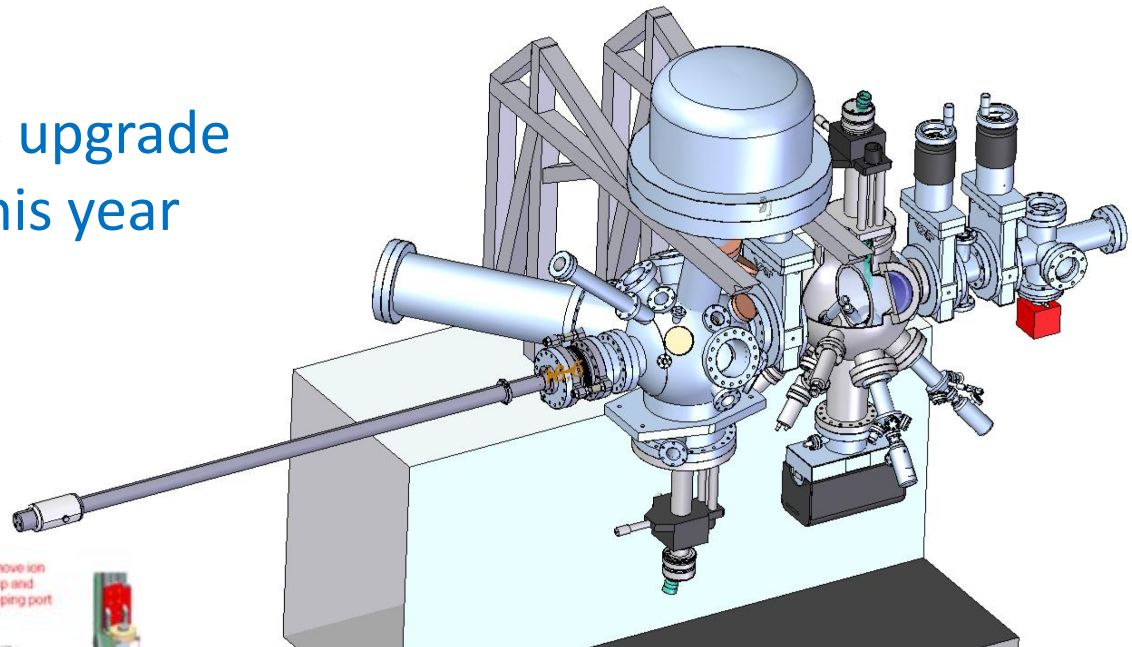
Transverse and longitudinal energy spread measurements from metal photocathodes

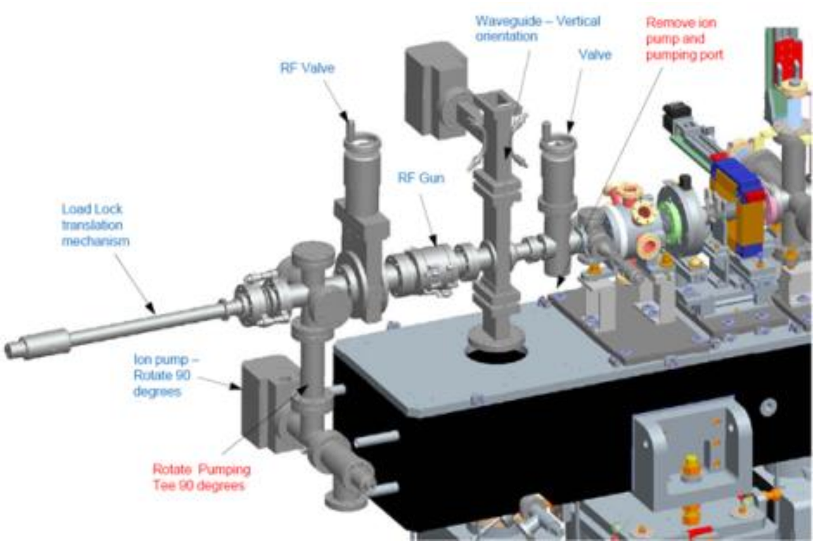
Test metal photocathodes in **VELA/CLARA**

Future Plans

ESCALAB upgrade
later this year

DESY / INFN puck design





High repetition rate gun
with photocathode transfer
facility to be commissioned
2016

Conclusions

- **New results for O_2 and Ar plasma cleaned photocathodes**
- **Preliminary results for Cu and Nb thin film photocathodes**
- **Progress with design work for ESCALAB upgrade**
- **Commissioning of High Repetition Rate gun in February 2016**

For Further Information: -
DELIVERABLE REPORT: 12.4, *'SCIENTIFIC REPORT ON PHOTOCATHODE R&D'*
MILESTONE REPORT: MS75, *'INVESTIGATION OF QUANTUM YIELD AND ENERGY SPECTRUM OF THE ELECTRONS, EMITTED FROM THE METAL PHOTOCATHODE'*

Acknowledgements

STFC ASTeC

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Ryan Cash and Barry Fell

Loughborough University

Mike Cropper

Thank you for listening!

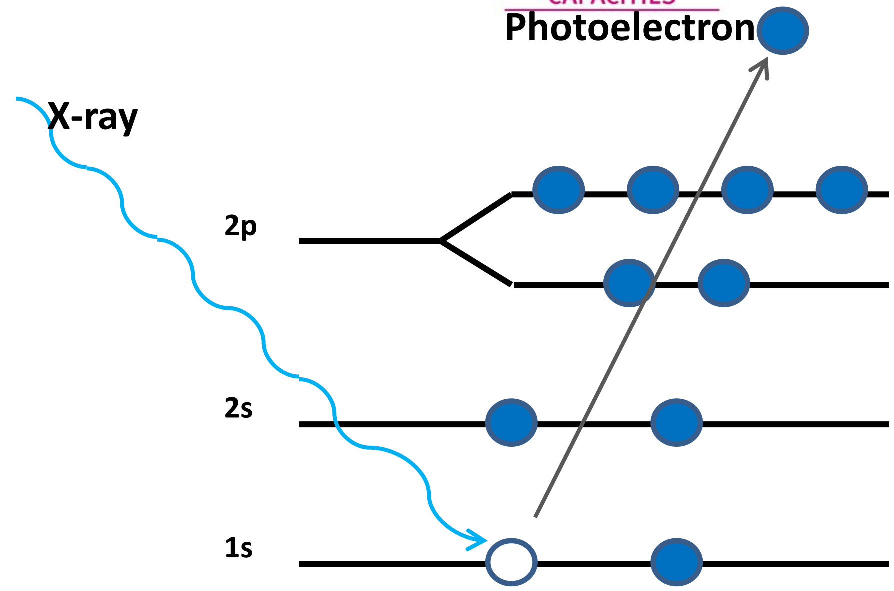
XPS

XPS process:

- Sample surface illuminated with X-Rays
- X-Rays absorbed within 10 nm of sample
- Core level electrons are emitted
- Measure E_k of photoelectrons
- Corresponding E_b is deduced:

$$E_k = h\nu - E_b - \phi_s$$

Kinetic Energy — X-Ray Energy — Binding Energy — Spectrometer work function



- E_b for core level electrons are unique for each chemical species
- Therefore spectrum represents surface composition

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Kelvin Probe

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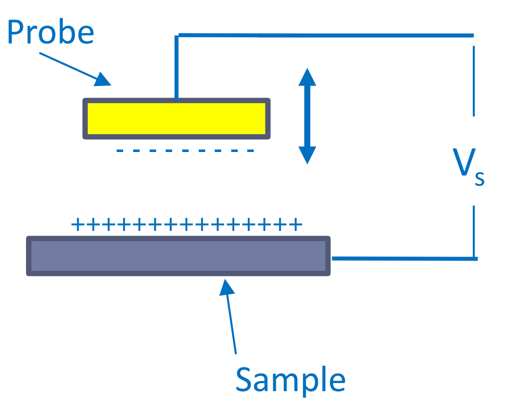
CAPACITIES

- Probe set to vibrate upon close contact with sample surface

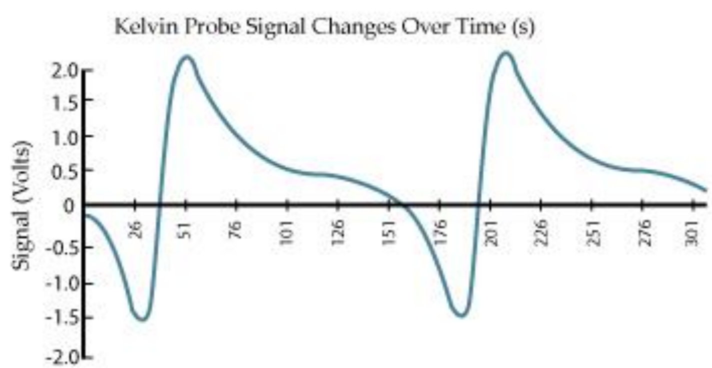
$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d}$$

- As d varies, so does C



$$eV_{CPD} = \phi_{probe} - \phi_{sample}$$

- Result is a periodic flow of charge around the circuit, and thus a varying voltage
- Output signal is periodic (V_s)

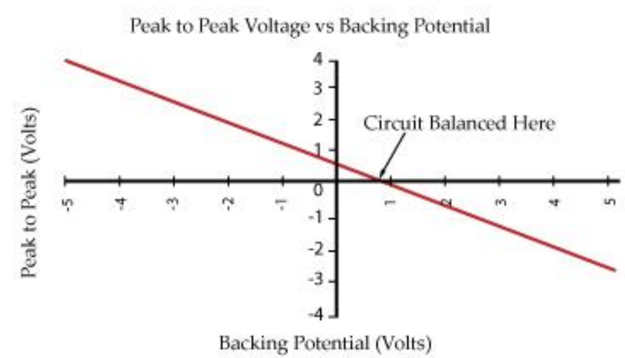


$$V_{ptp} = k(V_{CPD} + V_b)$$

Peak to peak voltgae

Externally applied backing potential

- V_b is set to a range of potentials and a plot of V_{ptp} verses V_b is made.
- When $V_{ptp} = 0$ the V_{CPD} of the surface is equal and opposite to V_b.



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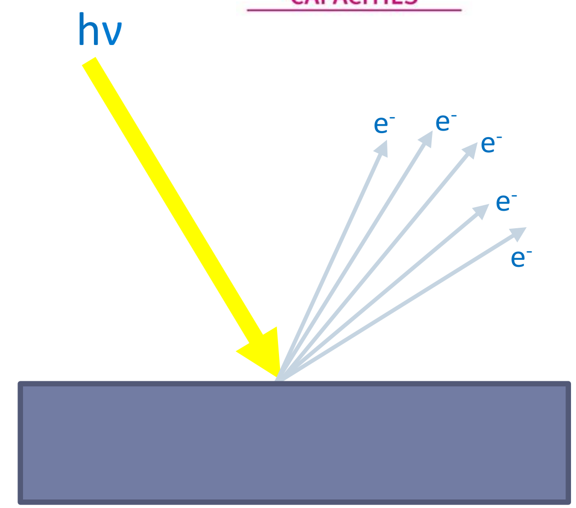
QE

- QE is the average photoelectric yield per incident photon.

- QE measurements comprise
  - a LED source giving 265 nm (4.65 eV) light and a pico-ammeter to measure drain current.
  - a UV LASER source which offers higher intensity at 266 nm
  - Photodiode used to measure LED power

- QE suggests how much current can be extracted from a cathode and as such is an indication of the potential beam current.

- This property is unique to each photocathode material and is a function of the laser wavelength and the photocurrent produced.



$$QE = \frac{Ihc}{\lambda eP} \times 100\%$$

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