VUV Spectroscopic Ellipsometry and Internal Photoemission Characterization of Combinatory High-K Dielectrics and Metals

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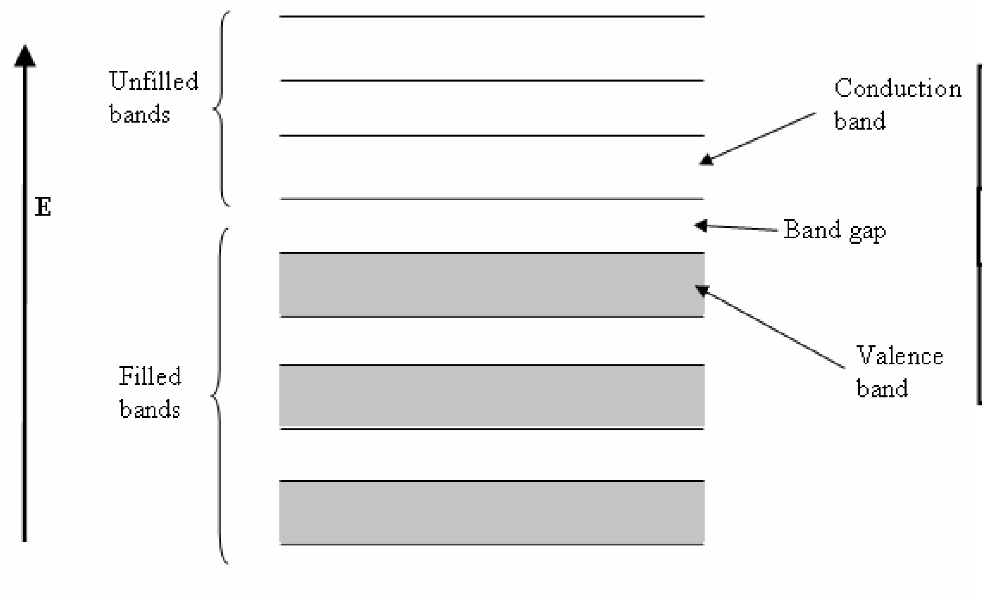
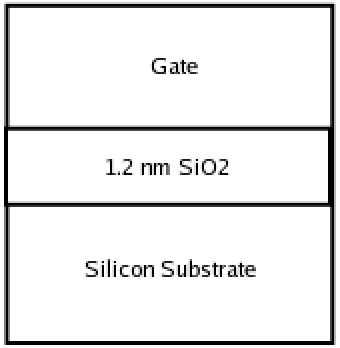
SPS

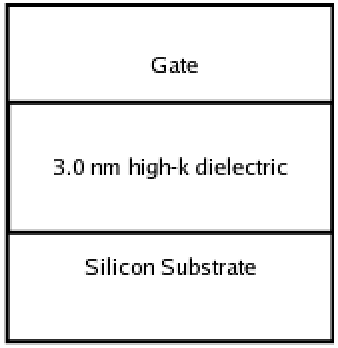
Semiconductors

$$C \propto \frac{\kappa}{d}$$





Existing 90 nm Process
Capacitance = 1 x
Leakage Current = 1 x



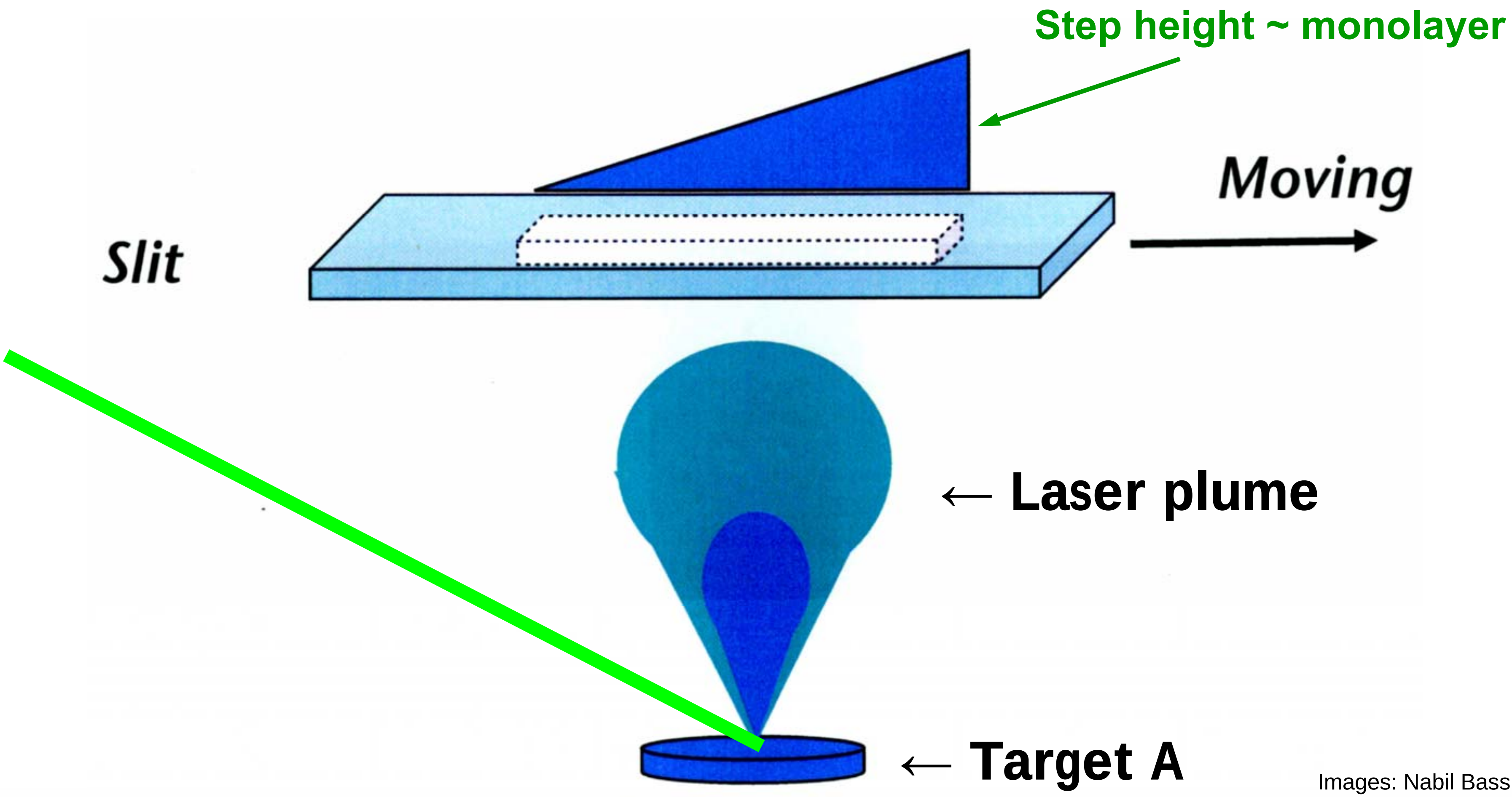
A potential high-k process
Capacitance = 1.6 x
Leakage Current = 0.01 x

1.2nm=~4 atomic layers

Motivation

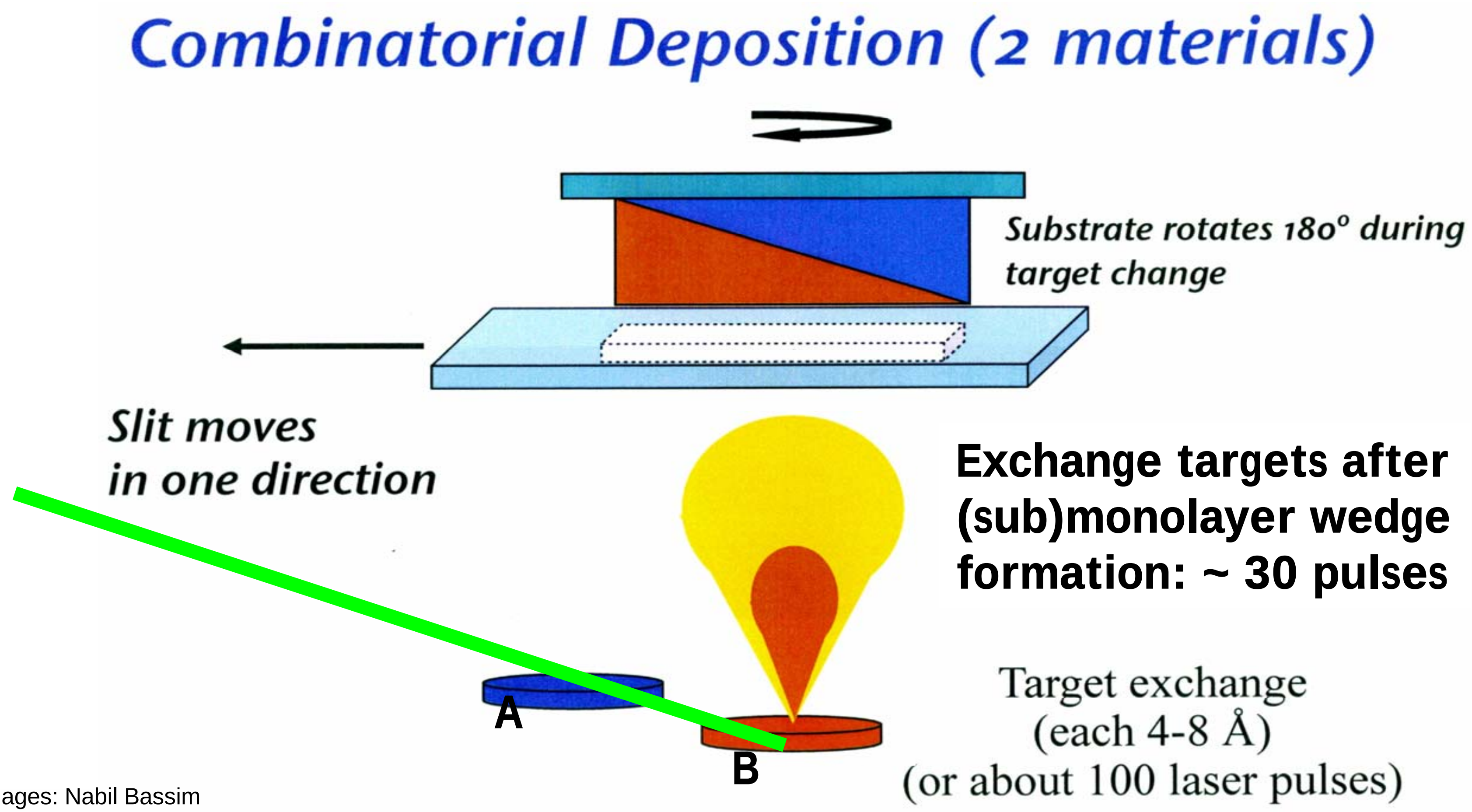
- Spectroscopic Ellipsometry
  - Determine the Optical Properties of combi-film grown by PLD
- Internal Photoemission
  - Determine Barrier Height between film and magnetron sputtering

Compositional Gradient:
Pulsed Laser Deposition (PLD)



Images: Nabil Bassim

Compositional Gradient:
Pulsed Laser Deposition (PLD)



Combinatorial Deposition (2 materials)

Substrate rotates 180° during target change

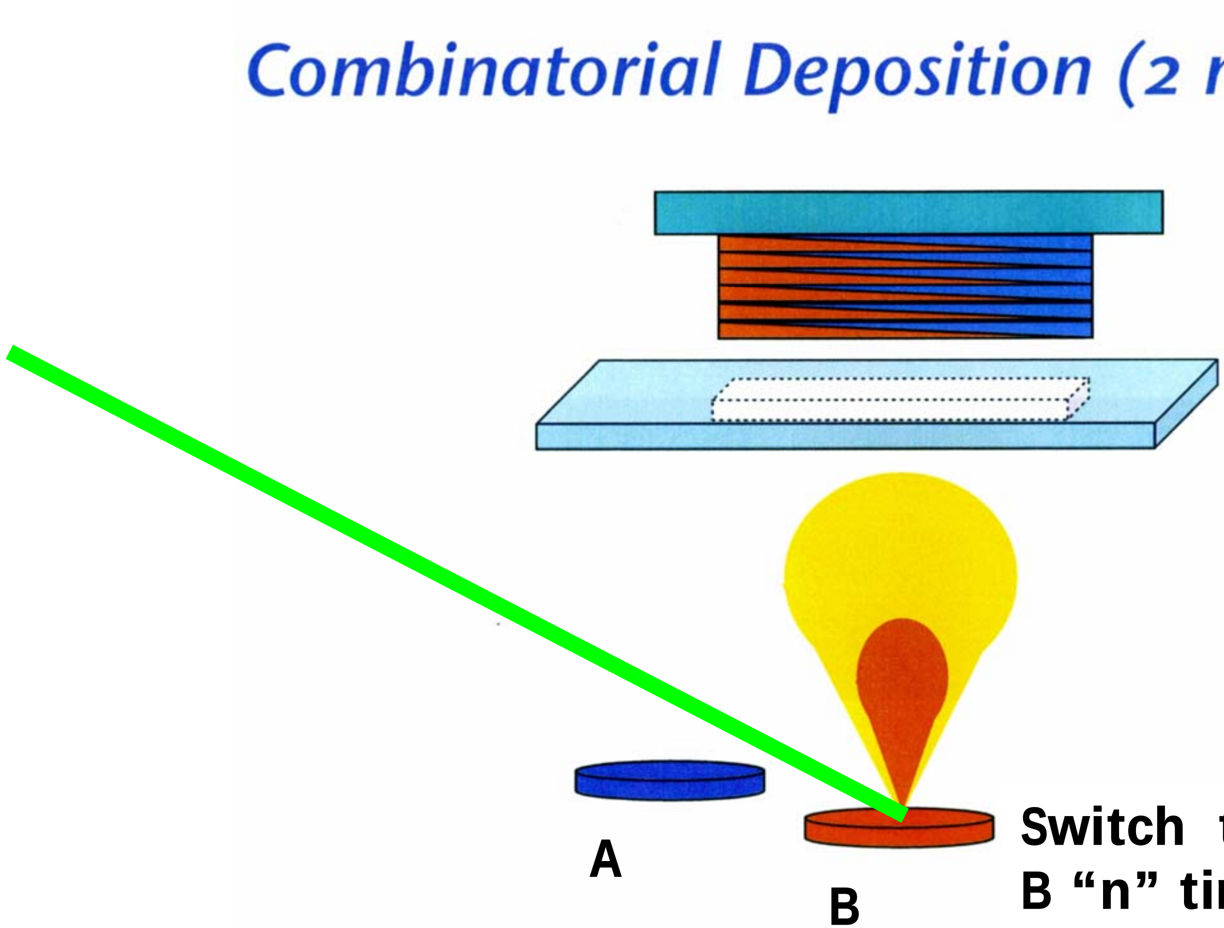
Slit moves in one direction

Exchange targets after (sub)monolayer wedge formation: ~ 30 pulses

Target exchange
(each 4-8 Å)
(or about 100 laser pulses)

Images: Nabil Bassim

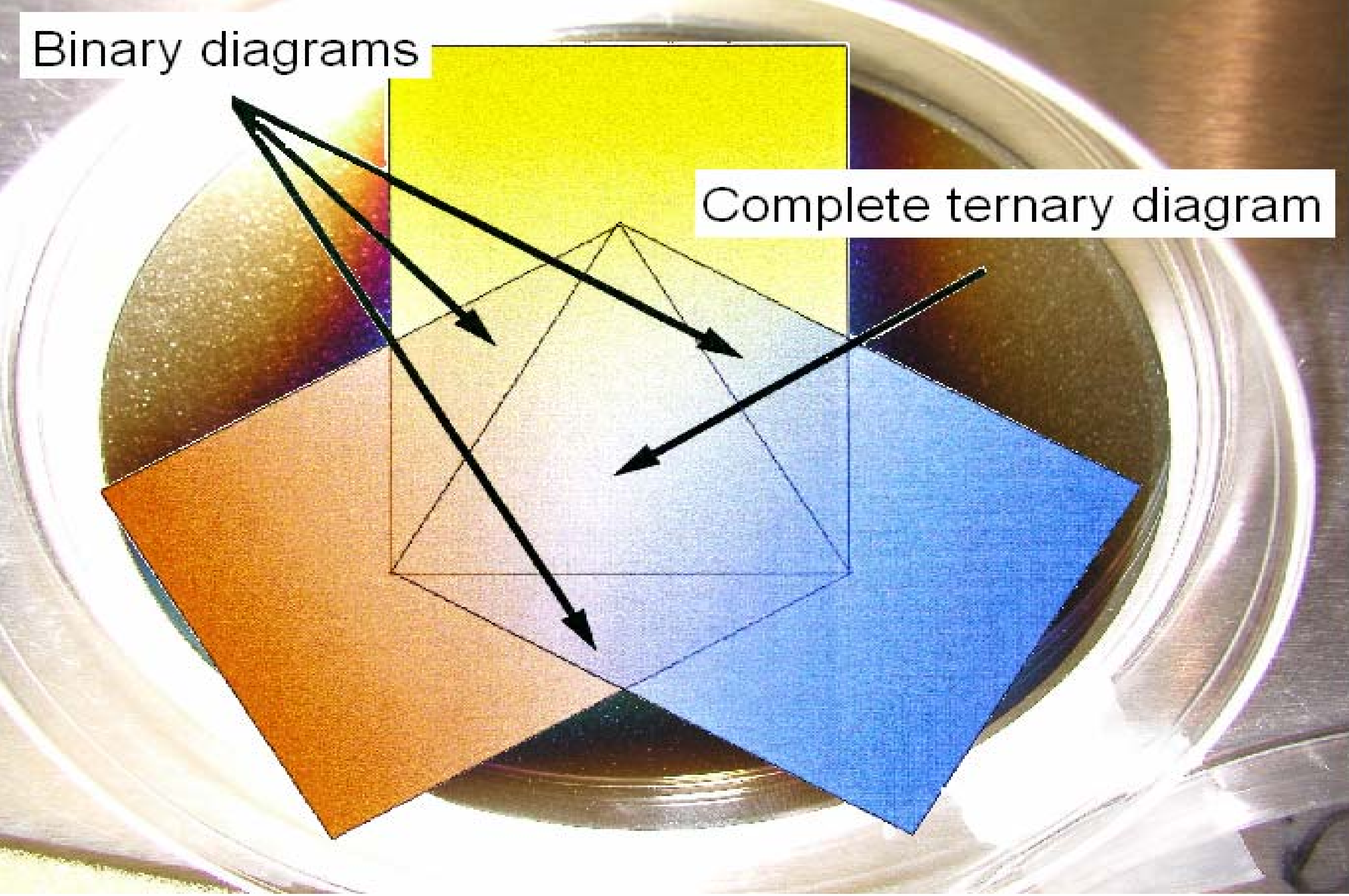
Compositional Gradient:
Pulsed Laser Deposition (PLD)



Annealing results in uniform graded layer of any thickness

Switch targets A and B "n" times for thicker layers

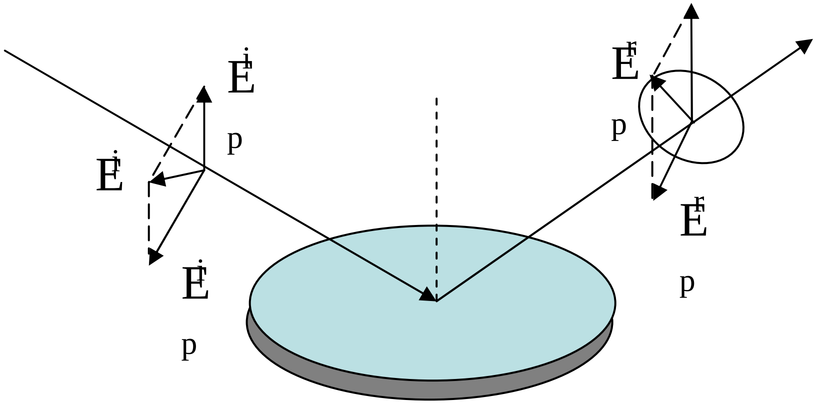
Images: Nabil Bassim

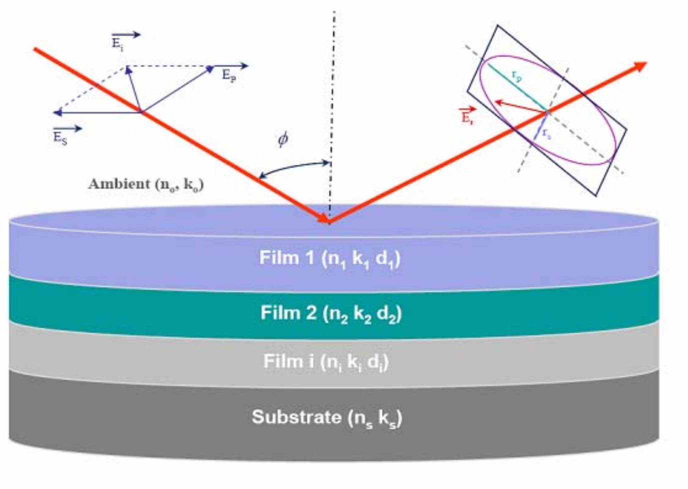


Binary diagrams

Complete ternary diagram

Ellipsometry (Non-destructive, non-invasive, indirect technique, submonolayer sensitivity)





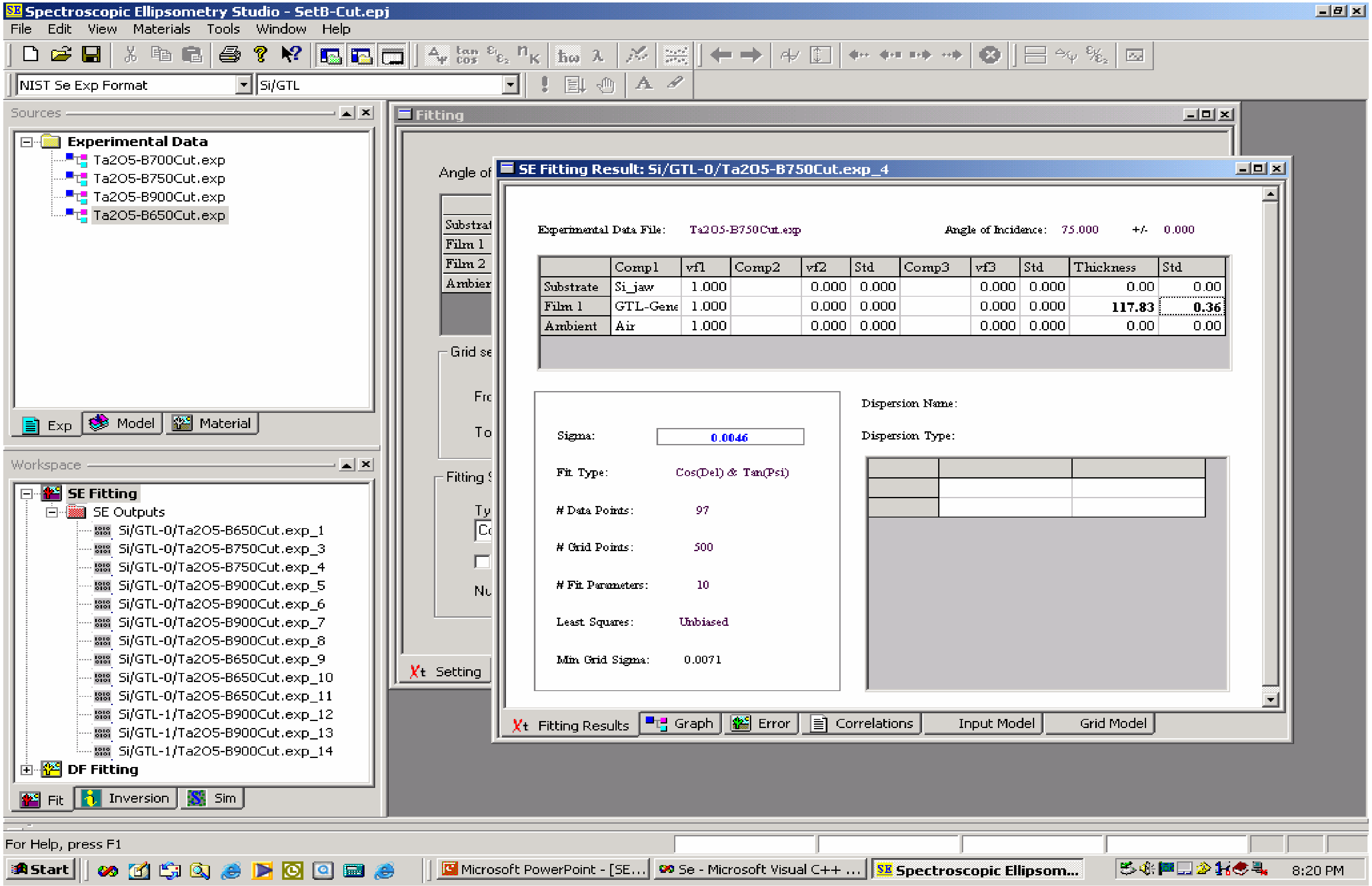
Spectral Range 1.5eV-9.0eV

SE gives us Δ and Ψ

- Thickness
- Index of Refraction (n,k)

d, n, k →Band Gap

Modeling software: SE Studio by Dr. Nhan V. Nguyen



Experimental Data File: Ta2O5-B750Cut.exp

Angle of Incidence: 75.000 +/- 0.000

	Comp1	vf1	Comp2	vf2	Std	Comp3	vf3	Std	Thickness	Std
Substrate	Si_jaw	1.000		0.000	0.000		0.000	0.000	0.00	0.00
Film 1	GTL-Gene	1.000		0.000	0.000		0.000	0.000	**117.83**	**0.36**
Ambient	Air	1.000		0.000	0.000		0.000	0.000	0.00	0.00

Sigma: 0.0046

Fit Type: Cos(Del) & Tan(Psi)

Data Points: 97

Grid Points: 500

Fit Parameters: 10

Least Squares: Unbiased

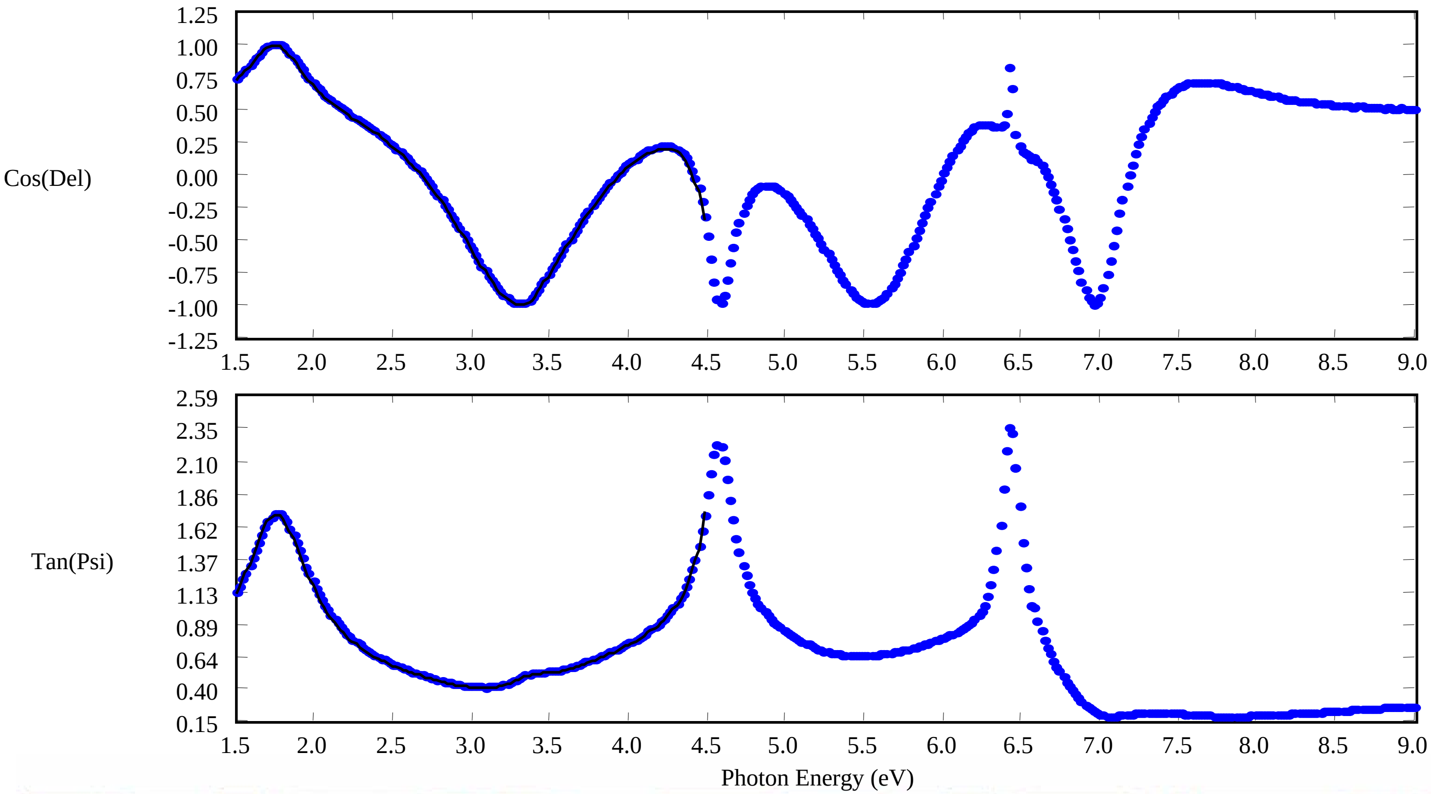
Min Grid Sigma: 0.0071

Dispersion Name:

Dispersion Type:

Fitting Data to Model

- Fit Experimental Data to Cauchy Plot below the band gap, where sample is transparent
  - Determine thickness
- Using the same data, assume thickness known,
  - Invert ellipsometry data to determine e1 and e2



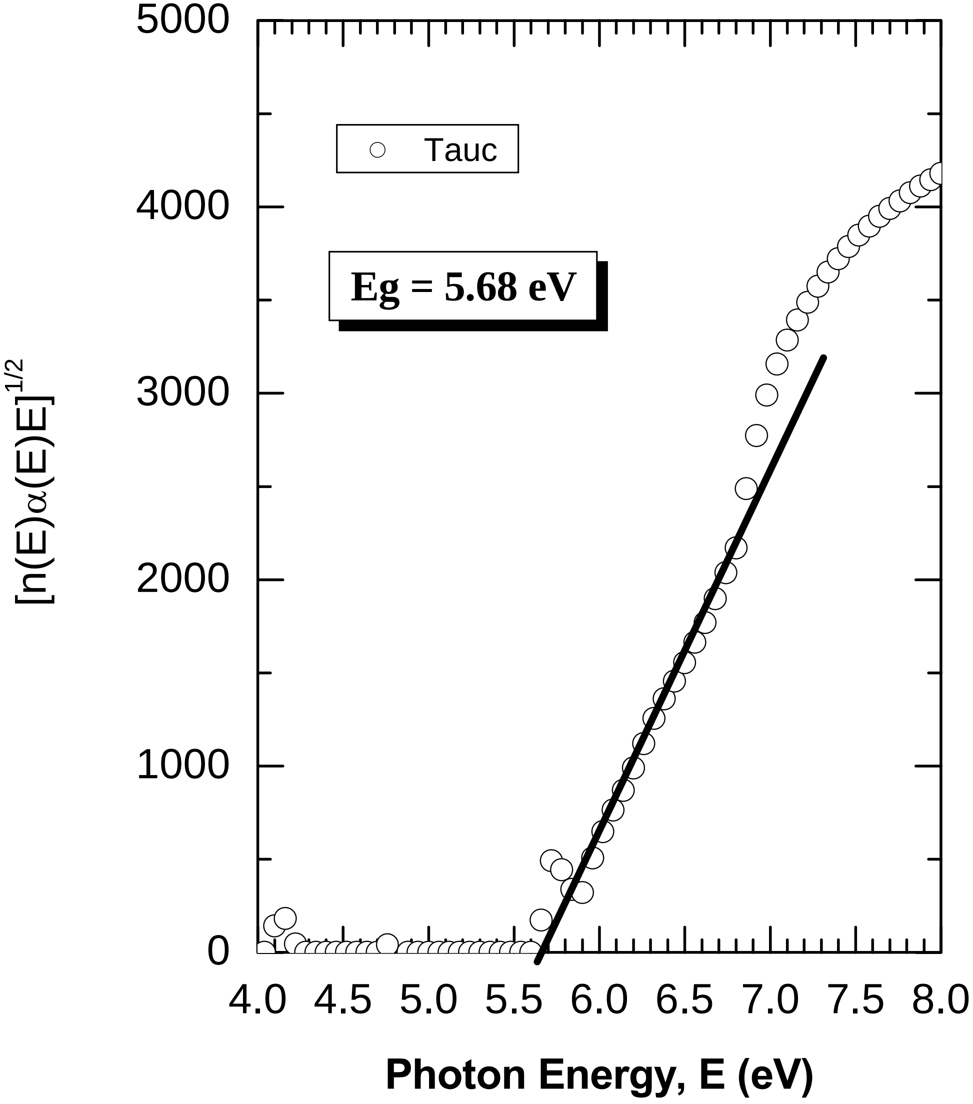
$n = A + B^2 / \lambda^2$

λ is in Angstrom

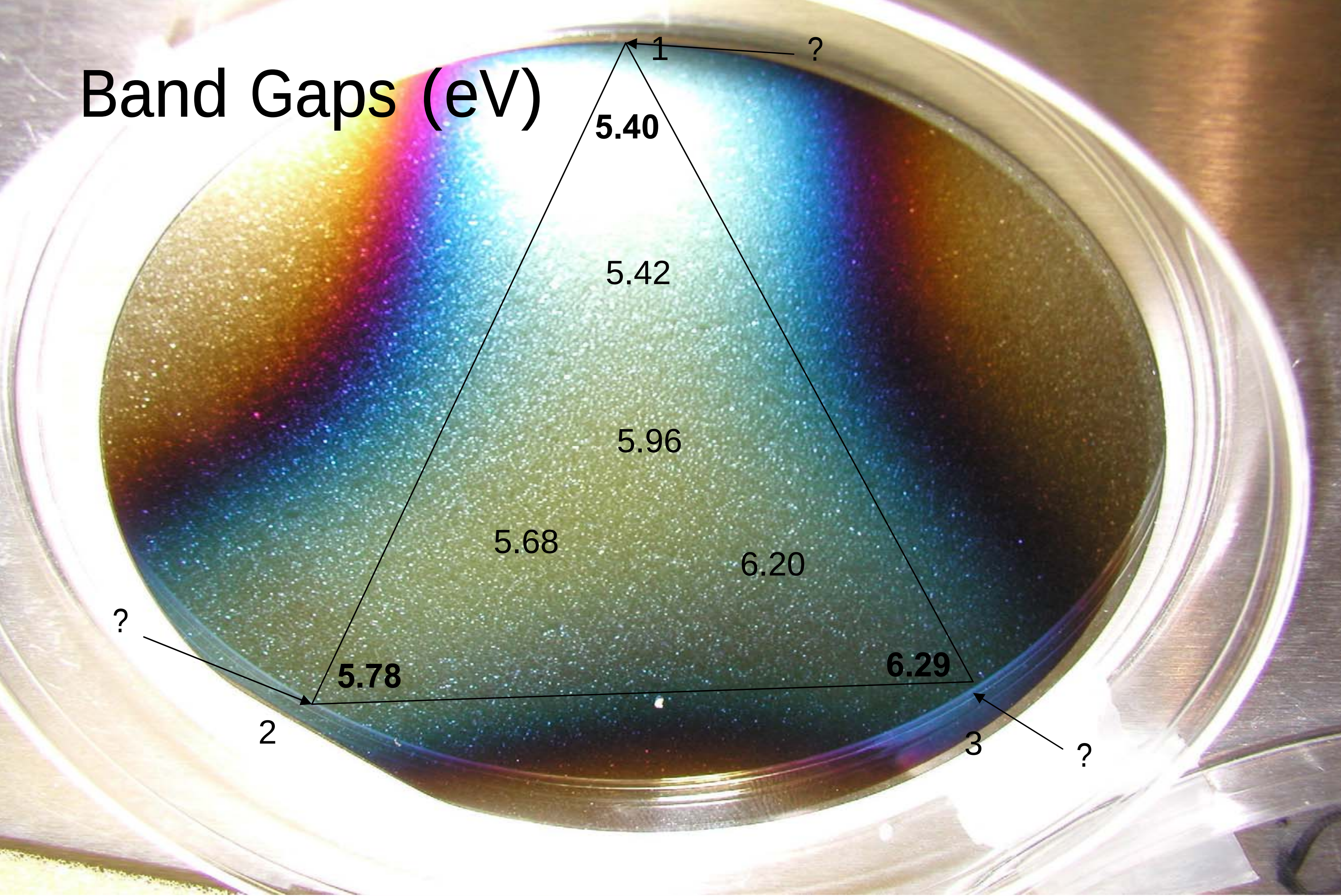
Inversion of Ellipsometry Data with linear fit to Determine Band gap energy

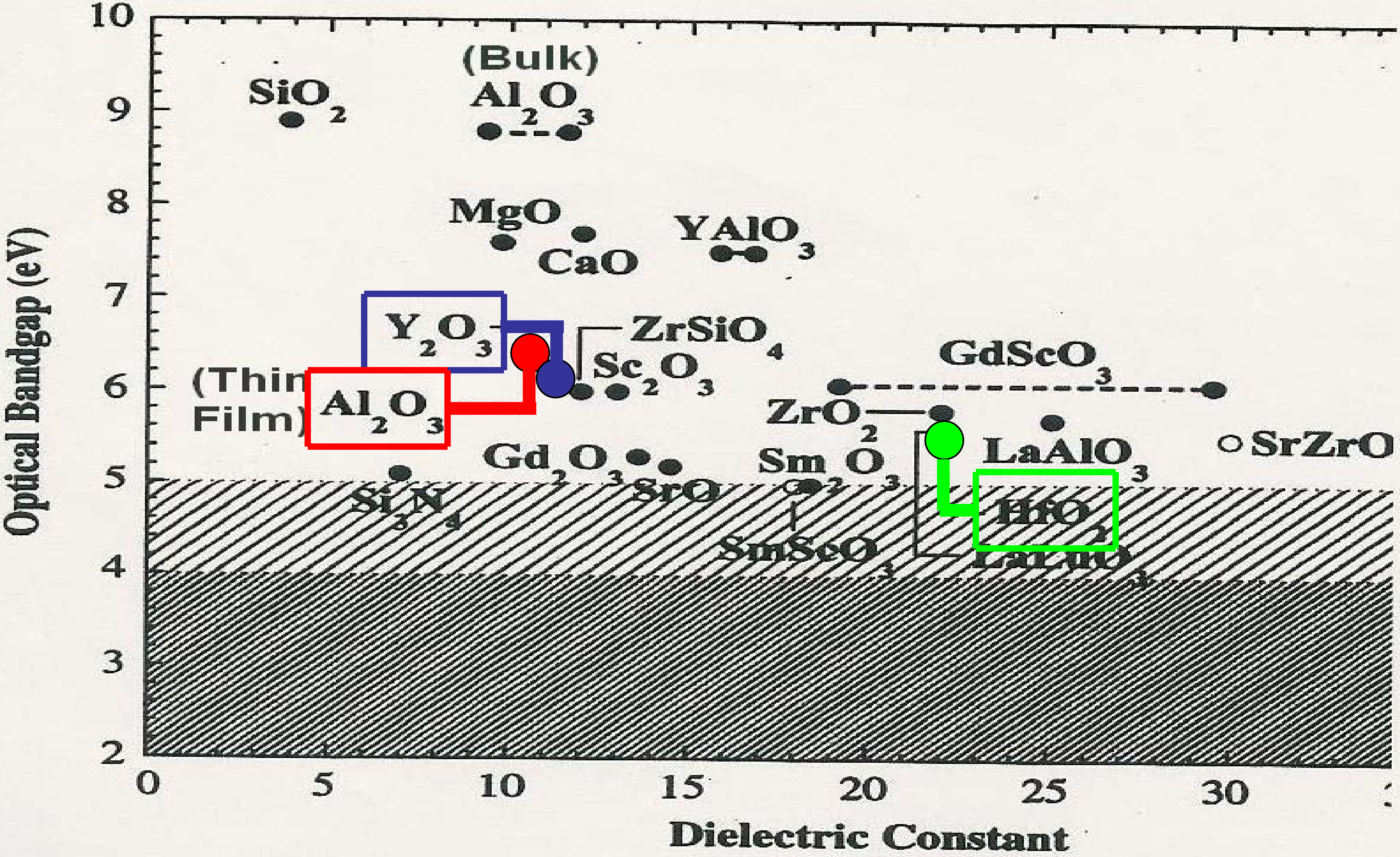
$$\alpha \equiv \frac{4 \times \pi \times k}{\lambda}$$

Tauc Plot vs. Photon Energy for 2-0

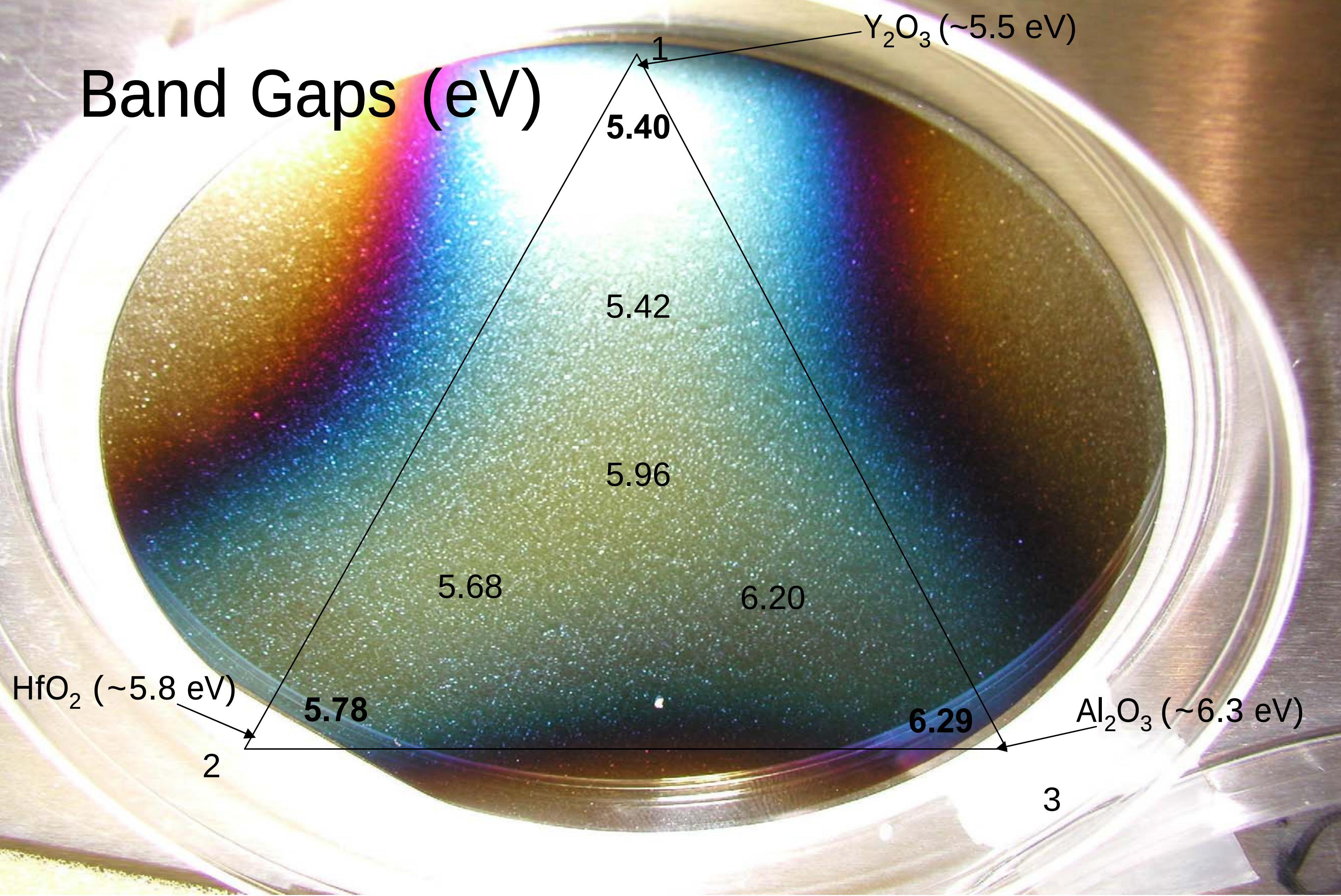


Band Gaps (eV)

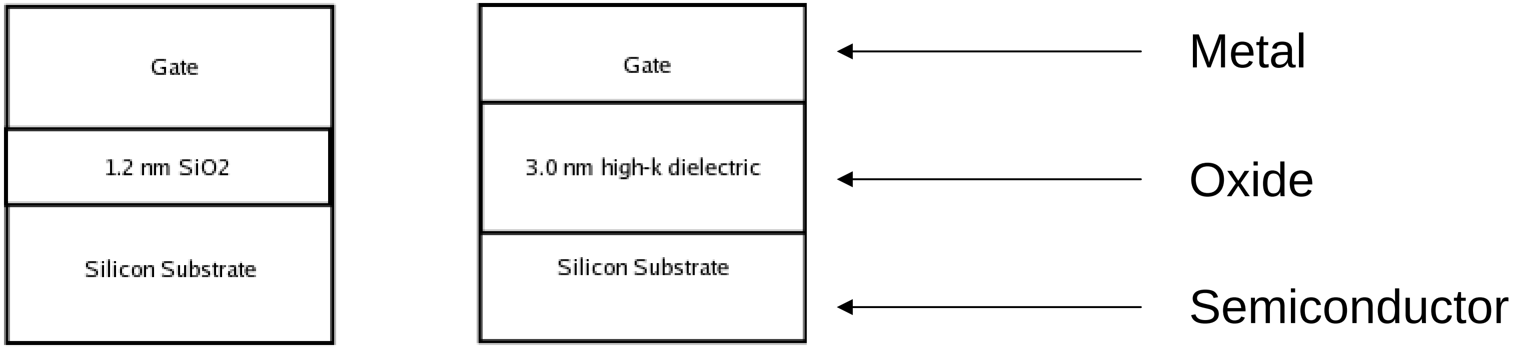



(Bulk)
Al_2O_3
SiO_2
MgO
CaO
$YAlO_3$
Y_2O_3
$ZrSiO_4$
Sc_2O_3
(Thin Film)
Al_2O_3
$GdScO_3$
ZrO_2
$LaAlO_3$
SrZrO
Gd_2O_3
SrO
Sm_2O_3
Si_3N_4
$SmScO_3$
HfO_2
$LaLuO_3$
Optical Bandgap (eV)
10
9
8
7
6
5
4
3
2
0
5
10
15
20
25
30
Dielectric Constant

Band Gaps (eV)



New Technique—New Wafer



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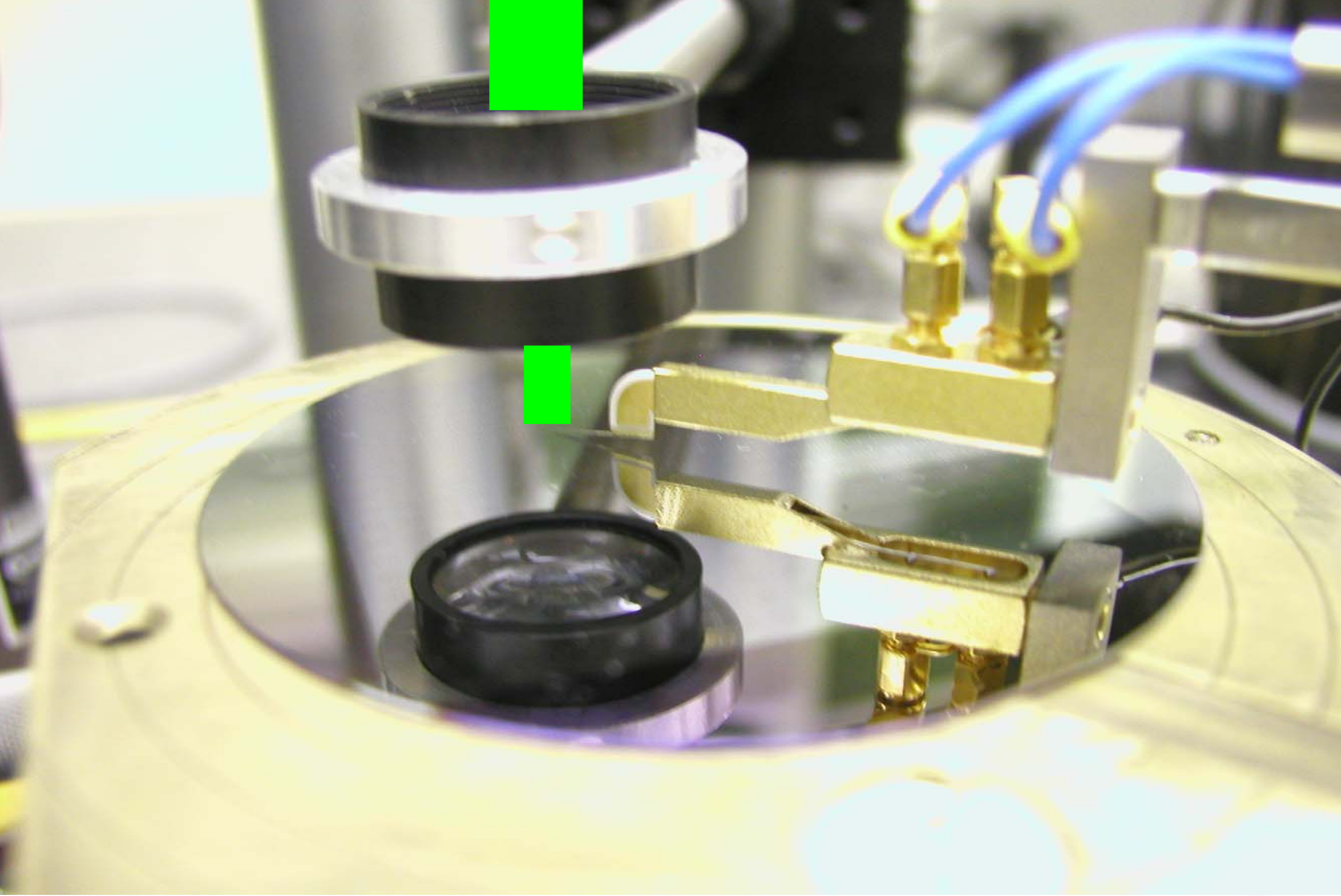
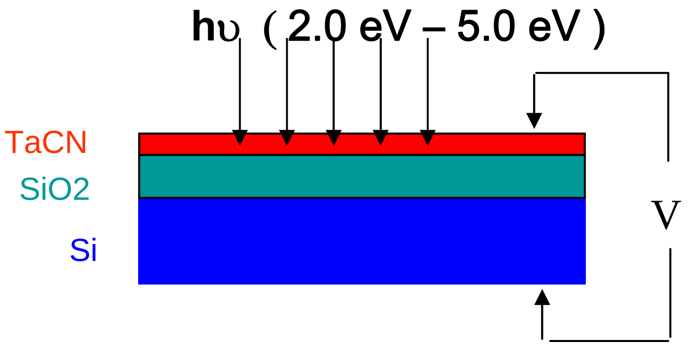
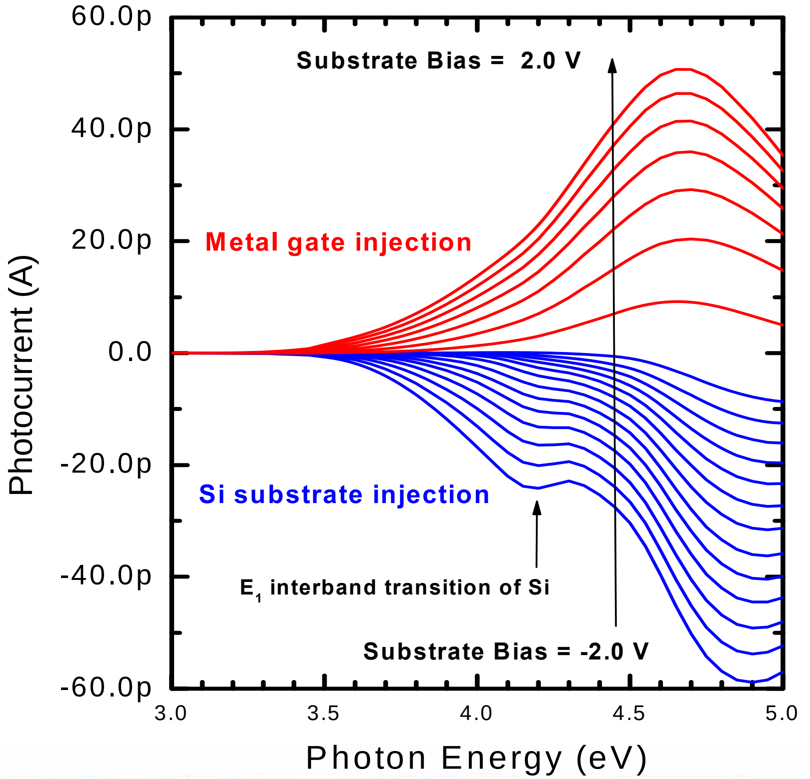


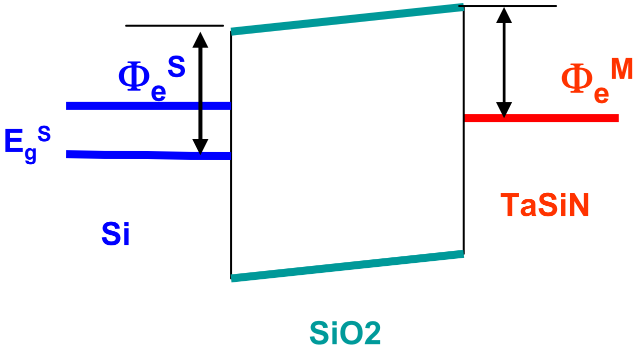
Work Function = Barrier Height + Energy from Dielectric film



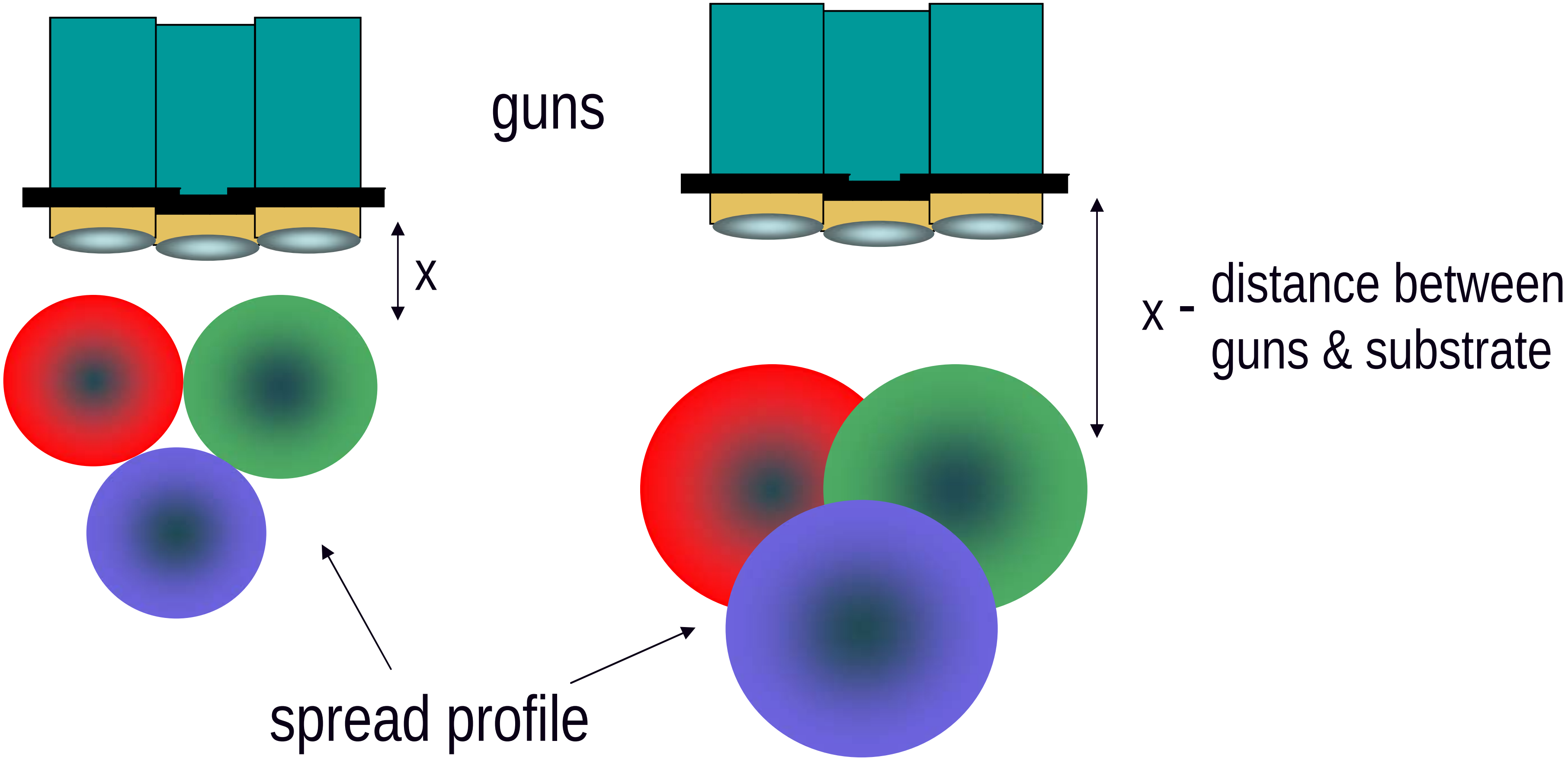


IPE spectra for TaCN / SiO_2 / Si

Similar for TaSiN / SiO_2 / Si



Combi-metal sputtering technique



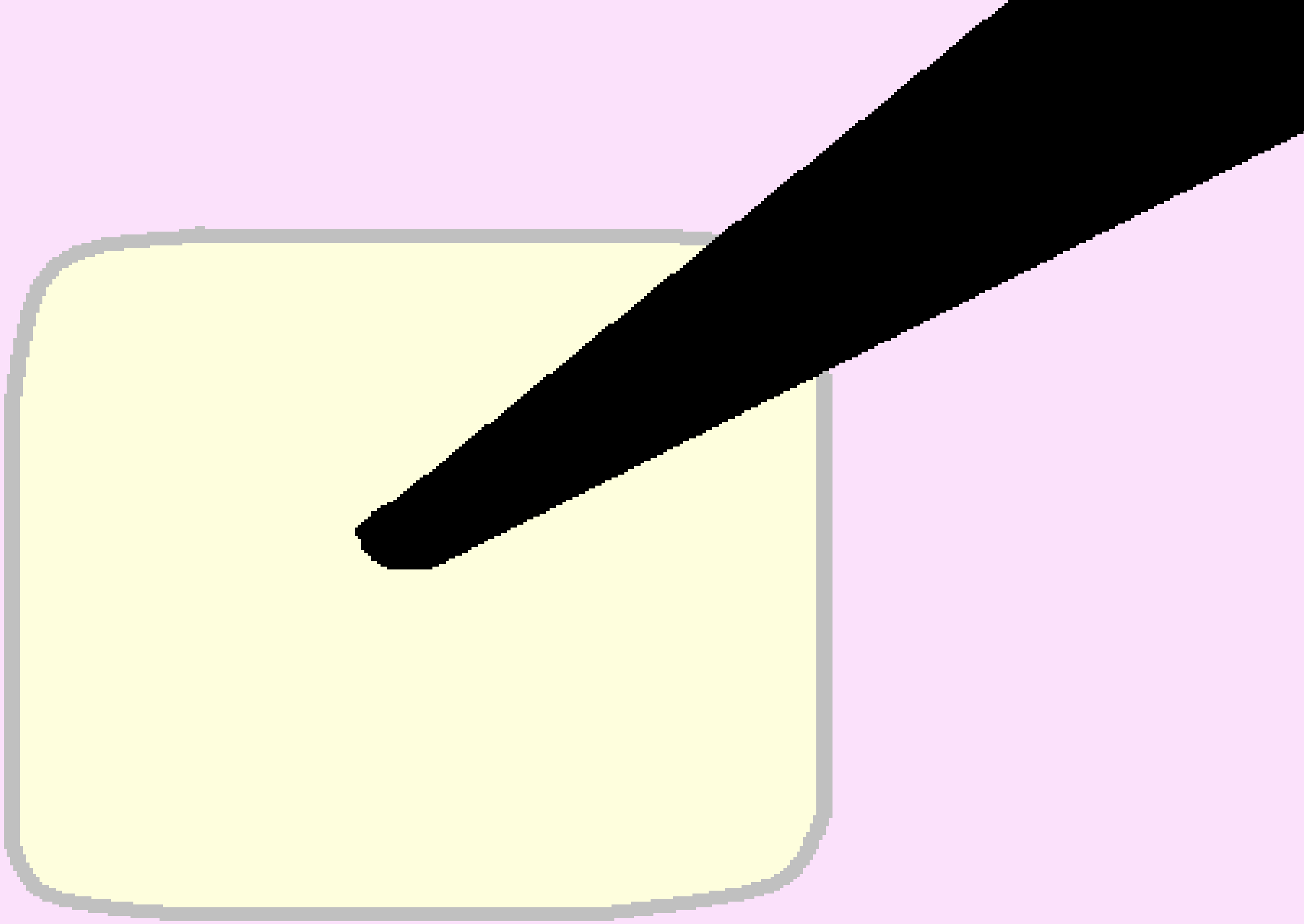
guns

x

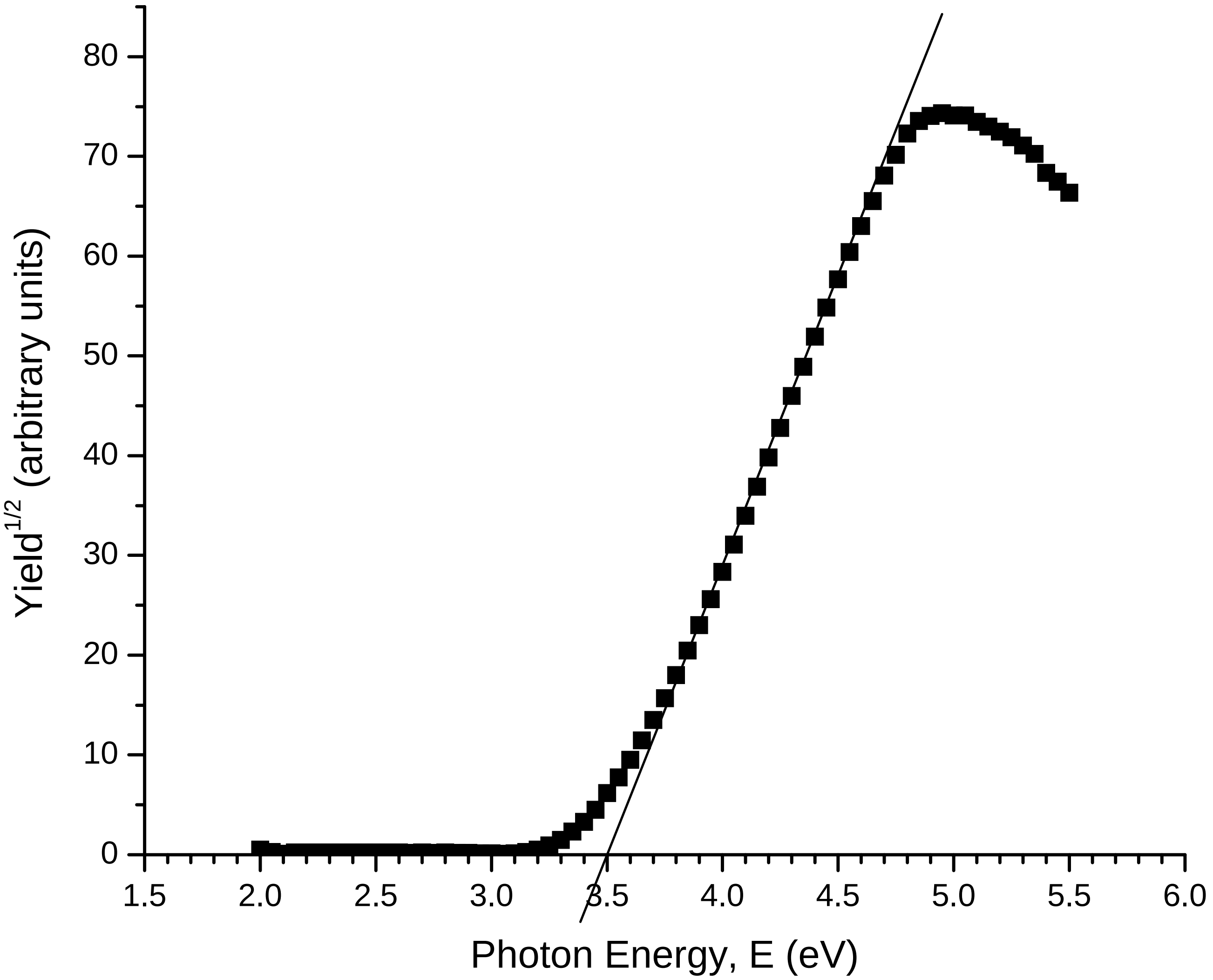
x - distance between guns & substrate

spread profile

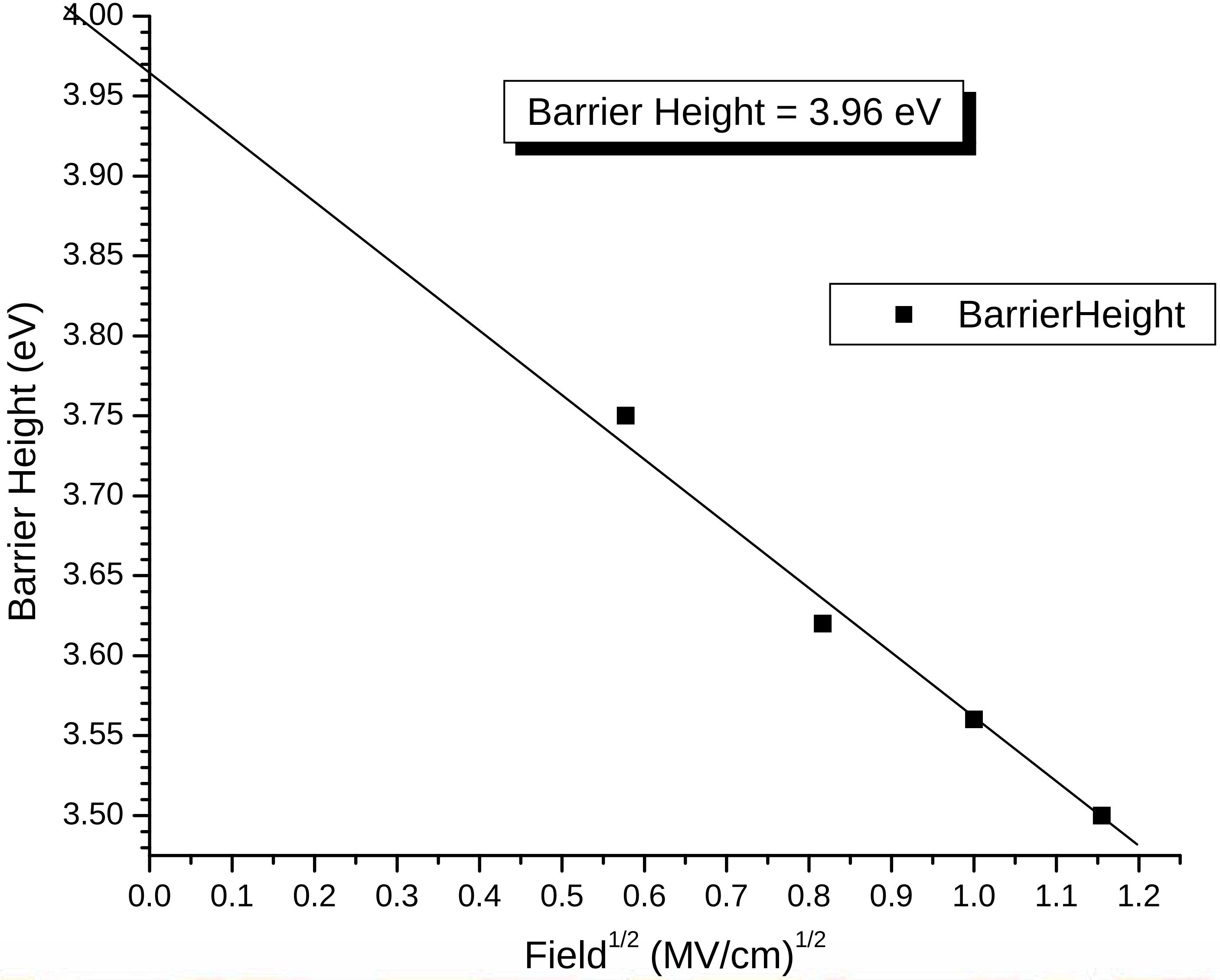
Image compliments of Dr. Kao-Shuo Chang



Yield$^{1/2}$ vs. Photon Energy for 2.0V Potential at Row 1 Column 18



Barrier Height vs. Field$^{1/2}$ for Row 1 Column18



Published Metal Work Functions

Targets used: Ti, Ni, Pt

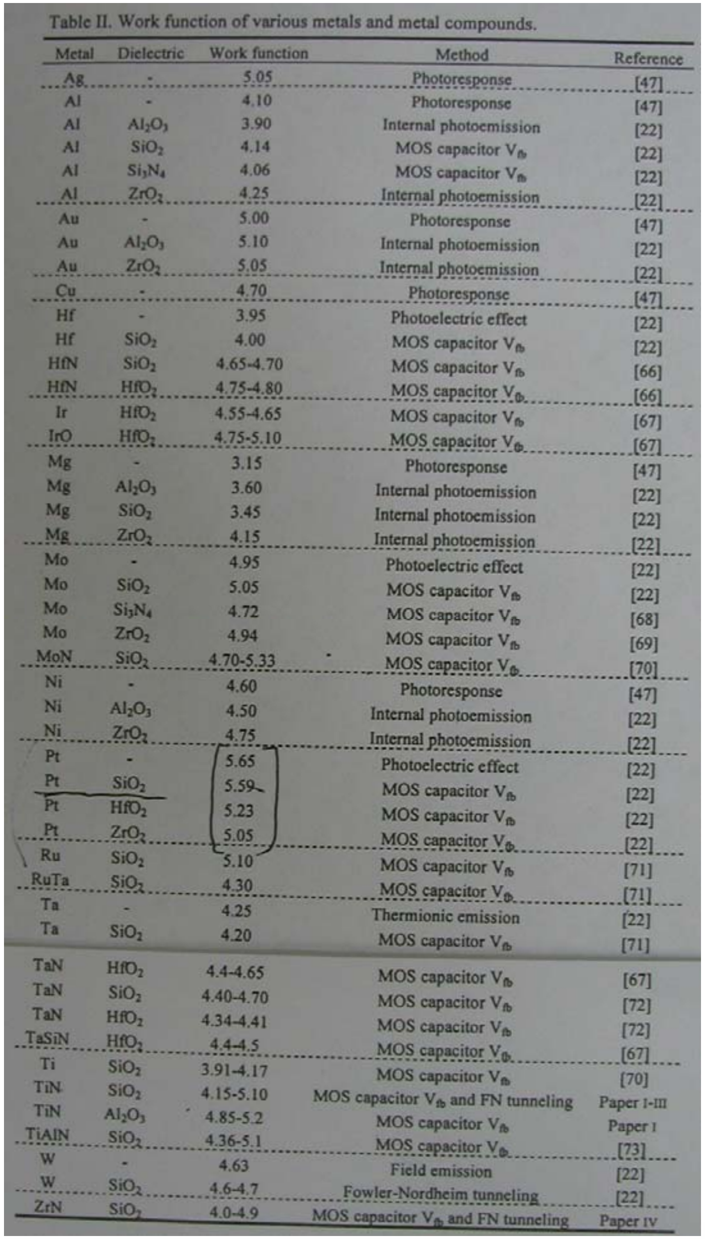
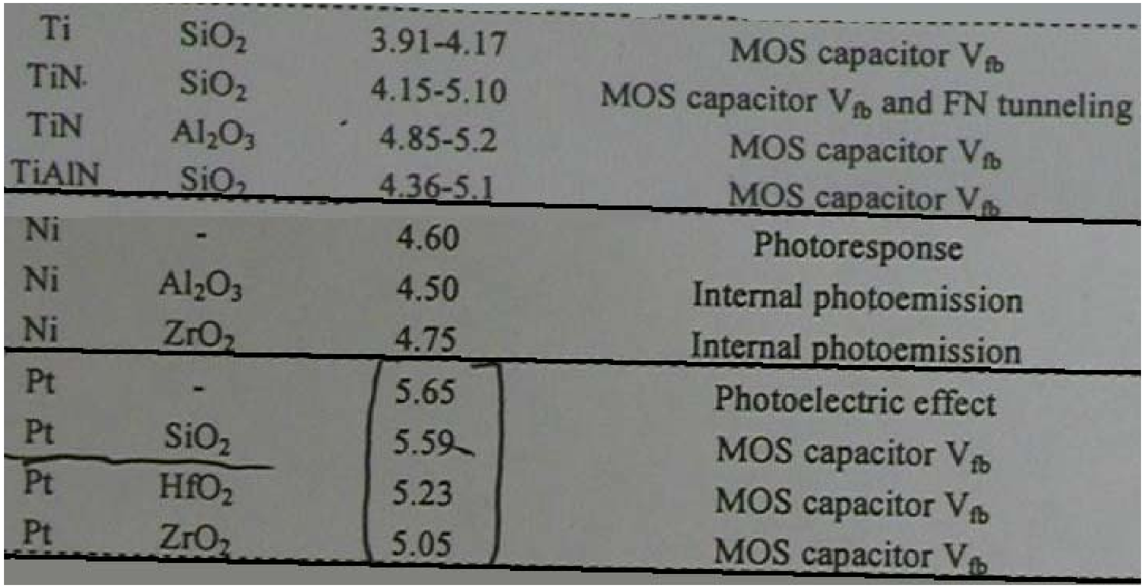
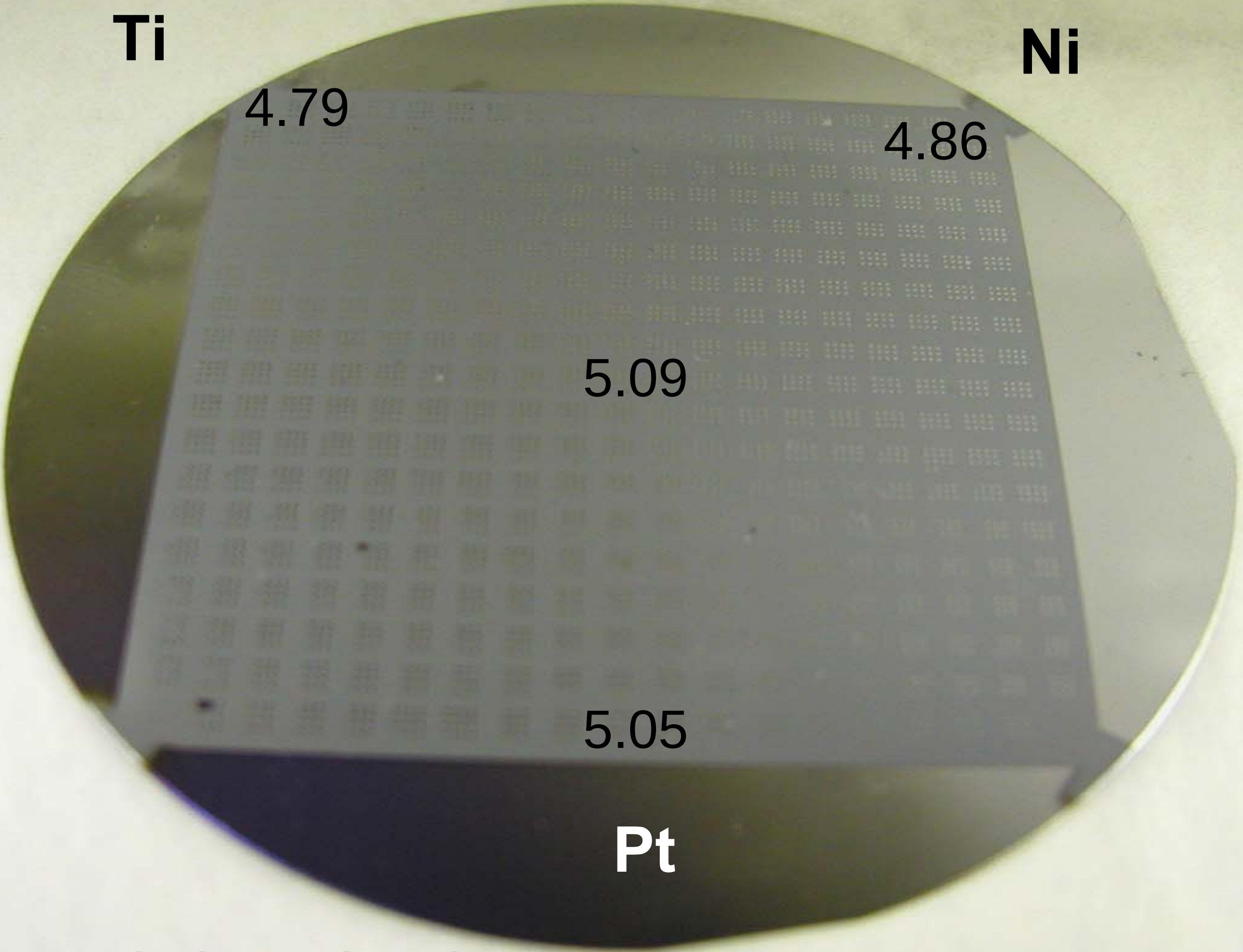


Table II. Work function of various metals and metal compounds.

Metal	Dielectric	Work function	Method	Reference
Ag	-	5.05	Photoresponse	[47]
Al	-	4.10	Photoresponse	[47]
Al	Al_2O_3	3.90	Internal photoemission	[22]
Al	SiO_2	4.14	MOS capacitor V_{fb}	[22]
Al	Si_3N_4	4.06	MOS capacitor V_{fb}	[22]
Al	ZrO_2	4.25	Internal photoemission	[22]
Au	-	5.00	Photoresponse	[47]
Au	Al_2O_3	5.10	Internal photoemission	[22]
Au	ZrO_2	5.05	Internal photoemission	[22]
Cu	-	4.70	Photoresponse	[47]
Hf	-	3.95	Photoelectric effect	[22]
Hf	SiO_2	4.00	MOS capacitor V_{fb}	[22]
HfN	SiO_2	4.65-4.70	MOS capacitor V_{fb}	[66]
HfN	HfO_2	4.75-4.80	MOS capacitor V_{fb}	[66]
Ir	HfO_2	4.55-4.65	MOS capacitor V_{fb}	[67]
IrO	HfO_2	4.75-5.10	MOS capacitor V_{fb}	[67]
Mg	-	3.15	Photoresponse	[47]
Mg	Al_2O_3	3.60	Internal photoemission	[22]
Mg	SiO_2	3.45	Internal photoemission	[22]
Mg	ZrO_2	4.15	Internal photoemission	[22]
Mo	-	4.95	Photoelectric effect	[22]
Mo	SiO_2	5.05	MOS capacitor V_{fb}	[22]
Mo	Si_3N_4	4.72	MOS capacitor V_{fb}	[68]
Mo	ZrO_2	4.94	MOS capacitor V_{fb}	[69]
MoN	SiO_2	4.70-5.33	MOS capacitor V_{fb}	[70]
Ni	-	4.60	Photoresponse	[47]
Ni	Al_2O_3	4.50	Internal photoemission	[22]
Ni	ZrO_2	4.75	Internal photoemission	[22]
Pt	-	5.65	Photoelectric effect	[22]
Pt	SiO_2	5.59	MOS capacitor V_{fb}	[22]
Pt	HfO_2	5.23	MOS capacitor V_{fb}	[22]
Pt	ZrO_2	5.05	MOS capacitor V_{fb}	[22]
Ru	SiO_2	5.10	MOS capacitor V_{fb}	[71]
RuTa	SiO_2	4.30	MOS capacitor V_{fb}	[71]
Ta	-	4.25	Thermionic emission	[22]
Ta	SiO_2	4.20	MOS capacitor V_{fb}	[71]
TaN	HfO_2	4.4-4.65	MOS capacitor V_{fb}	[67]
TaN	SiO_2	4.40-4.70	MOS capacitor V_{fb}	[72]
TaN	HfO_2	4.34-4.41	MOS capacitor V_{fb}	[72]
TaSiN	HfO_2	4.4-4.5	MOS capacitor V_{fb}	[67]
Ti	SiO_2	3.91-4.17	MOS capacitor V_{fb}	[70]
TiN	SiO_2	4.15-5.10	MOS capacitor V_{fb} and FN tunneling	Paper I-III
TiN	Al_2O_3	4.85-5.2	MOS capacitor V_{fb}	Paper I
TiAlN	SiO_2	4.36-5.1	MOS capacitor V_{fb}	[73]
W	-	4.63	Field emission	[22]
W	SiO_2	4.6-4.7	Fowler-Nordheim tunneling	[22]
ZrN	SiO_2	4.0-4.9	MOS capacitor V_{fb} and FN tunneling	Paper IV



Ti	SiO_2	3.91-4.17	MOS capacitor V_{fb}
TiN	SiO_2	4.15-5.10	MOS capacitor V_{fb} and FN tunneling
TiN	Al_2O_3	4.85-5.2	MOS capacitor V_{fb}
TiAlN	SiO_2	4.36-5.1	MOS capacitor V_{fb}
Ni	-	4.60	Photoresponse
Ni	Al_2O_3	4.50	Internal photoemission
Ni	ZrO_2	4.75	Internal photoemission
Pt	-	5.65	Photoelectric effect
Pt	SiO_2	5.59	MOS capacitor V_{fb}
Pt	HfO_2	5.23	MOS capacitor V_{fb}
Pt	ZrO_2	5.05	MOS capacitor V_{fb}



Barrier Heights (eV)

Conclusion

- SE was used to determine band gap for Novel devices
- IPE was used to determine barrier height for CMOS devices
- Combi methods provide route to rapidly survey CMOS and Novel devices

Acknowledgements

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