Personal Reflections on Utilization of XPS Over 1/2 Century

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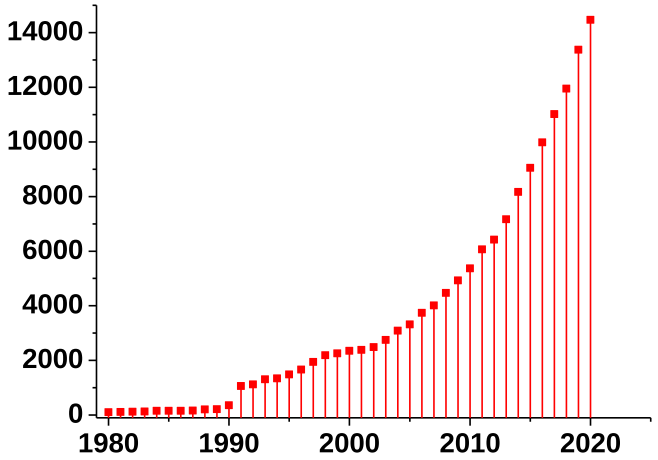
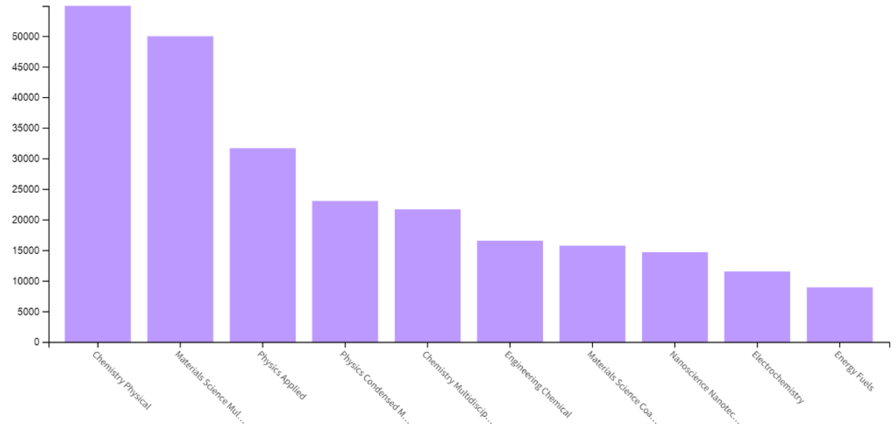
07 September 2022
HESEB - SESAME WORKSHOP
Istanbul University, Istanbul, Turkey

XPS, X-Ray Photoelectron Spectroscopy
A Surface Analysis Technique





“Web of Science”

Kai Siegbahn
Nobel Laureate 1981
ESCA

Ş. Süzer'in PES Research
(UC Berkeley, 1970-76)

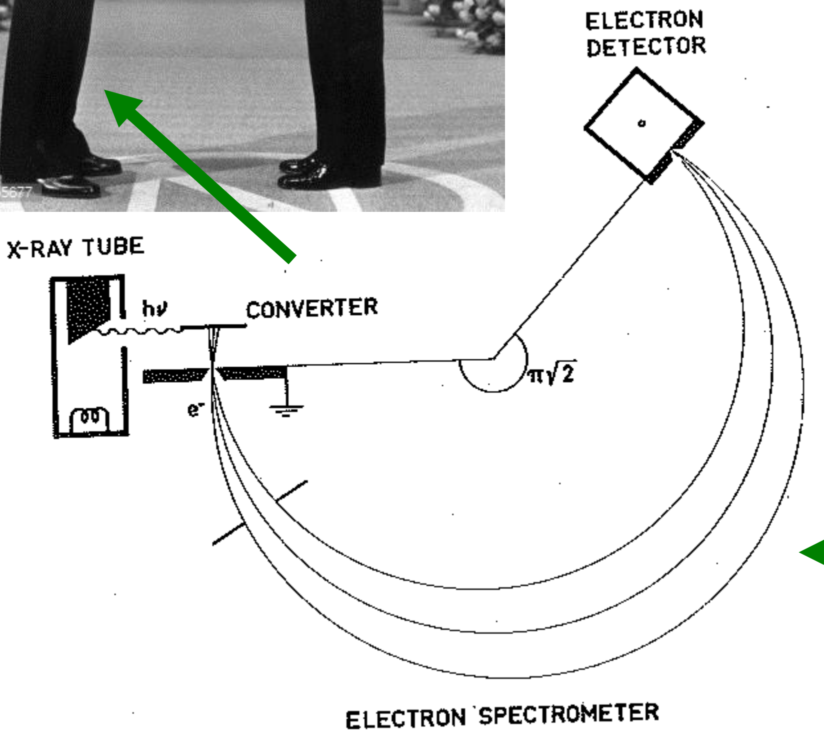


Fig. I:2. Schematic view of an ESCA arrangement for the study of electrons expelled by X-rays.

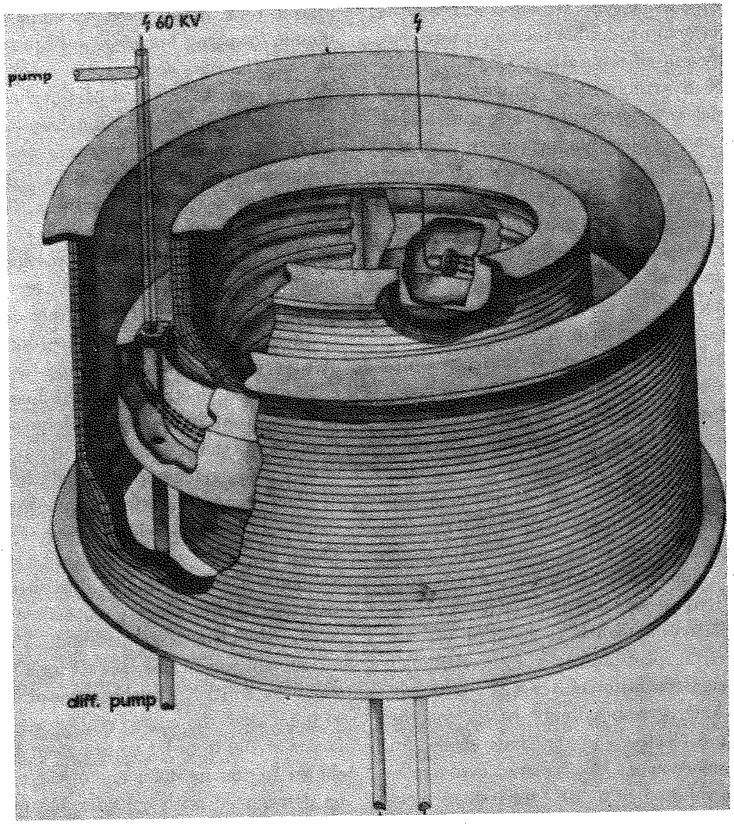
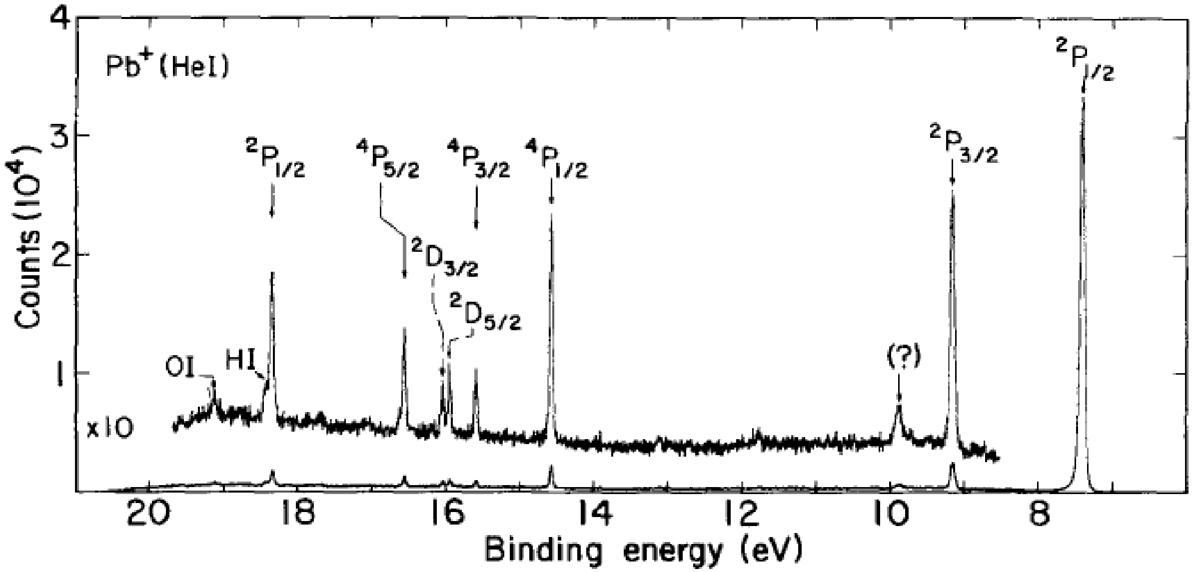


Fig. I:3. First iron-free double focussing spectrometer adapted for ESCA. The magnetic field is obtained from two co-axial coils with radii 24 cm and 36 cm, and height 48 cm.[5]

Large Spin-Orbit Splitting

Pb: $6s^26p^2$:	L-S Coupling	50% $6p_{1/2}$ – 50% $6p_{3/2}$
	Intermed. Coupling	93% $6p_{1/2}$ – 7% $6p_{3/2}$
	J-J Coupling	100% $6p_{1/2}$ – 0% $6p_{3/2}$



J. Chem. Phys., Vol. 63, No. 8, 15 October 1975

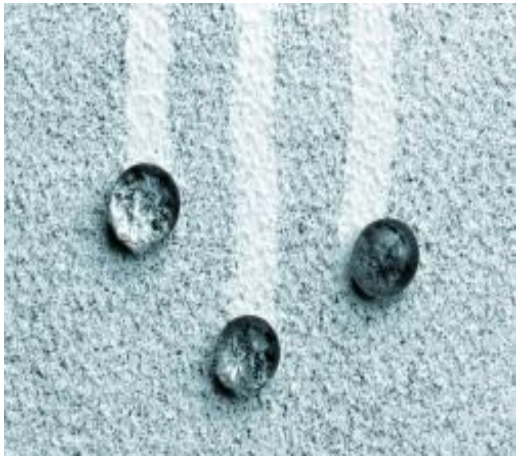
INERT-PAIR EFFECT

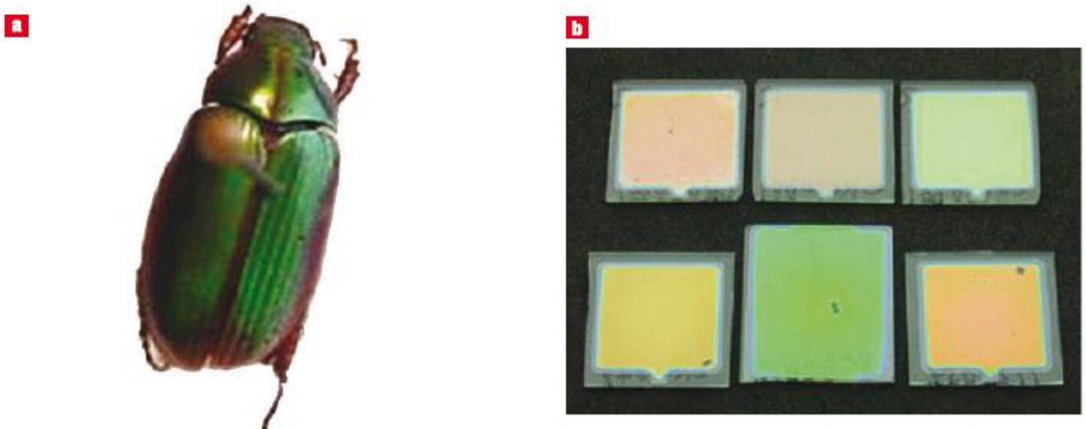
SPIN POLARIZATION

(SPINTRONICS , MOTTRONICS)

Why Surface?

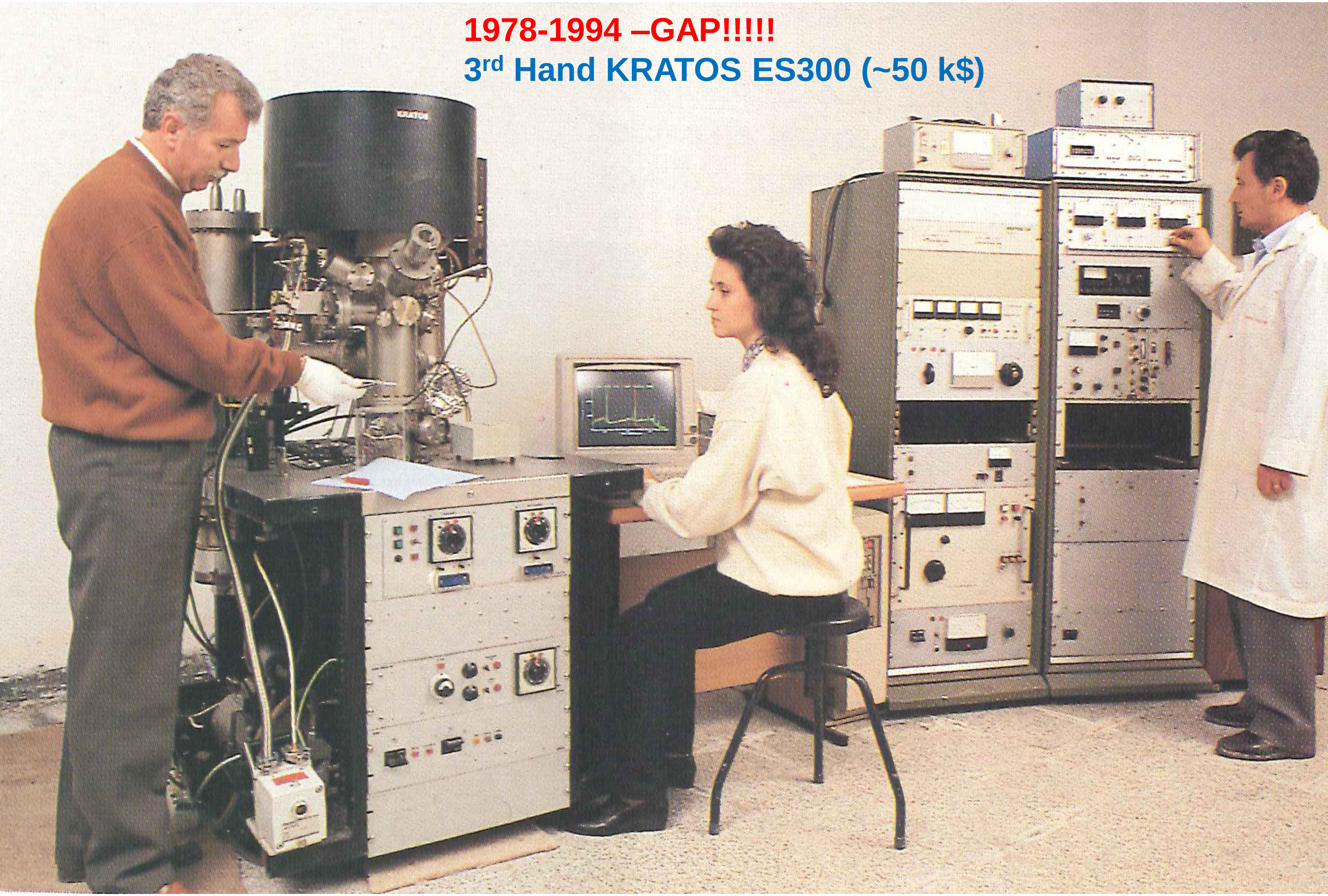
- Hydrophopicity x Hydrophilicity
- Wettability
- Adhesion
- Self - Cleaning
- Friction
- Corrosion, Protection, etc.
- Color – Optical Prop.



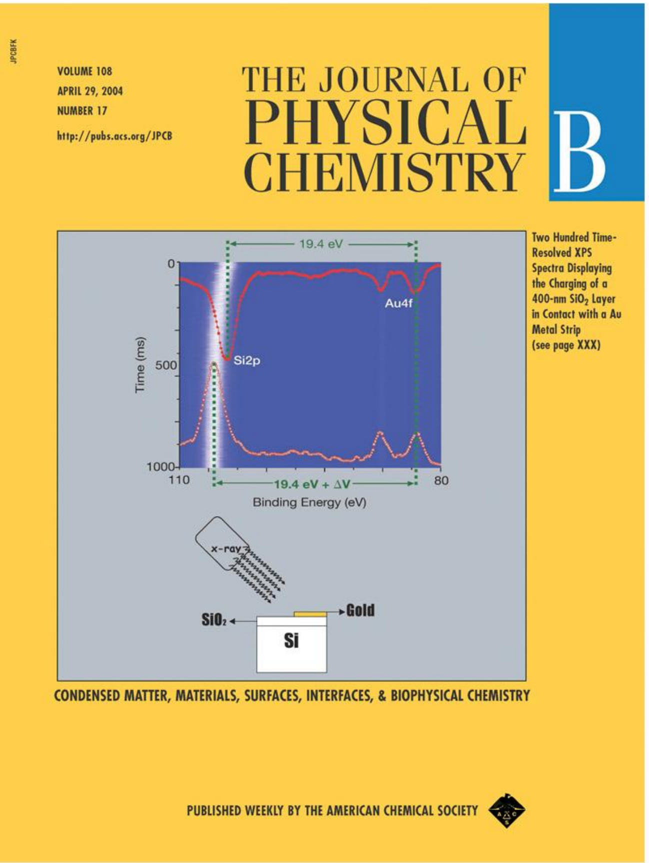


1978-1994 –GAP!!!!!

3rd Hand KRATOS ES300 (~50 k$)



2002 2rd Hand KRATOS ES800 (~60 k$)



JPCBFK

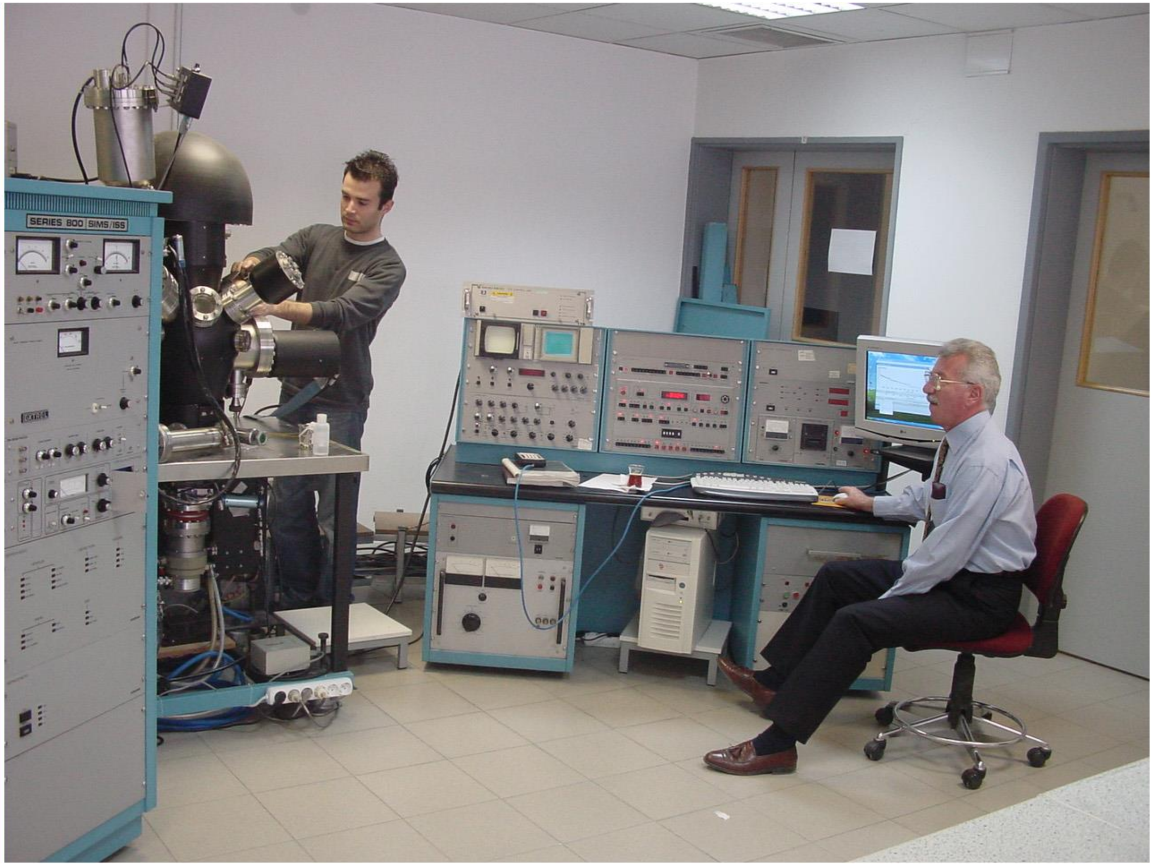
VOLUME 108
APRIL 29, 2004
NUMBER 17
http://pubs.acs.org/JPCB

THE JOURNAL OF
PHYSICAL
CHEMISTRY
B

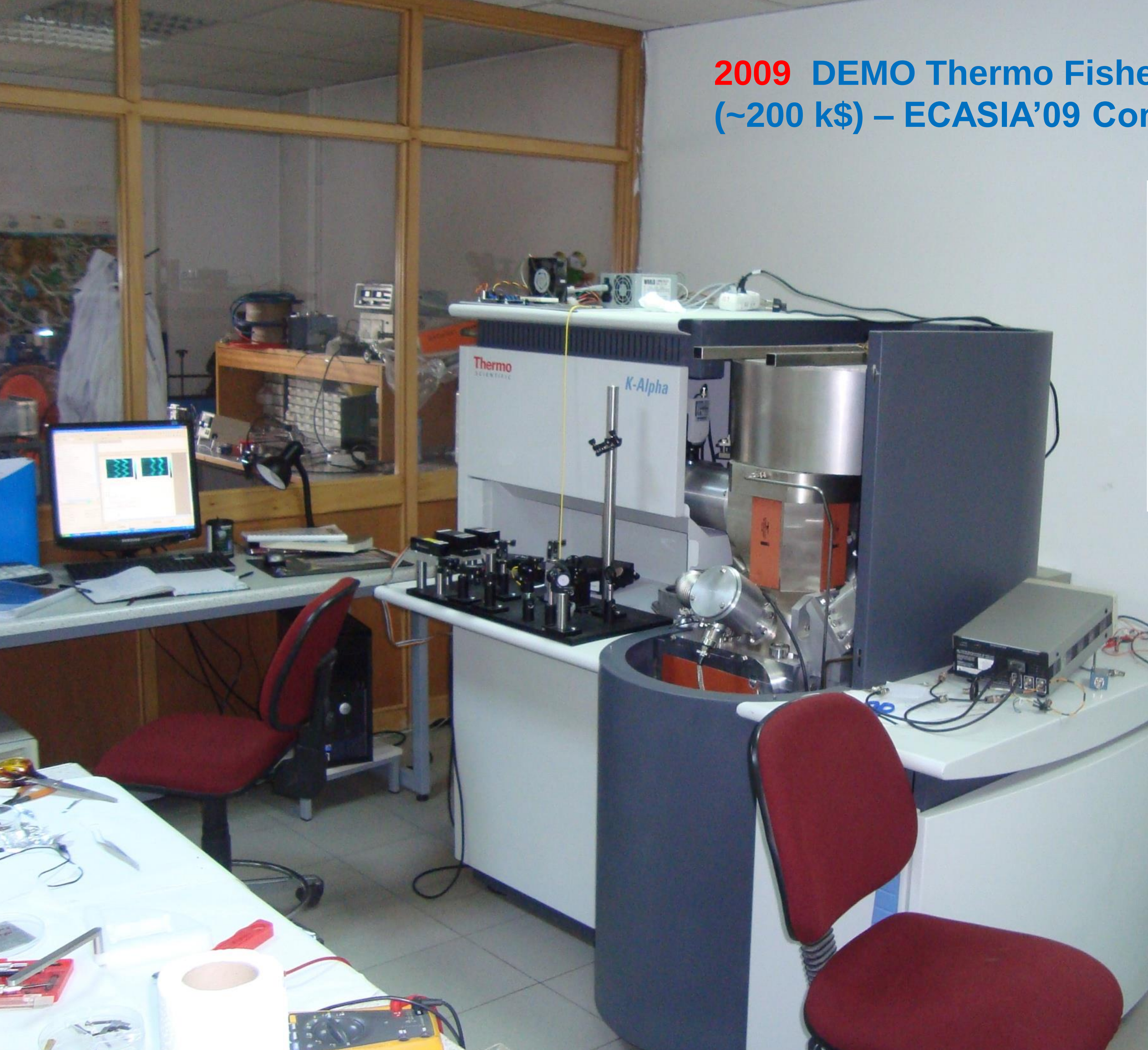
Two Hundred Time-Resolved XPS Spectra Displaying the Charging of a 400-nm SiO_2 Layer in Contact with a Au Metal Strip (see page XXX)

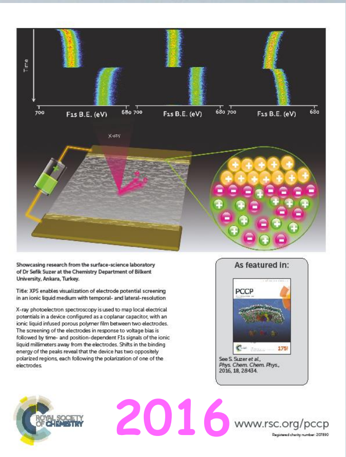
CONDENSED MATTER, MATERIALS, SURFACES, INTERFACES, & BIOPHYSICAL CHEMISTRY

PUBLISHED WEEKLY BY THE AMERICAN CHEMICAL SOCIETY



2009 DEMO Thermo Fisher K-Alpha (~200 k$) – ECASIA'09 Conference





Showcasing research from the surface-science laboratory of Dr Sefik Suzer at the Chemistry Department of Bilkent University, Ankara, Turkey.

Title: XPS enables visualization of electrode potential screening in an ionic liquid medium with temporal- and lateral-resolution

X-ray photoelectron spectroscopy is used to map local electrical potentials in a device configured as a coplanar capacitor, with an ionic liquid infused porous polymer film between two electrodes. The screening of the electrodes in response to voltage bias is followed by time- and position-dependent F1s signals of the ionic liquid millimeters away from the electrodes. Shifts in the binding energy of the peaks reveal that the device has two oppositely polarized regions, each following the polarization of one of the electrodes.

As featured in:

PCCP

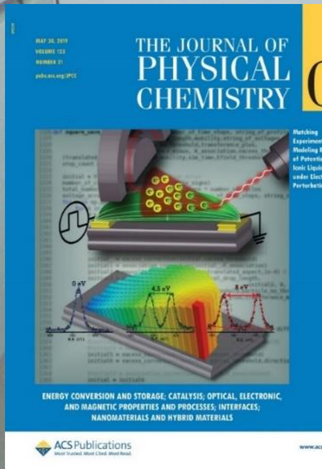
See S. Suzer *et al.*, *Phys. Chem. Chem. Phys.*, 2016, 18, 28434.

2016

www.rsc.org/pccp

Registered charity number: 207890

2019



MAY 30, 2019
VOLUME 123
NUMBER 21
pubs.acs.org/JPCC

THE JOURNAL OF PHYSICAL CHEMISTRY

Matching
Experiment
Modeling
of Potenti
Ionic Liqui
under Elect
Perturbati

ENERGY CONVERSION AND STORAGE; CATALYSIS; OPTICAL, ELECTRONIC, AND MAGNETIC PROPERTIES AND PROCESSES; INTERFACES; NANOMATERIALS AND HYBRID MATERIALS

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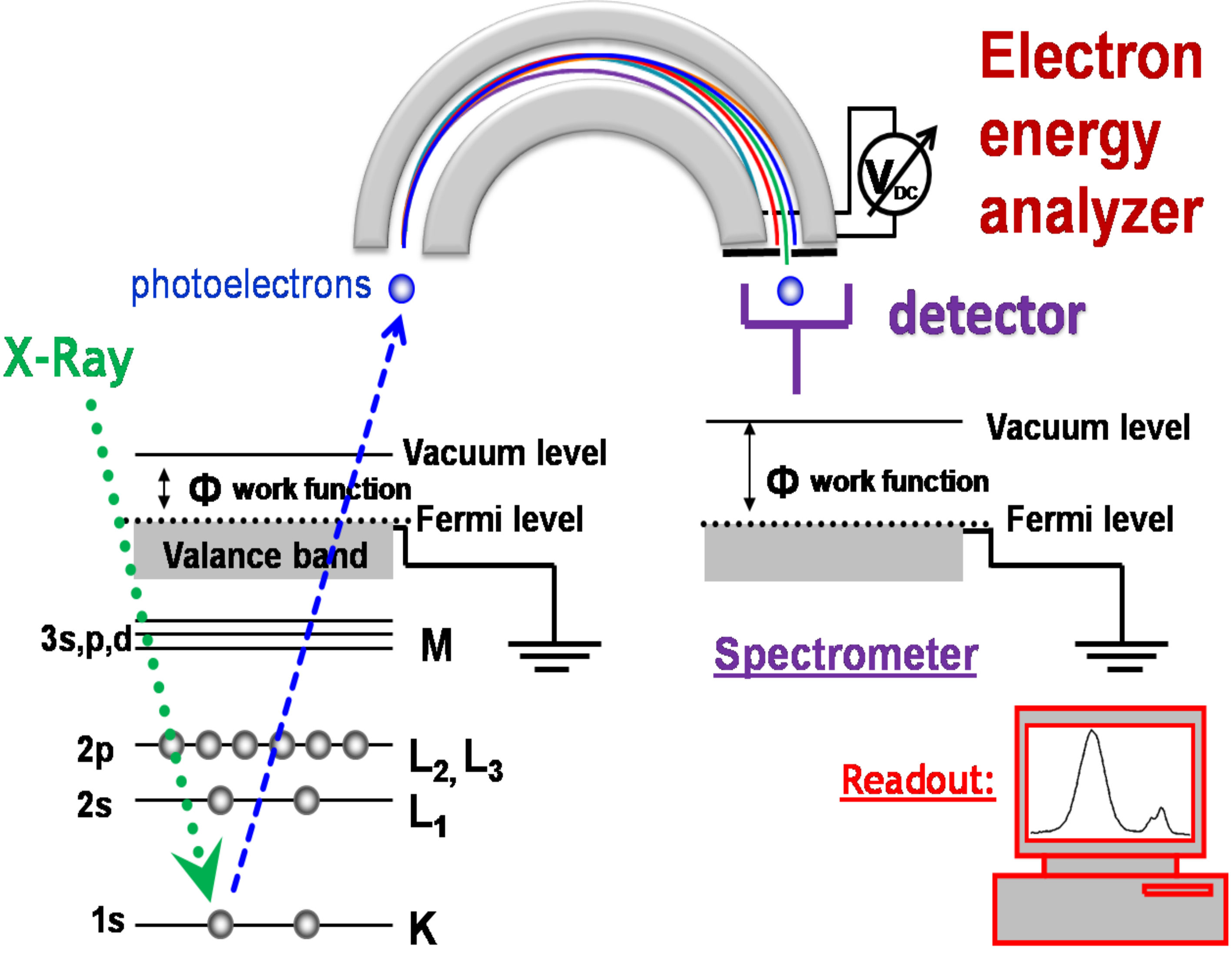


Electron energy analyzer

photoelectrons

detector

X-Ray

Vacuum level

Φ work function

Fermi level

Valance band

3s,p,d

M

2p

L_2, L_3

2s

L_1

1s

K

Vacuum level

Φ work function

Fermi level

Spectrometer

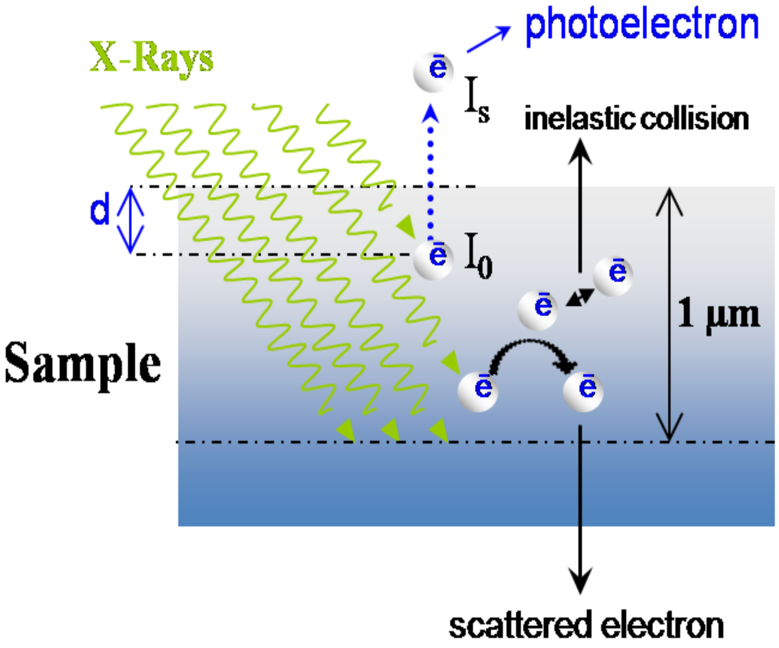
Readout:

Sample

$$BE_{pe} = h\upsilon_{x\text{-}ray} - KE_{pe}$$

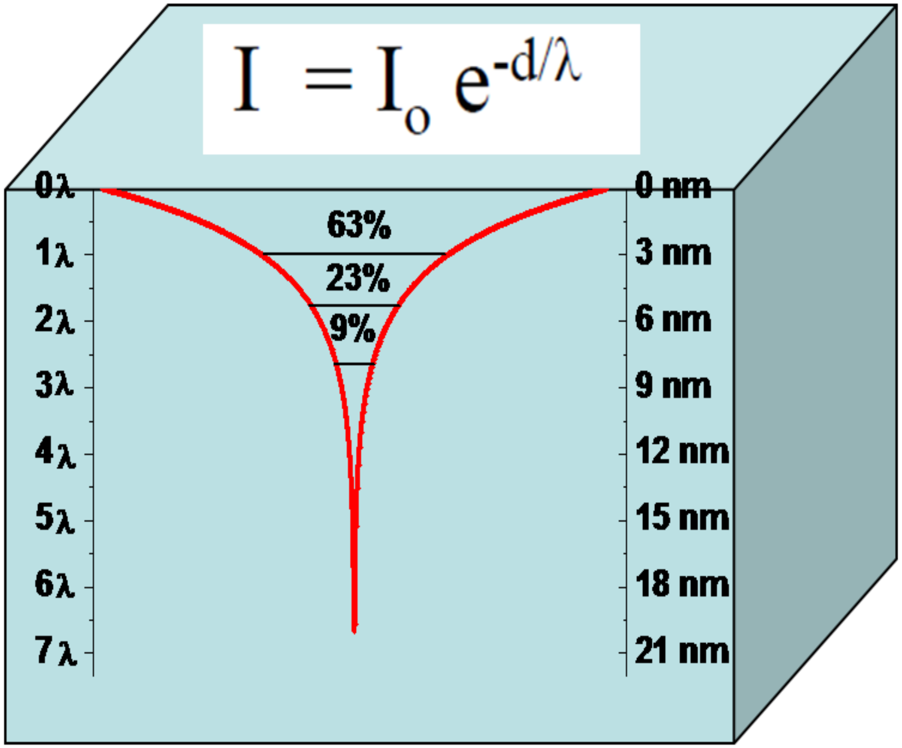
Surface Sensitive

(a)



(b)

Beer-Lambert equ.:



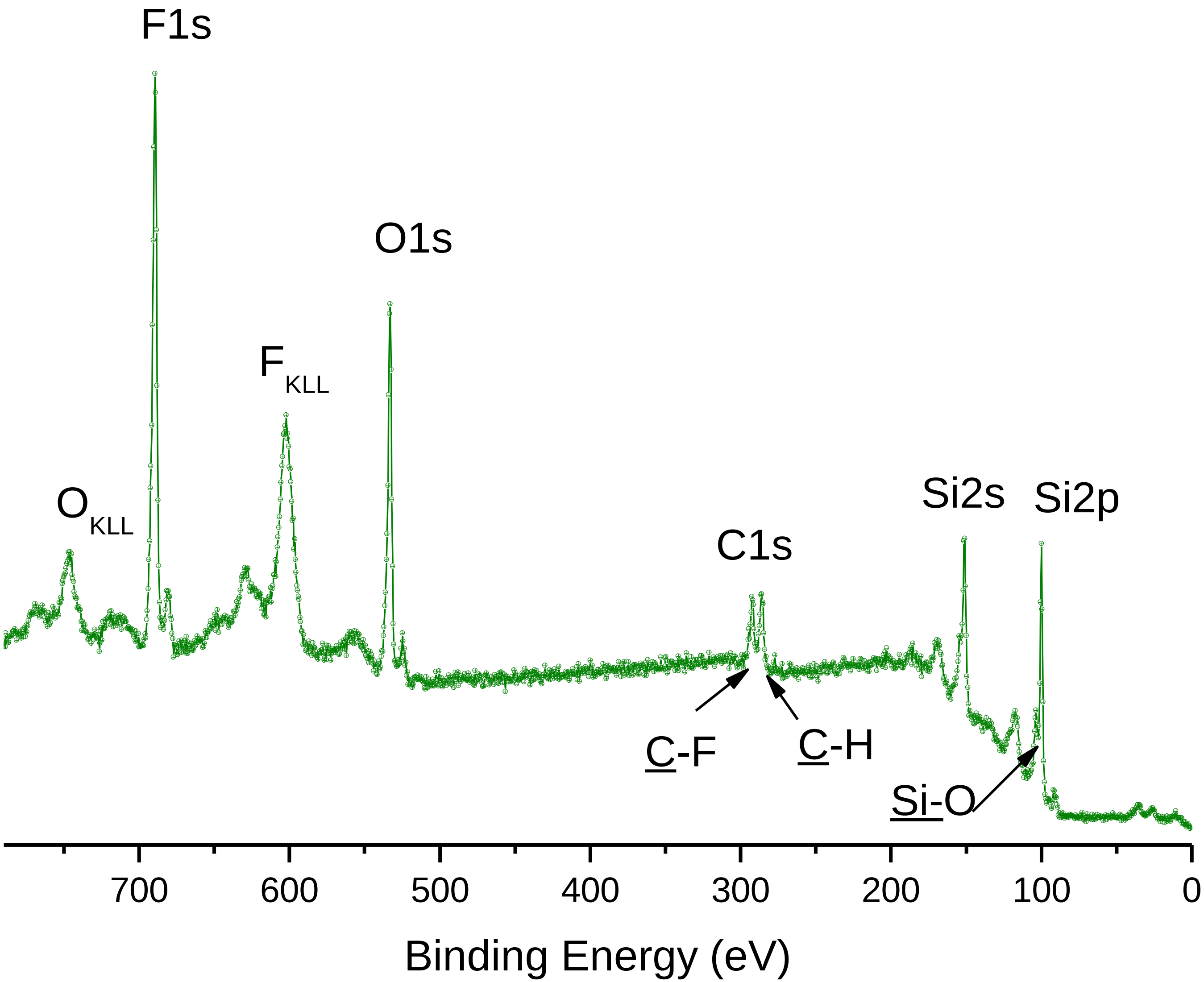
$$I = I_o e^{-d/\lambda}$$

1- Surface Sensitive

2- Element Specificity

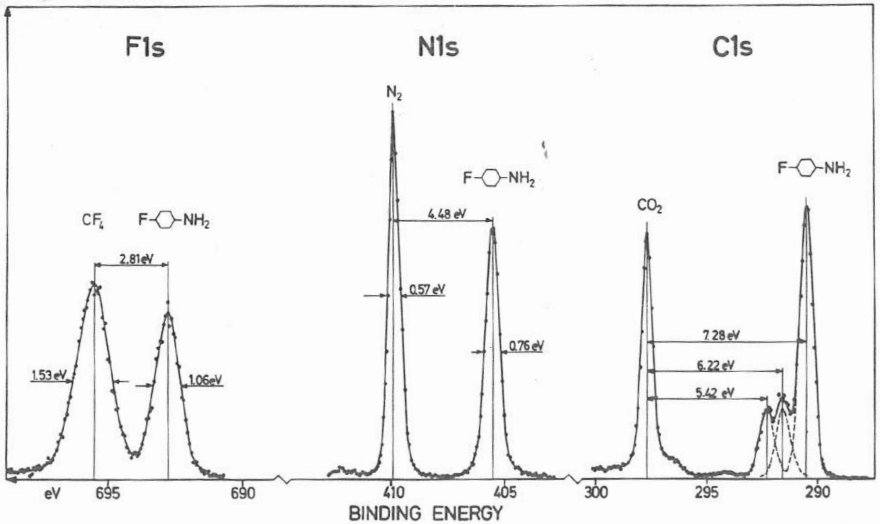
3- Chemical Specificity

Hyrdrophobic Si (<10nm)



Chemical Shifts

1975



39. The core electron spectrum of *para*-aminofluorobenzene. CF$_4$, N$_2$ and CO$_2$ have been used as calibration gases, mixed with the gas sample under study.

CRYSTAL GROWTH & DESIGN

2015

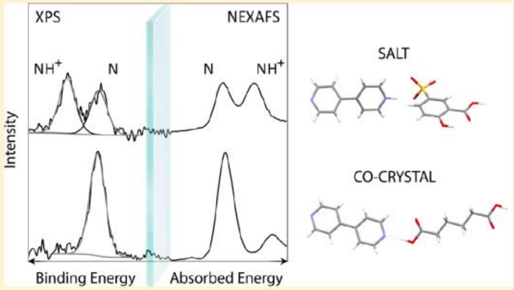
Proton Transfer, Hydrogen Bonding, and Disorder: Edge X-ray Absorption Fine Structure and X-ray Ph Spectroscopy of Bipyridine–Acid Salts and Co-crystals

Joanna S. Stevens,*[†] Lauren K. Newton,[†] Cherno Jaye,[∥] Christopher A. Muryn,[§] Daniel A. Fischer,[∥] and Sven L. M. Schroeder*[†,‡,§]

[†]School of Chemical Engineering and Analytical Science, The University of Manchester, Oxford Road, Manchester M13 9PL, U.K.
[‡]School of Chemical and Process Engineering, University of Leeds, Leeds LS2 9JT, U.K.
[§]School of Chemistry, The University of Manchester, Brunswick Street, Manchester M13 9PL, U.K.
[∥]National Measurement Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, United States

Ⓢ *Supporting Information*

ABSTRACT: The sensitivity of near-edge X-ray absorption fine structure (NEXAFS) spectroscopy to Brønsted donation and the protonation state of nitrogen in the solid state is investigated through a series of multicomponent bipyridine–acid systems alongside X-ray photoelectron spectroscopy (XPS) data. A large shift to high energy occurs for the 1s → 1π^* resonance in the nitrogen K-edge NEXAFS with proton transfer from the acid to the bipyridine base molecule and allows assignment as a salt (C=NH$^+$), with the peak ratio providing the stoichiometry of the types of nitrogen species present. A corresponding binding energy shift for C=NH$^+$ is observed in the nitrogen XPS, clearly identifying protonation and formation of a salt. The similar magnitude shifts observed with both techniques relative to the unprotonated nitrogen of co-crystals (C=N) suggest that the chemical state (initial-state) effects dominate. Results from both techniques reveal the sensitivity to identify proton transfer, hydrogen bond disorder, and even the potential to distinguish variations in hydrogen bond length to nitrogen.



NANO LETTERS

Letter

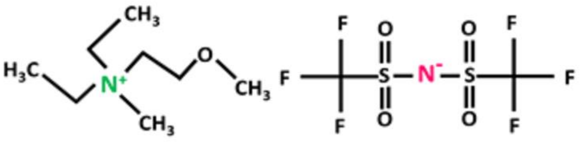
Cite This: *Nano Lett.* 2018, 18, 4541−4548

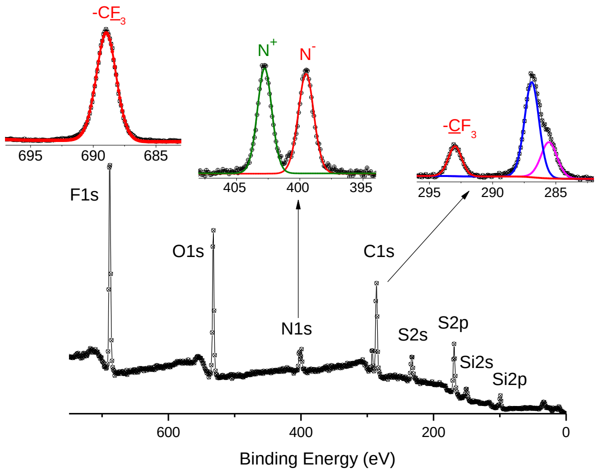
pubs.acs.org/NanoLett

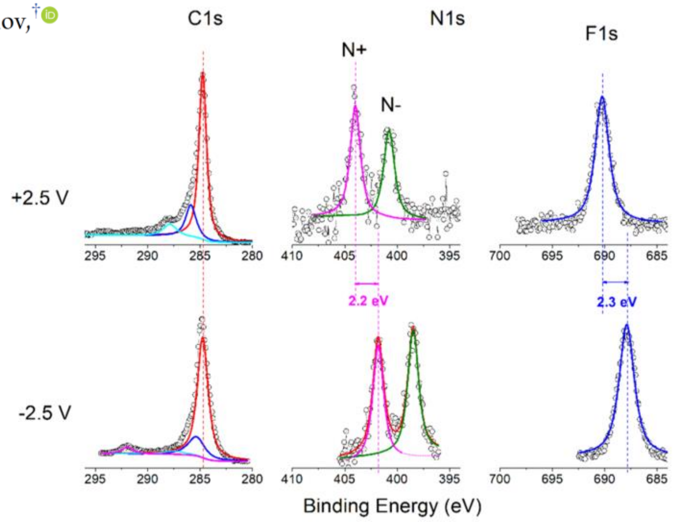
2018

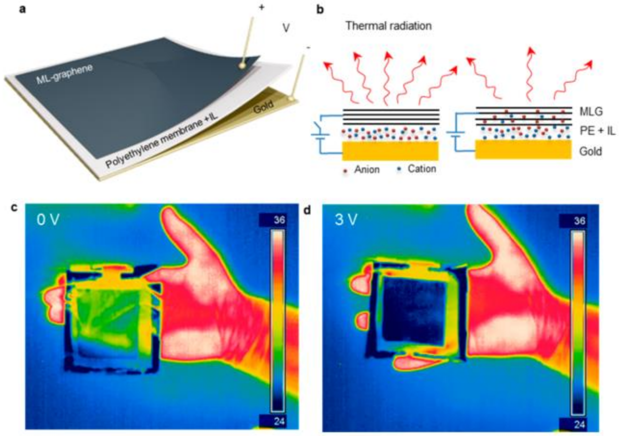
Graphene-Based Adaptive Thermal Camouflage

Omer Salihoglu,[†] Hasan Burkay Uzlu,[†] Ozan Yakar,[†] Shahnaz Aas,[†] Osman Balci,[†] Nurbek Kakenov,[†] Sinan Balci,[‡] Selim Olcum,[§] Sefik Süzer,[∥] and Coskun Kocabas*[,†,⊥]







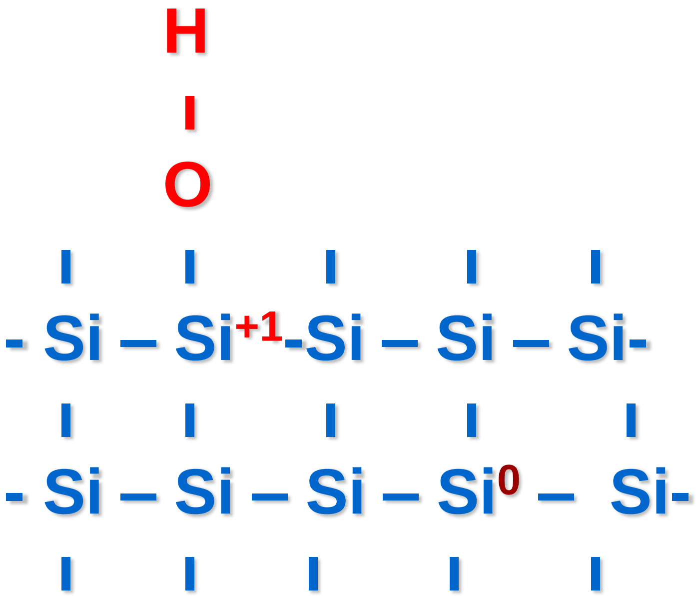


Ionic Liquid Intercalates MLC

Elecetrical Potentials on MLC and IL DIFFER!!!

Chemical Shift

What is it?



H
|
O
| | | | |
- Si – Si^{+1}-Si – Si – Si-
| | | | |
- Si – Si – Si – Si^{0} – Si-
| | | | |

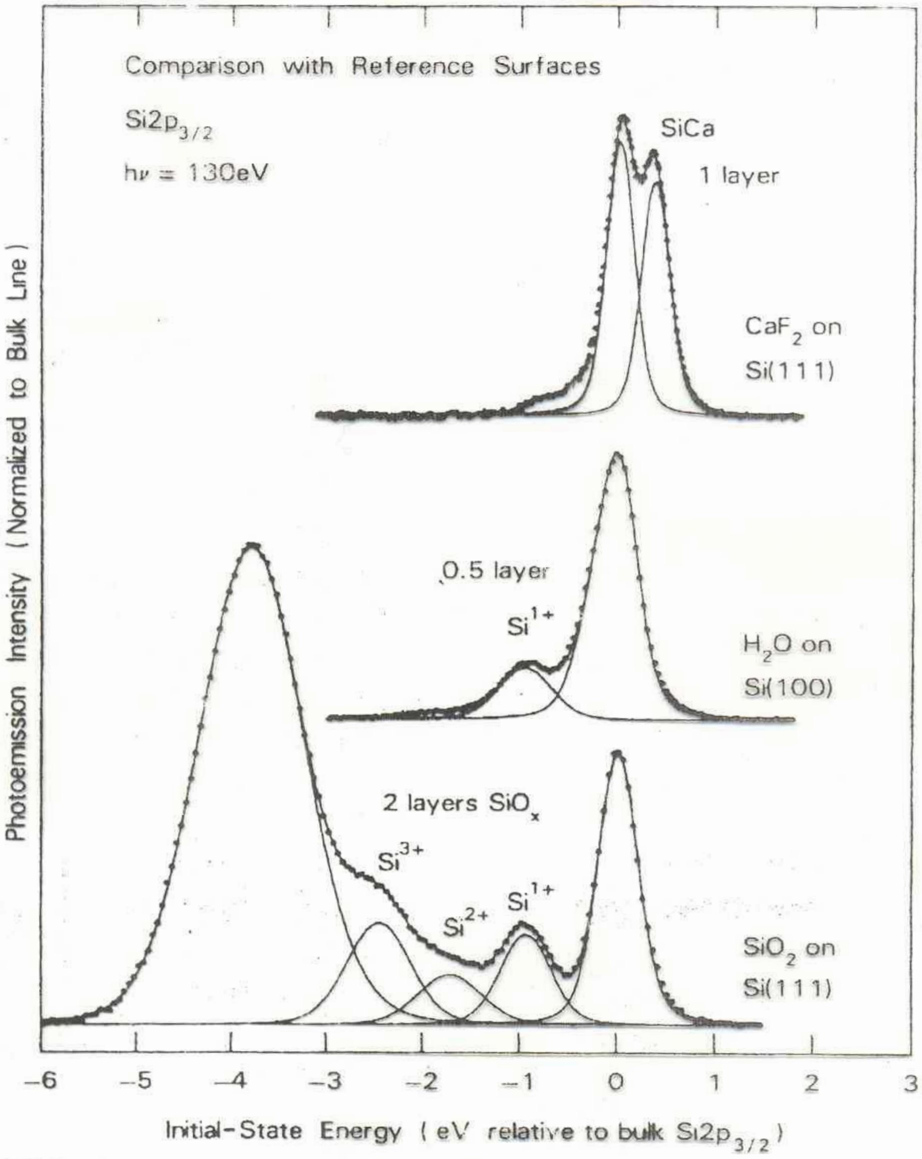
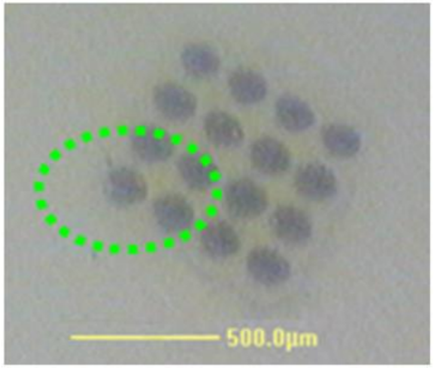
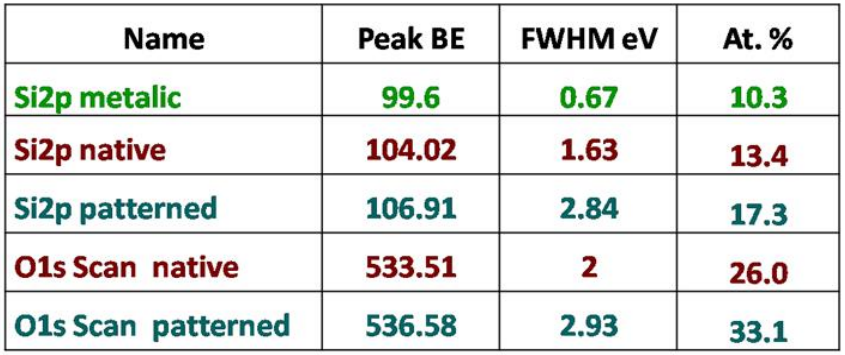


FIG. 3. Comparison of core-level spectra from SiO_2/Si(111) with the CaF_2/Si(111) interface and the H_2O-exposed Si(100)2×1 surface. A density of two Si layers is derived for the Si atoms in intermediate-oxidation states by comparing with the H_2O/Si(100) reference surface.

Elemental Characterization with XPS

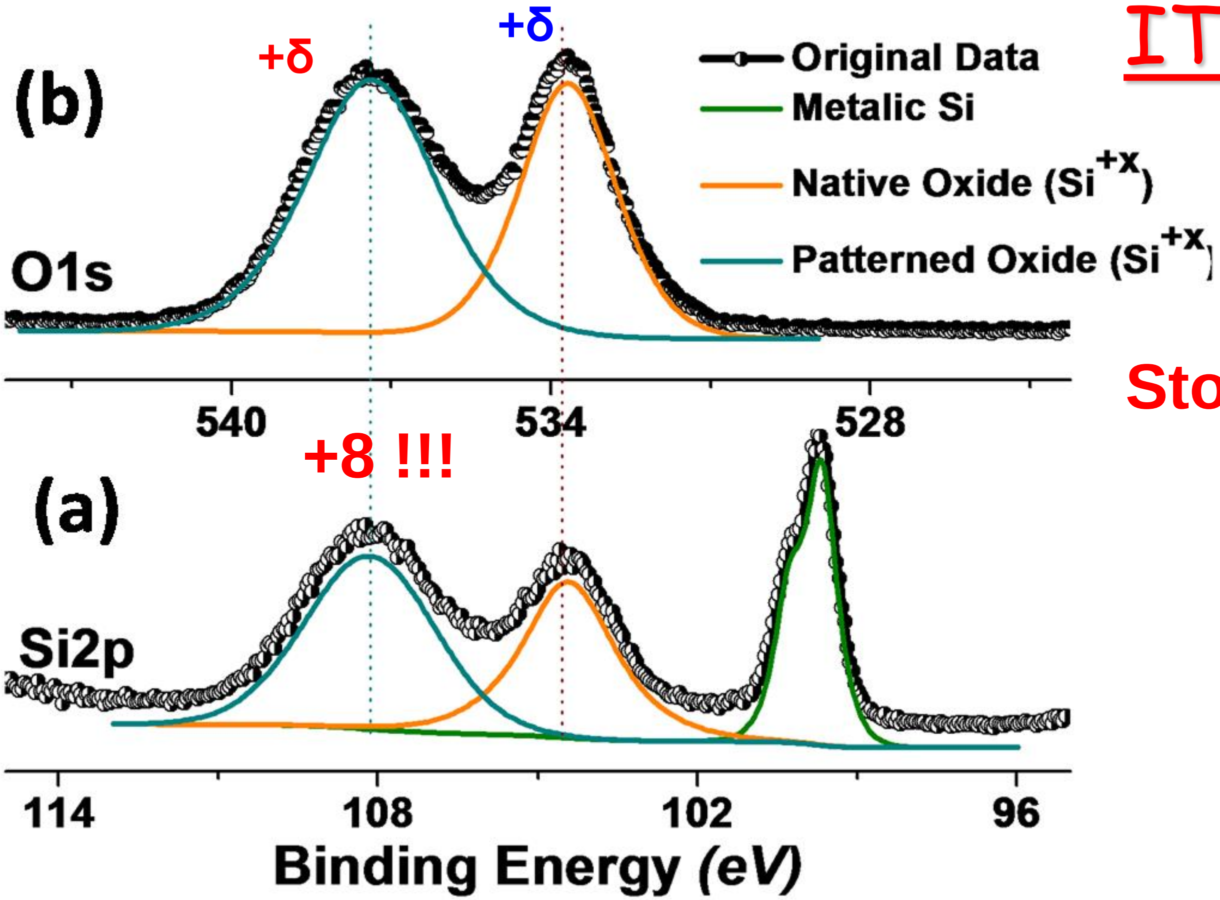




Name	Peak BE	FWHM eV	At. %
Si2p metalic	99.6	0.67	10.3
Si2p native	104.02	1.63	13.4
Si2p patterned	106.91	2.84	17.3
O1s Scan native	533.51	2	26.0
O1s Scan patterned	536.58	2.93	33.1

What

IT IS NOT?

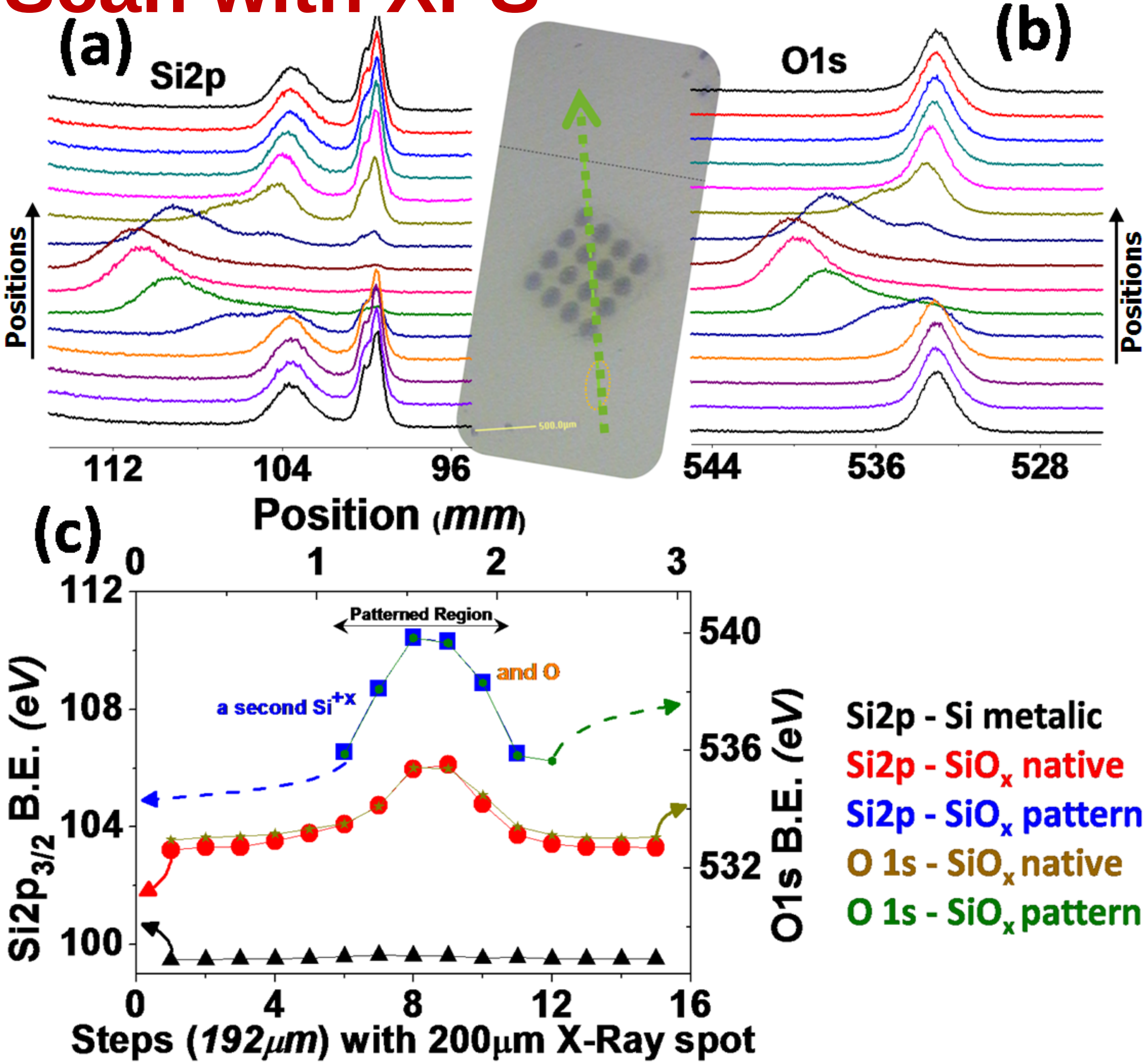


Stoichiometric ratio:

Si:O

~1:2

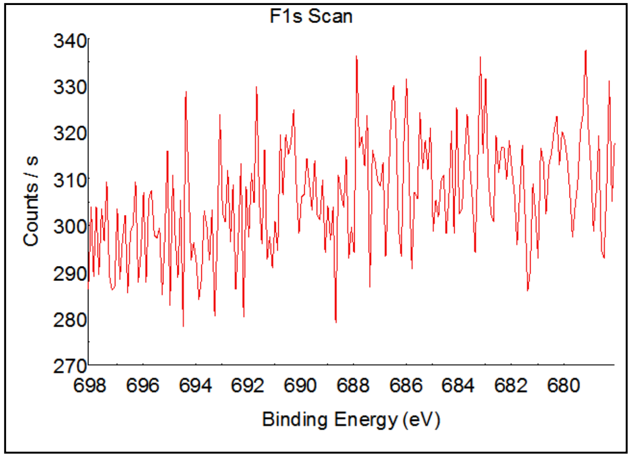
Line Scan with XPS

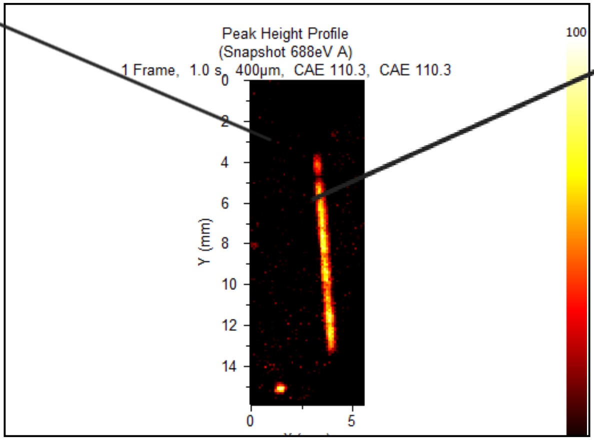


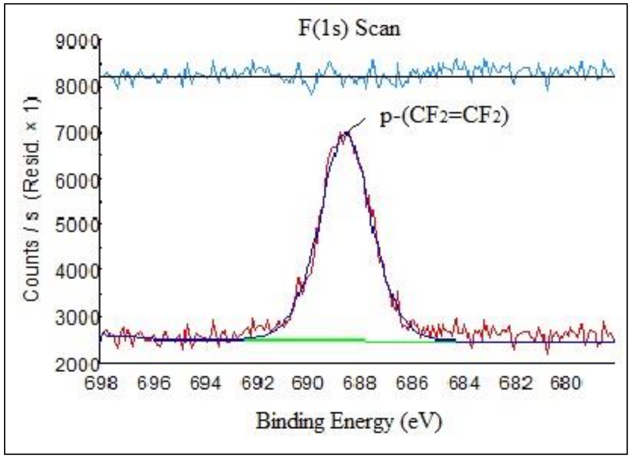
XPS-SEM RESULTS

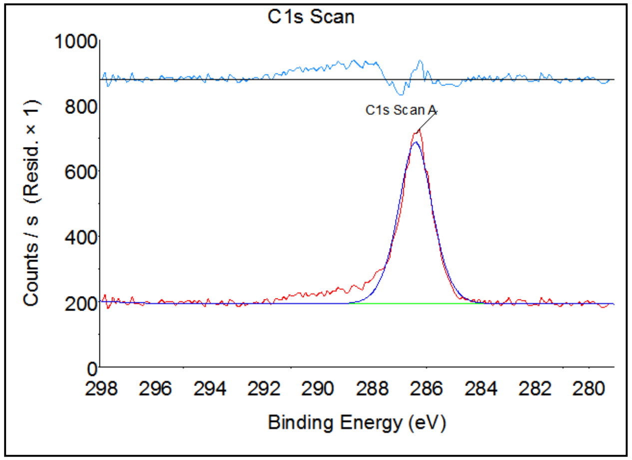
off the line

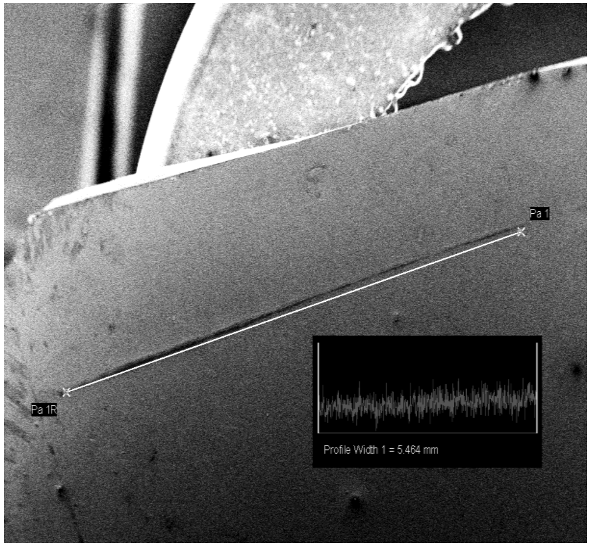
on the line

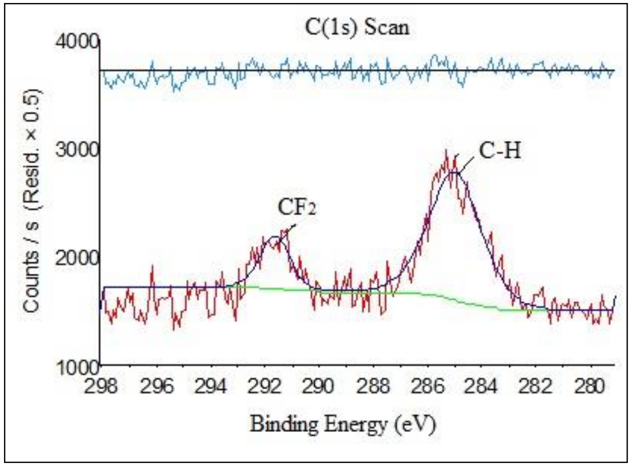




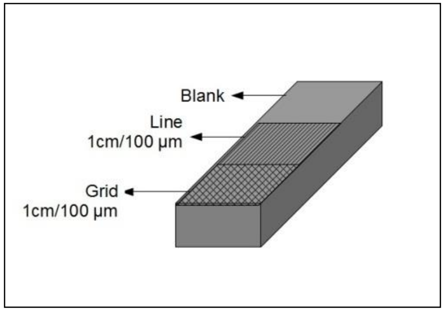


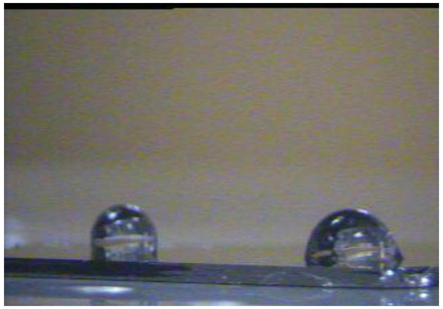


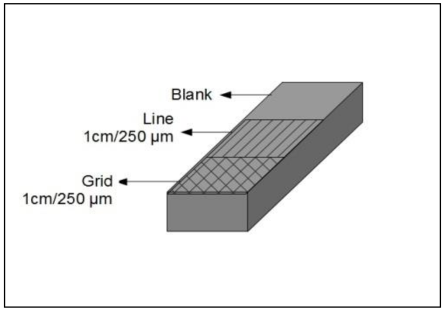




WCA results of ‘as is’ surfaces – Case: Grid+Line+Blank







WCA(^{0}) Results

Density of PTFE	Blank	Line	Grid
(1cm/100μm)	51	76	98
(1cm/250μm)	46	89	100

Experimental Details

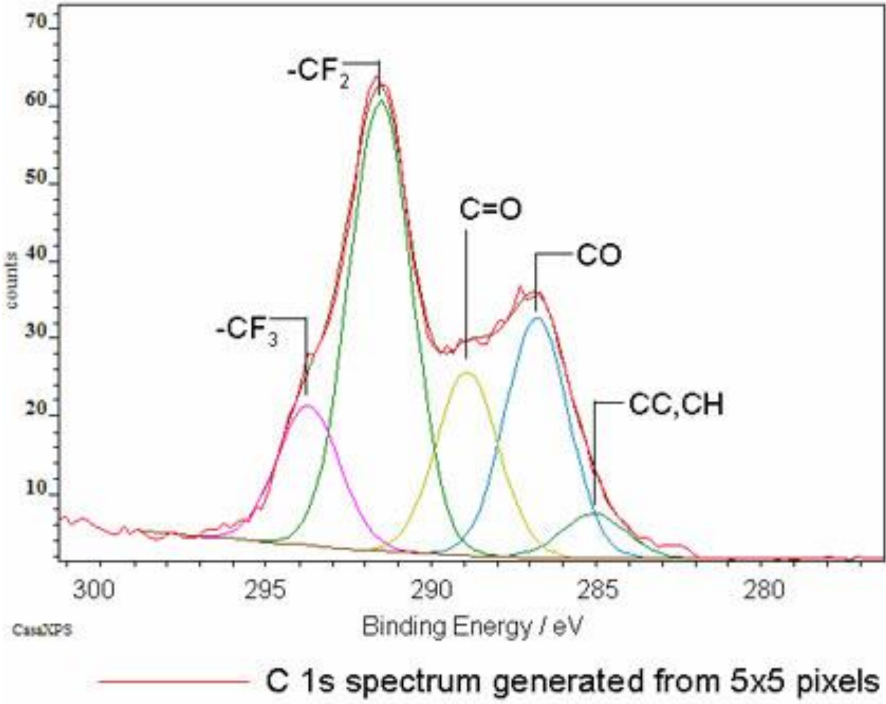
- -Data Gathering Modes
    - -Survey Scans (Poorer Energy Resolution)
    - -Regions Scans
    - -Line Scans
    - -Iterations in Snap-Shot Mode (>10 ms)
    - -Areal Scans and Maps
        - Lateral Position or Energy

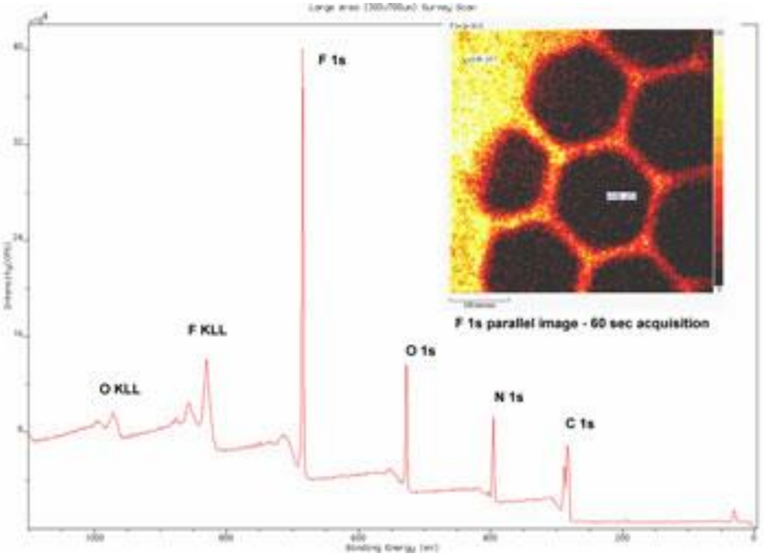
-Lateral Resolution	30-400 μm
-Time Resolution	>10 ms

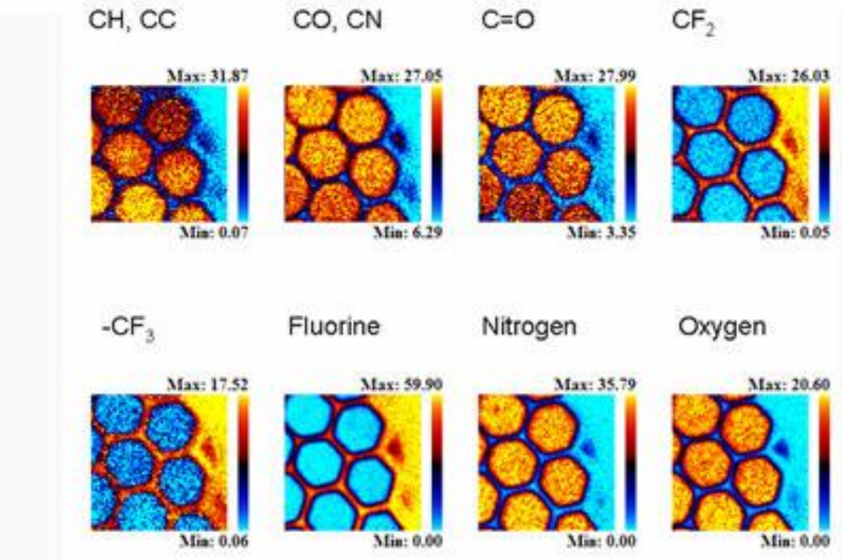
-Depth Information (4-6 nm, XPS)

LIMITATIONS

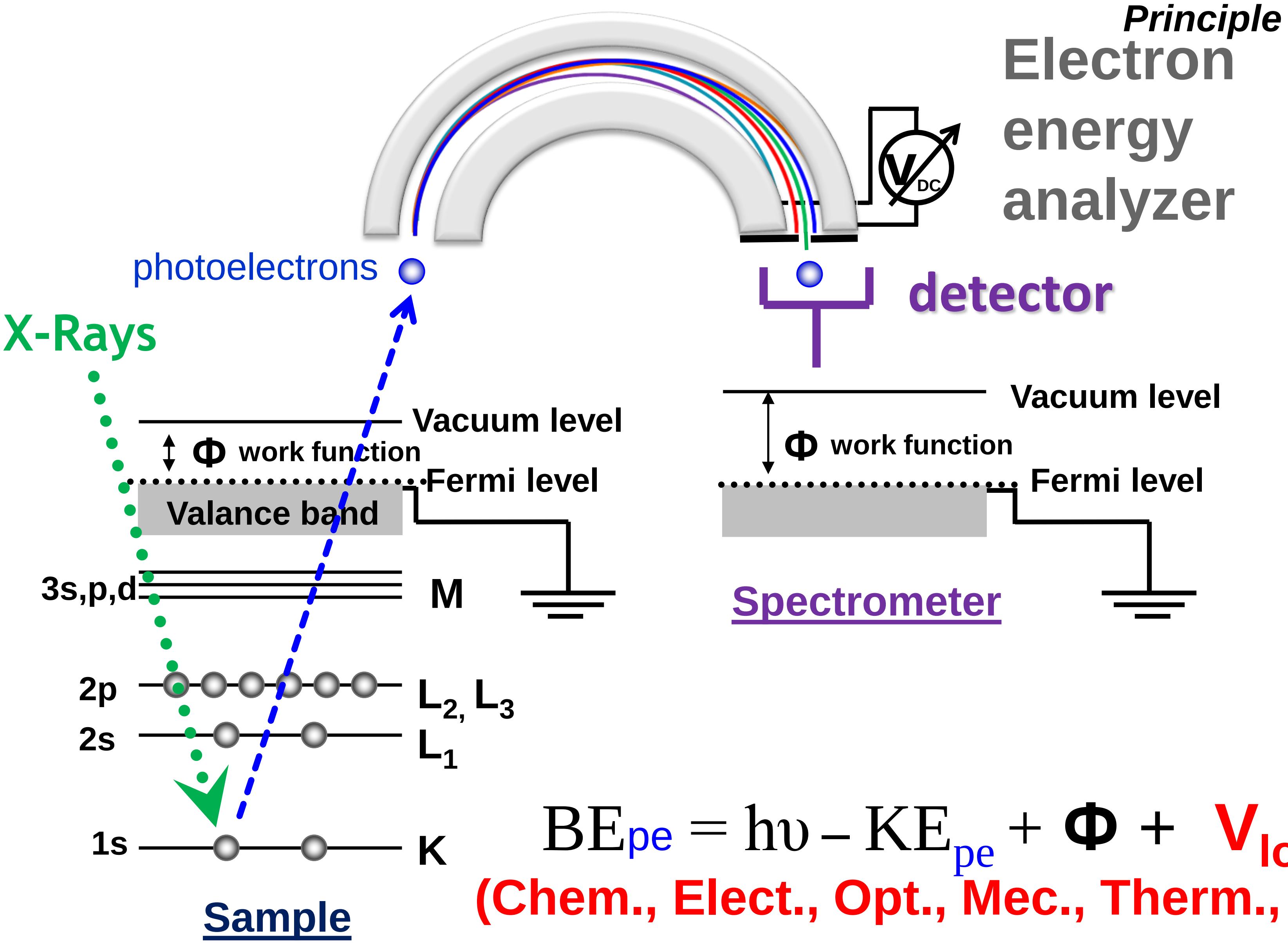
Lateral Resolution: ~5 μm
Time Resolution: ~10 ms
Element Sensitivity: ~0.5 %
Chemical Sensitivity: Fair
Physical (Phases) Sen.: Poor
(No Way to Distinguish say btwn ANATASE x RUTILE !!!)







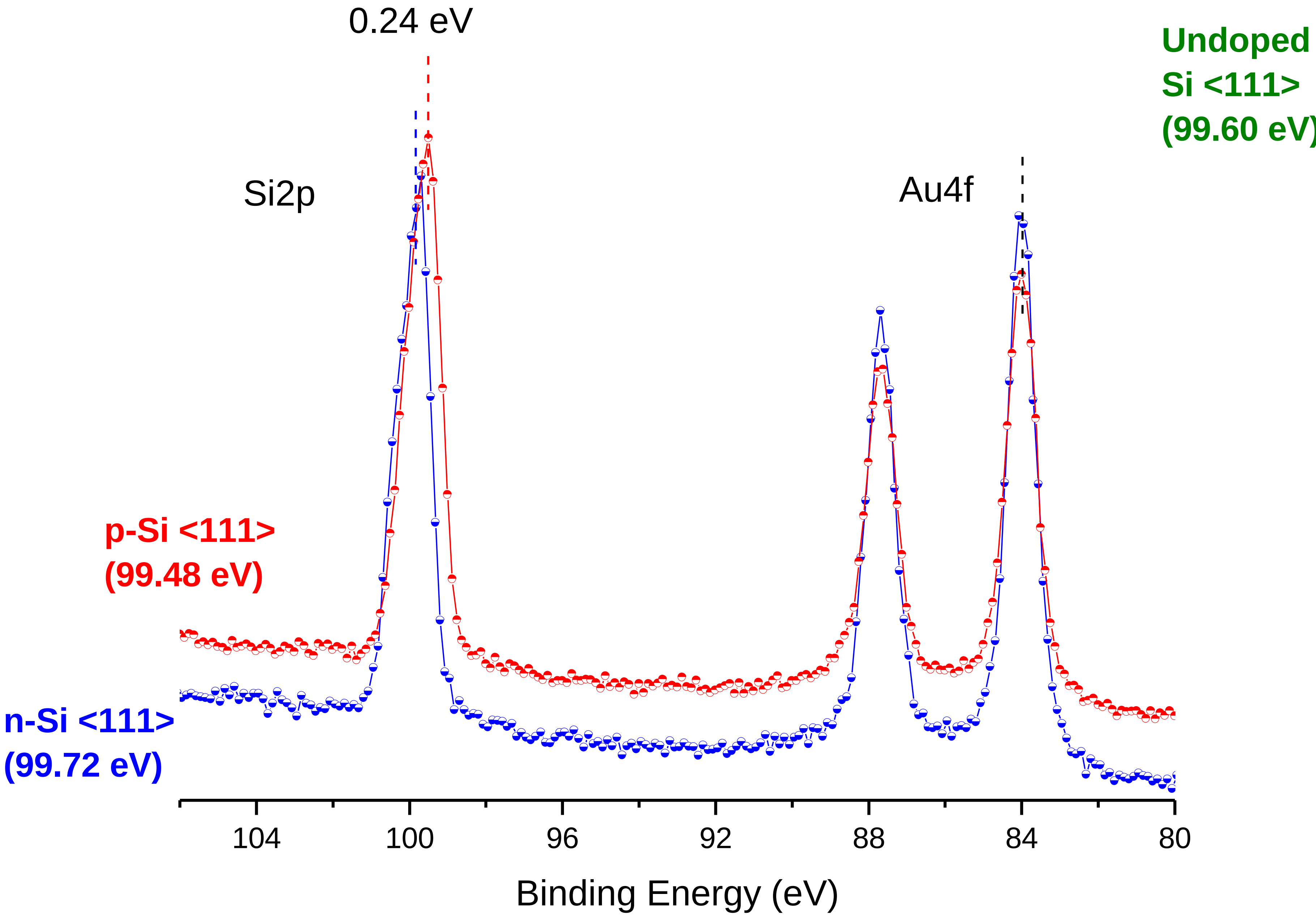
X-ray Photoelectron Spectroscopy:



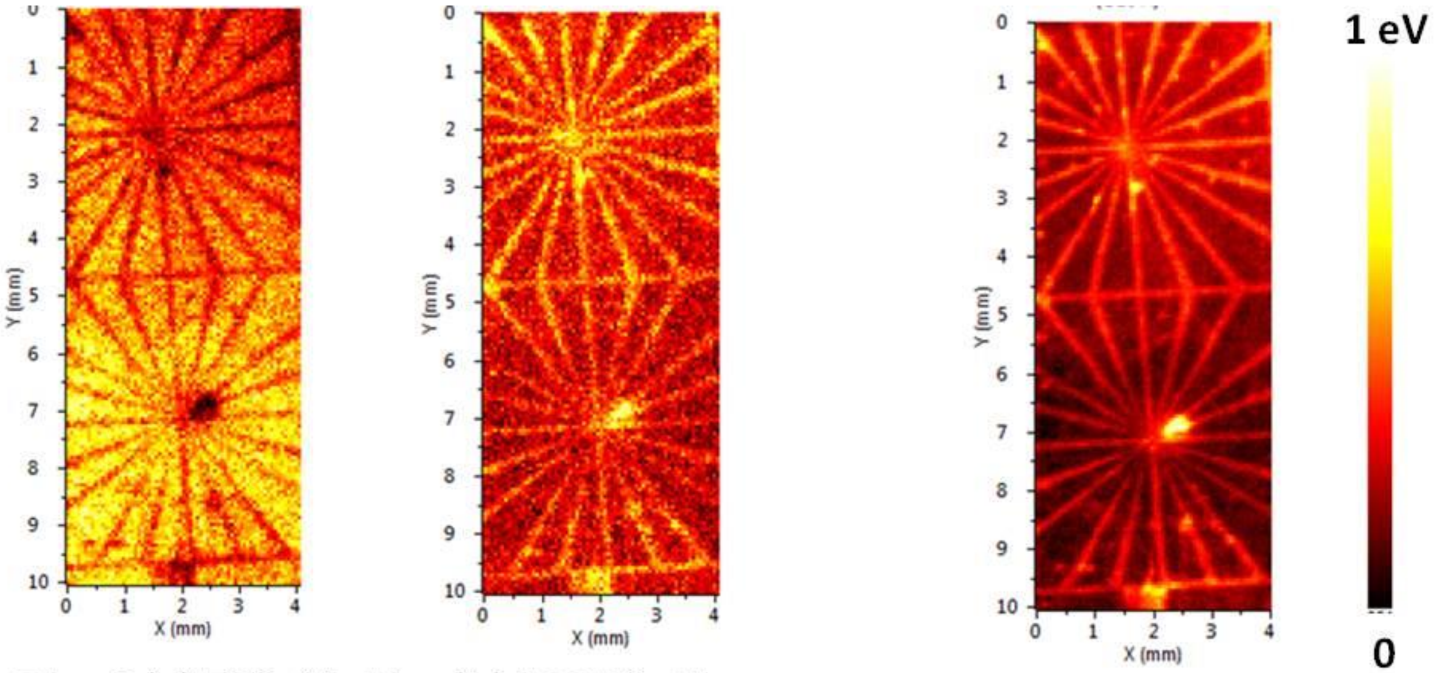
$$BE_{pe} = h\upsilon - KE_{pe} + \Phi + V_{loc}$$

(Chem., Elect., Opt., Mec., Therm., etc.)

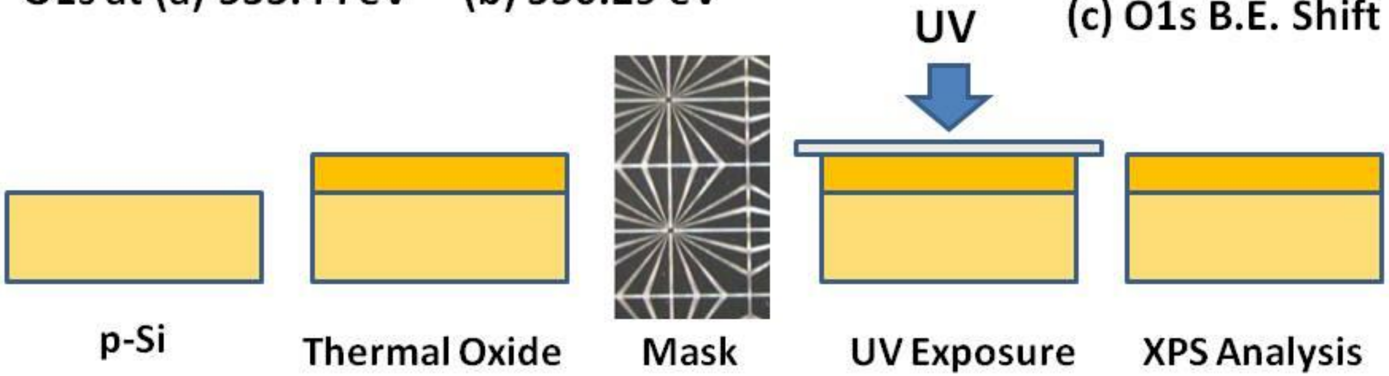
- Charge Sensitivity



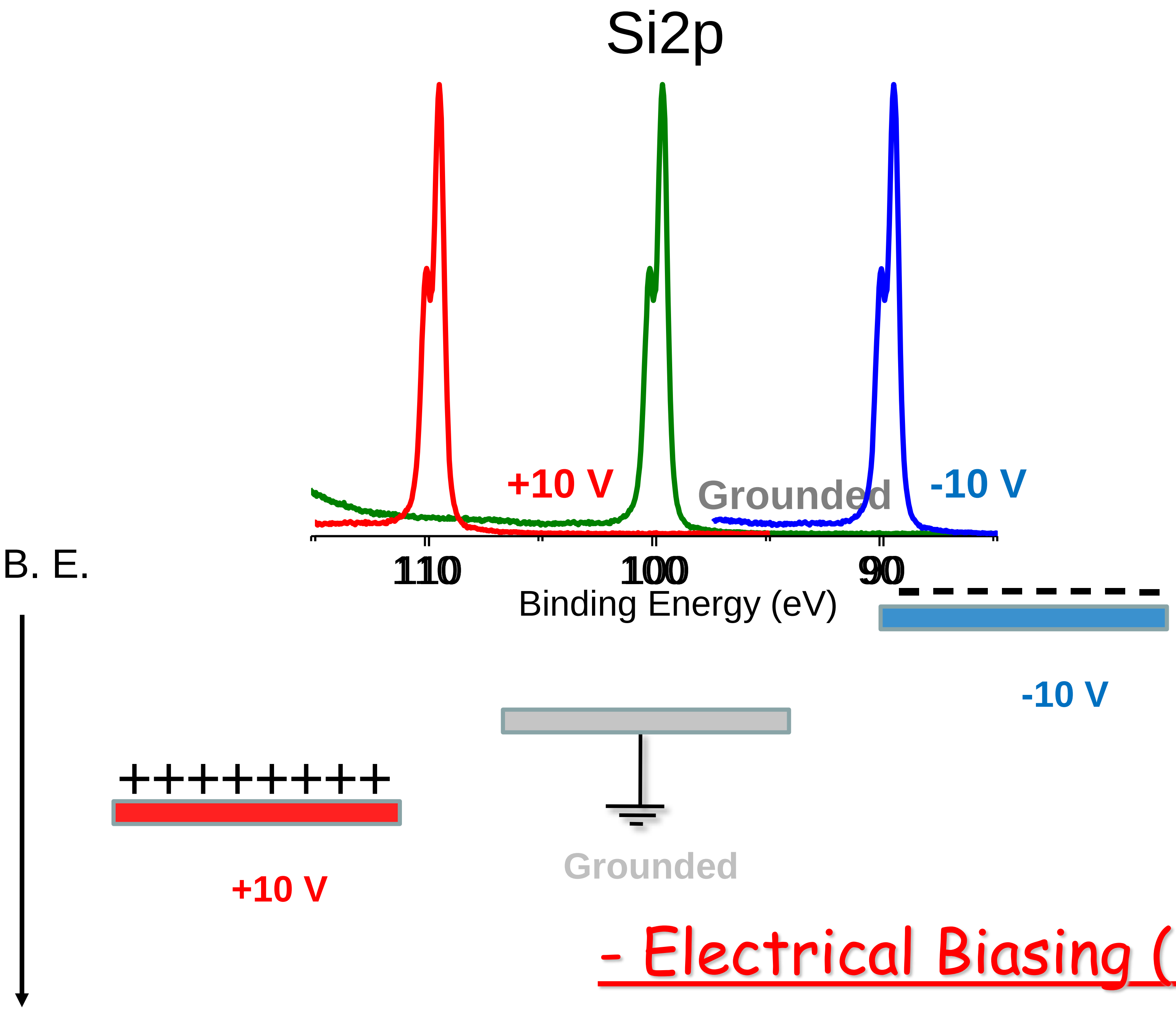
4- Charge Sensitive



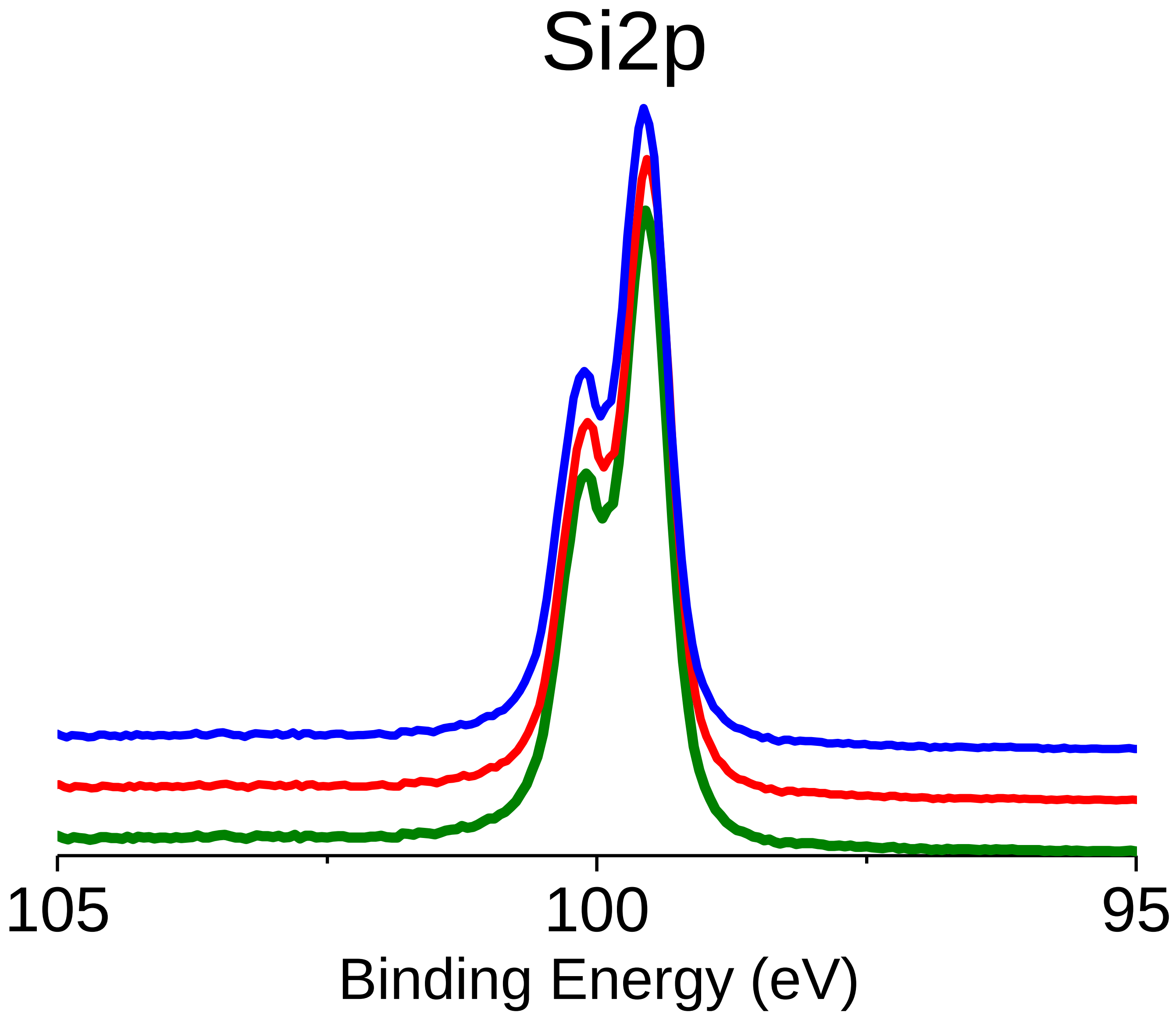
O1s at (a) 533.44 eV (b) 530.29 eV (c) O1s B.E. Shift



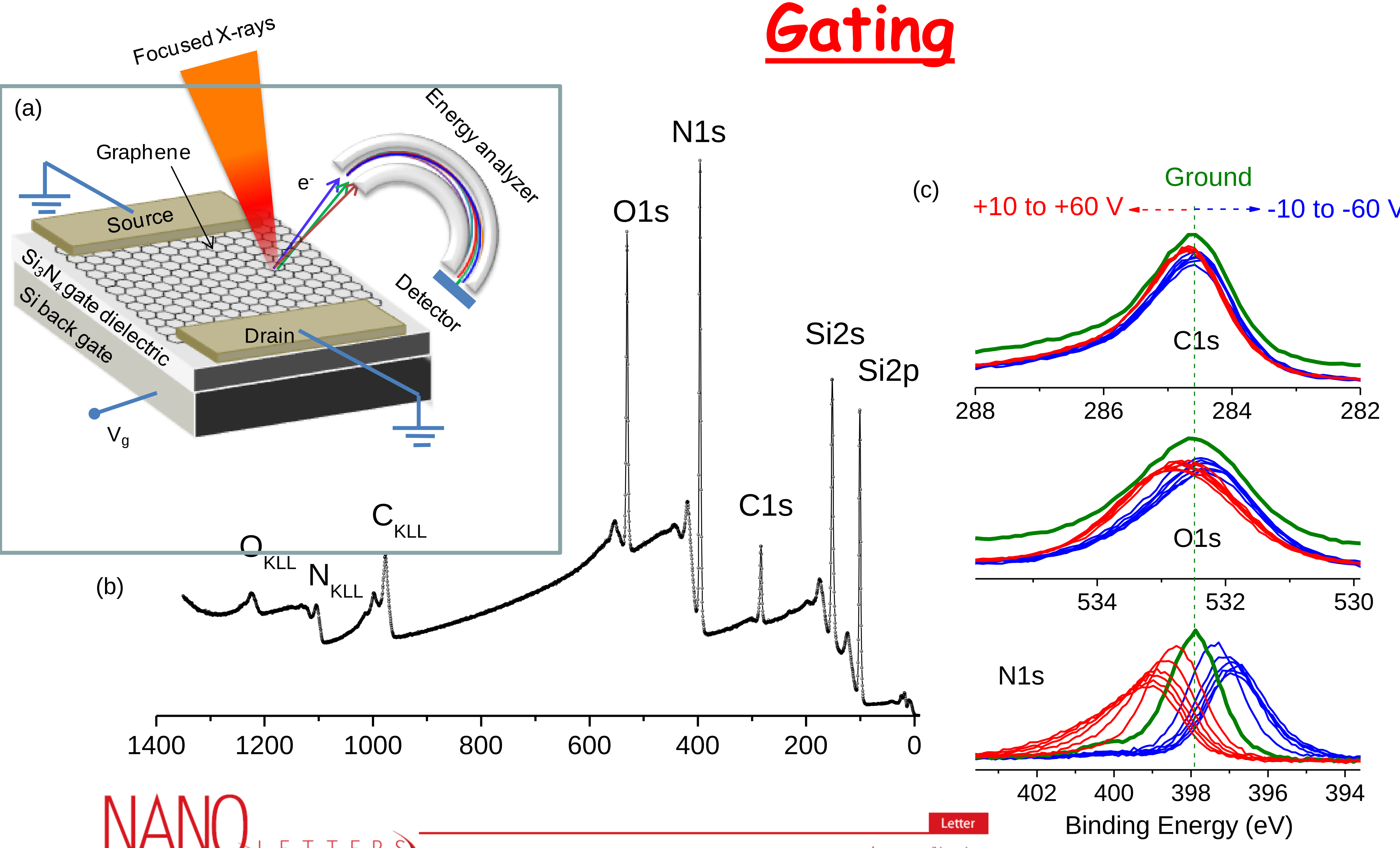
- Electrical Biasing (D.C.)



TRIVIAL SHIFTS FOR CONDUCTING MATERIALS



Gating



NANO LETTERS

Letter

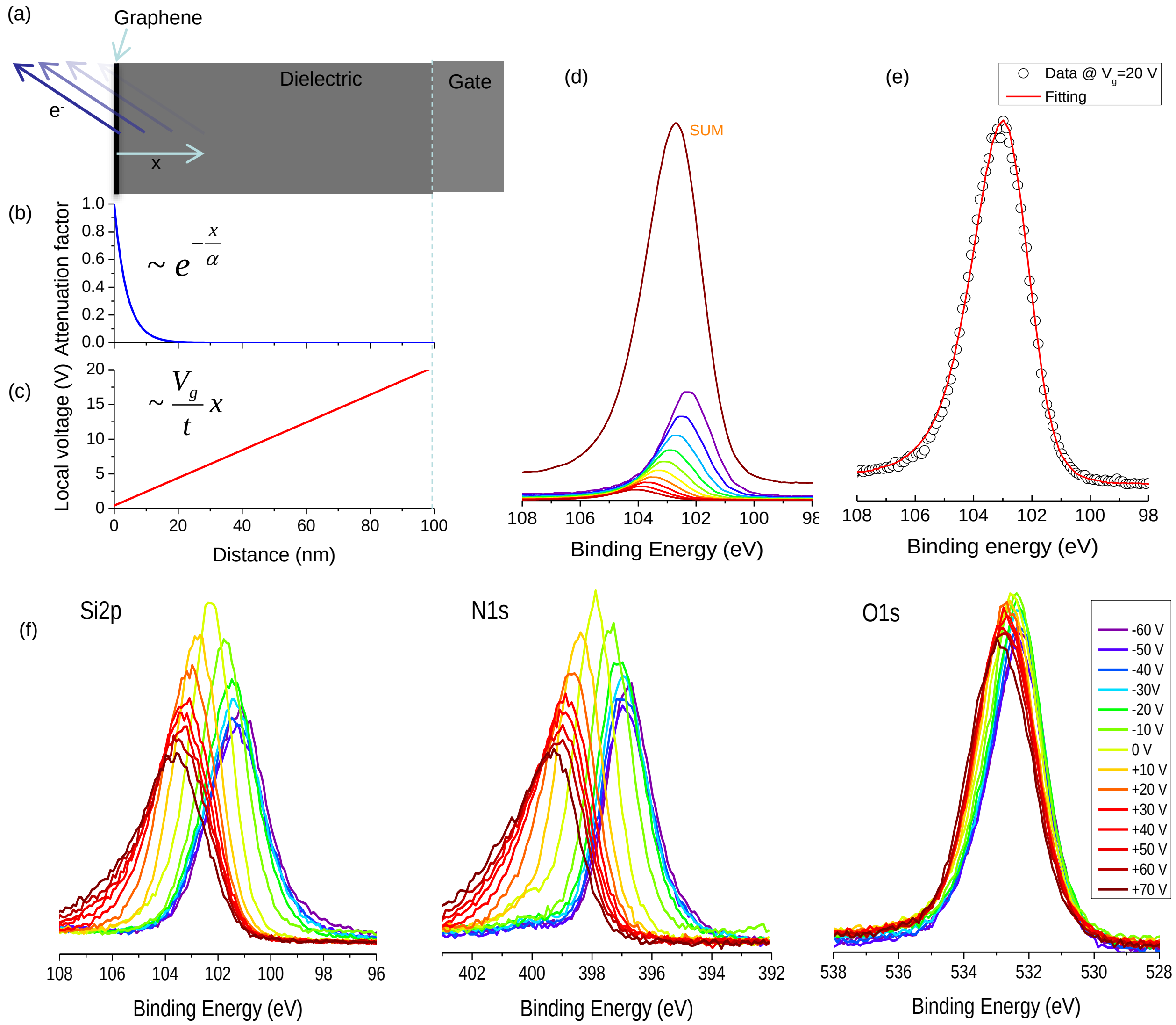
pubs.acs.org/NanoLett

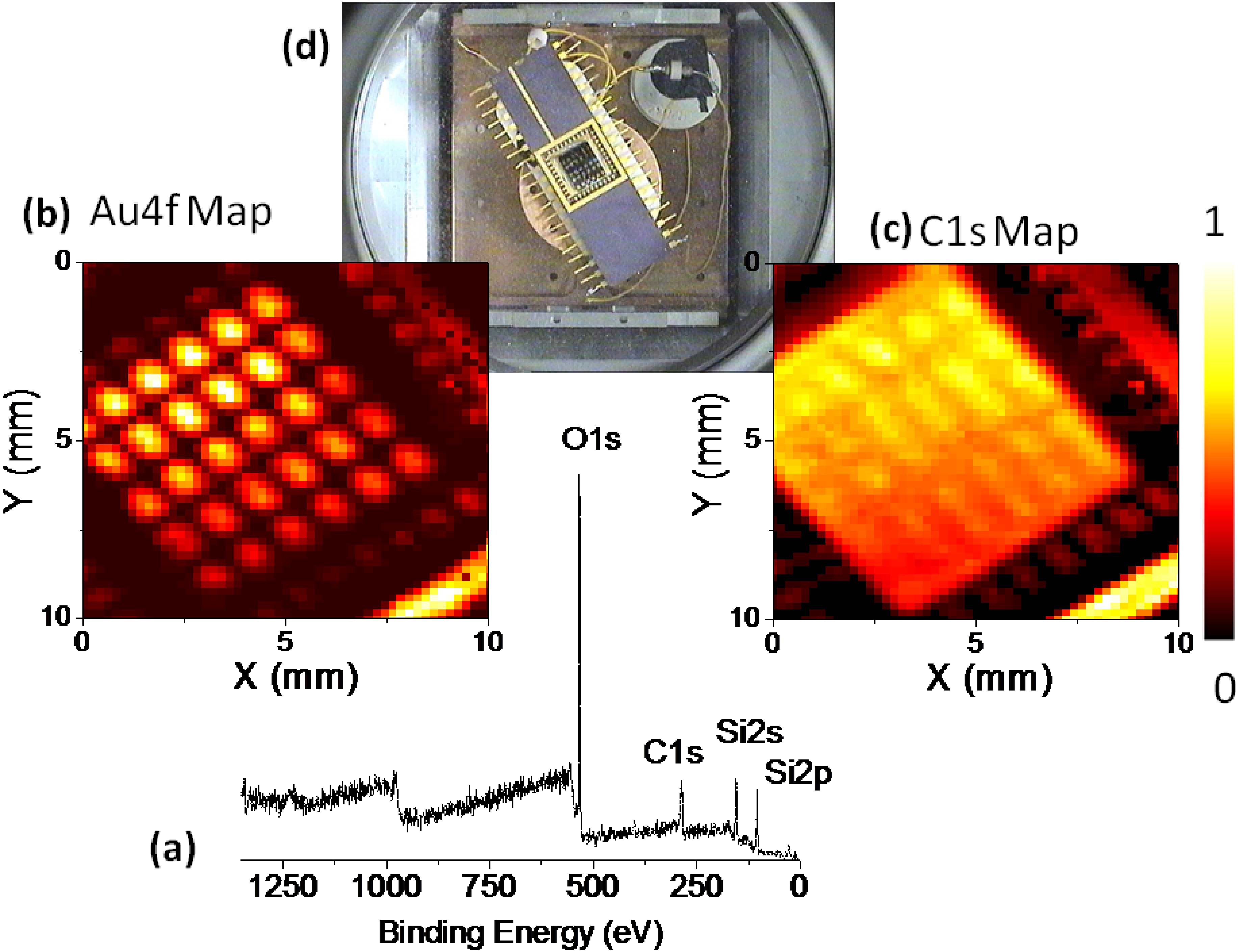
dx.doi.org/10.1021/nl500842y | *Nano Lett.* 2014, 14, 2837−2842

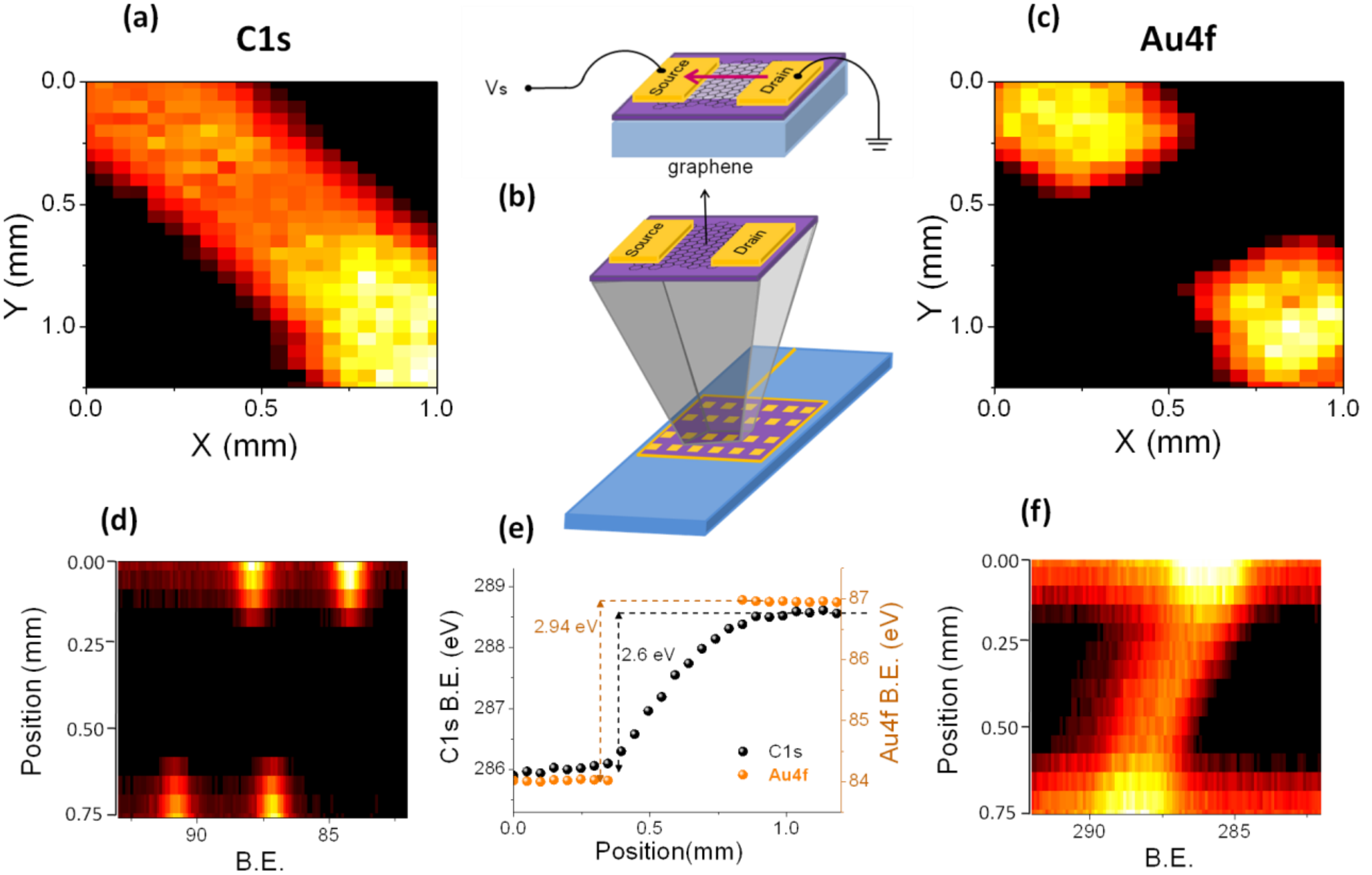
Gate-Tunable Photoemission from Graphene Transistors

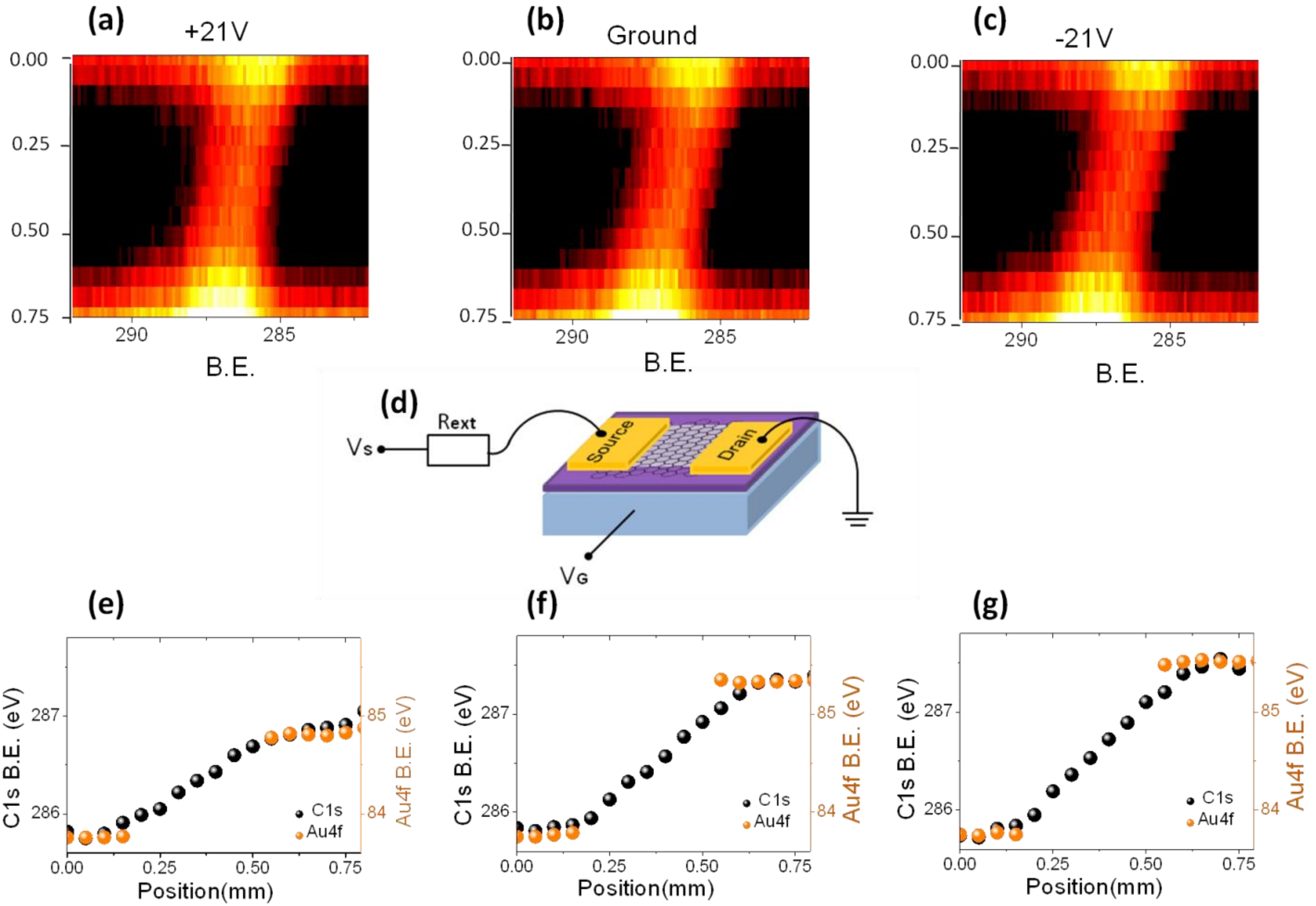
Mehmet Copuroglu,[†] Pinar Aydogan,[†] Emre O. Polat,[‡] Coskun Kocabas,[*,‡] and Sefik Süzer[*,†]

[†]Department of Chemistry and [‡]Department of Physics, Bilkent University, Ankara 06800, Turkey

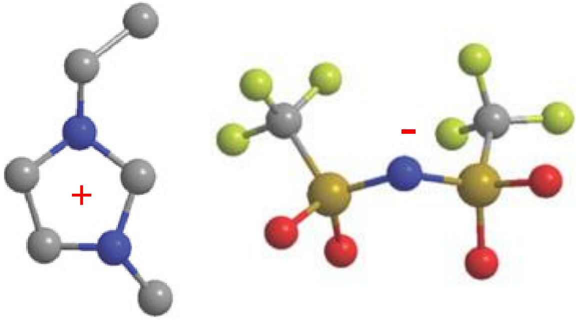

(a)
Graphene
Dielectric
Gate
e-
x
(b)
Attenuation factor
1.0
0.8
0.6
0.4
0.2
0.0
$\sim e^{-\frac{x}{\alpha}}$
(c)
Local voltage (V)
20
15
10
5
0
$\sim \frac{V_g}{t}x$
0
20
40
60
80
100
Distance (nm)
(d)
SUM
108
106
104
102
100
98
Binding Energy (eV)
(e)
Data @ V_g=20 V
Fitting
108
106
104
102
100
98
Binding energy (eV)
(f)
Si2p
108
106
104
102
100
98
96
Binding Energy (eV)
N1s
402
400
398
396
394
392
Binding Energy (eV)
O1s
538
536
534
532
530
528
Binding Energy (eV)
-60 V
-50 V
-40 V
-30V
-20 V
-10 V
0 V
+10 V
+20 V
+30 V
+40 V
+50 V
+60 V
+70 V


(d)
(b) Au4f Map
(c) C1s Map
1
0
0
5
10
Y (mm)
0
5
10
X (mm)
O1s
C1s
Si2s
Si2p
(a)
1250
1000
750
500
250
0
Binding Energy (eV)


(a)
C1s
Y (mm)
0.0
0.5
1.0
X (mm)
0.0
0.5
1.0
Vs
Source
Drain
graphene
(b)
Source
Drain
(c)
Au4f
Y (mm)
0.0
0.5
1.0
X (mm)
0.0
0.5
1.0
(d)
Position (mm)
0.00
0.25
0.50
0.75
90
85
B.E.
(e)
C1s B.E. (eV)
289
288
287
286
2.94 eV
2.6 eV
C1s
Au4f
Au4f B.E. (eV)
87
86
85
84
0.0
0.5
1.0
Position(mm)
(f)
Position (mm)
0.00
0.25
0.50
0.75
290
285
B.E.


(a)
+21V
(b)
Ground
(c)
-21V
0.00
0.25
0.50
0.75
290
285
B.E.
(d)
Rext
Vs
Source
Drain
VG
(e)
(f)
(g)
C1s B.E. (eV)
Au4f B.E. (eV)
286
287
84
85
C1s
Au4f
0.00
0.25
0.50
0.75
Position(mm)

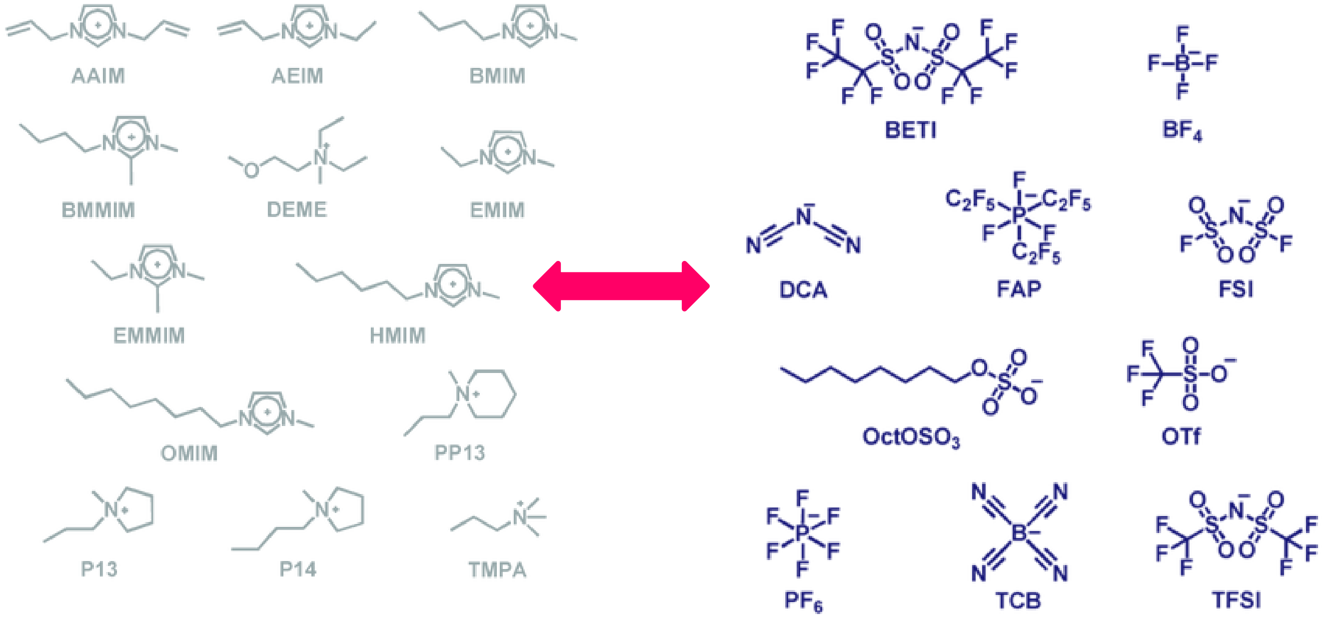
‘Ionic Liquid’



Ionic Liquids (IL) is.....

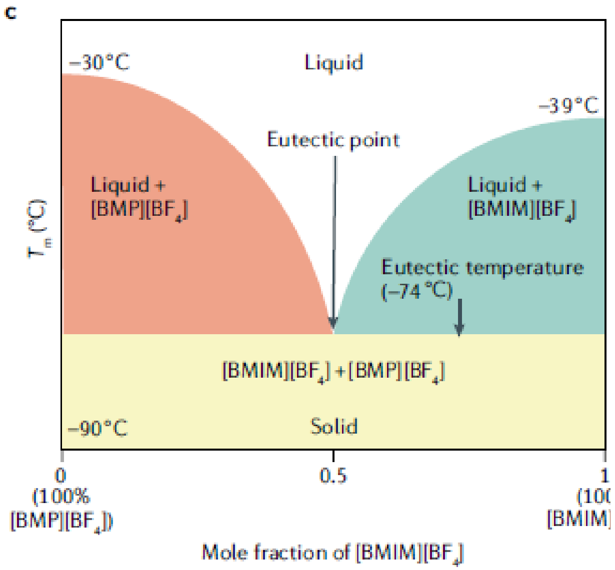
Molten salt but at Room Temperature
composed only of large anions & cations

- ➢ ~No vapor pressure
- ➢ Designable & unlimited combinations



Electrode material–ionic liquid coupling for electrochemical energy storage

Xuehang Wang[1], Maryam Salari[2], De-en Jiang[3], Jennifer Chapman Varela[2], Babak Anasori[1], David J. Wesolowski[4], Sheng Dai[4], Mark W. Grinstaff[2]✉ and Yury Gogotsi[1]✉



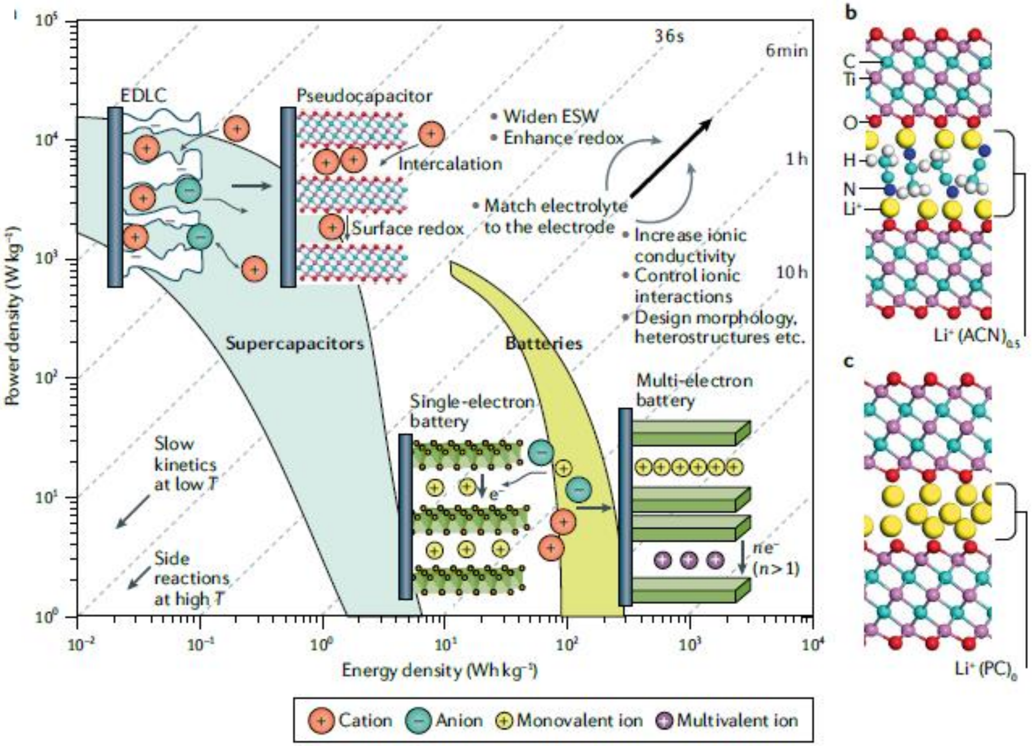
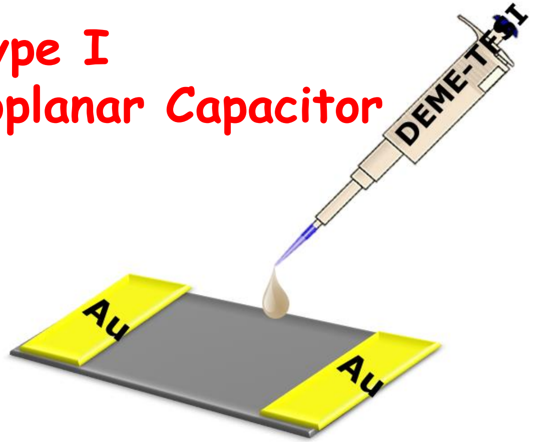


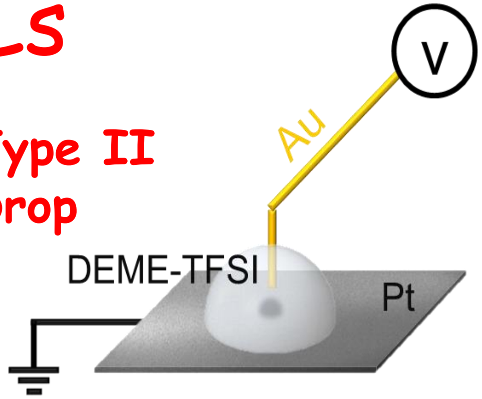
Fig. 6 | **New electrolyte–electrode interfaces. a** | A Ragone plot for electric double-layer capacitors (EDLCs) and Li-ion batteries, summarizing the key strategies to improve the energy and power density. The schematic shows that the introduction of pseudocapacitance (involving pseudocapacitive intercalation and surface redox process) and multi-electron redox processes (involving multi-phase transformations and multi-electron transfers per ion) can increase the energy density of EDLCs and batteries, respectively. The grey dashed lines indicate the time for complete charging or discharging of the device. **b** | A molecular dynamics (MD)-simulated image of a $Ti_3C_2T_x$ electrode in 1 M Li[TFSI] (where [TFSI]$^-$ is bis(trifluoromethanesulfonyl)imide) in acetonitrile (ACN), showing the arrangement of ACN and Li ions confined between the charged $Ti_3C_2T_x$ layers[212]. **c** | A MD-simulated image of a $Ti_3C_2T_x$ electrode in 1 M Li[TFSI] in propylene carbonate (PC), showing that the Li ions confined between the charged $Ti_3C_2T_x$ layers are fully desolvated[212]. The size of the Li ions is increased for clarity in the simulated images. ESW, electrochemical stability window; *T*, temperature. Panels **b** and **c** adapted from REF.[212], Springer Nature Limited.

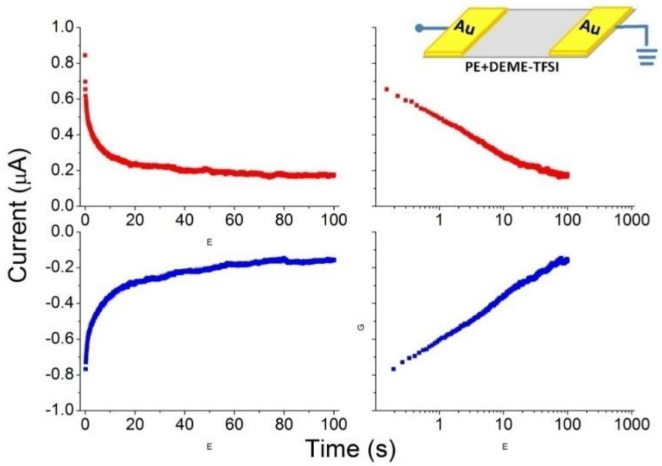
Devices with ILs

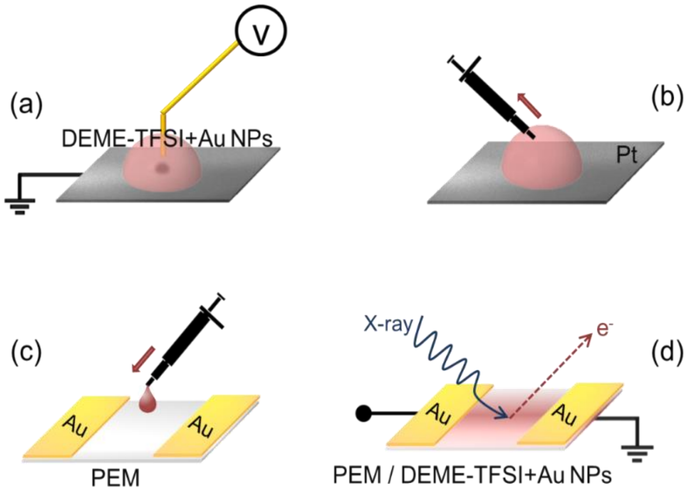
Type I
Coplanar Capacitor



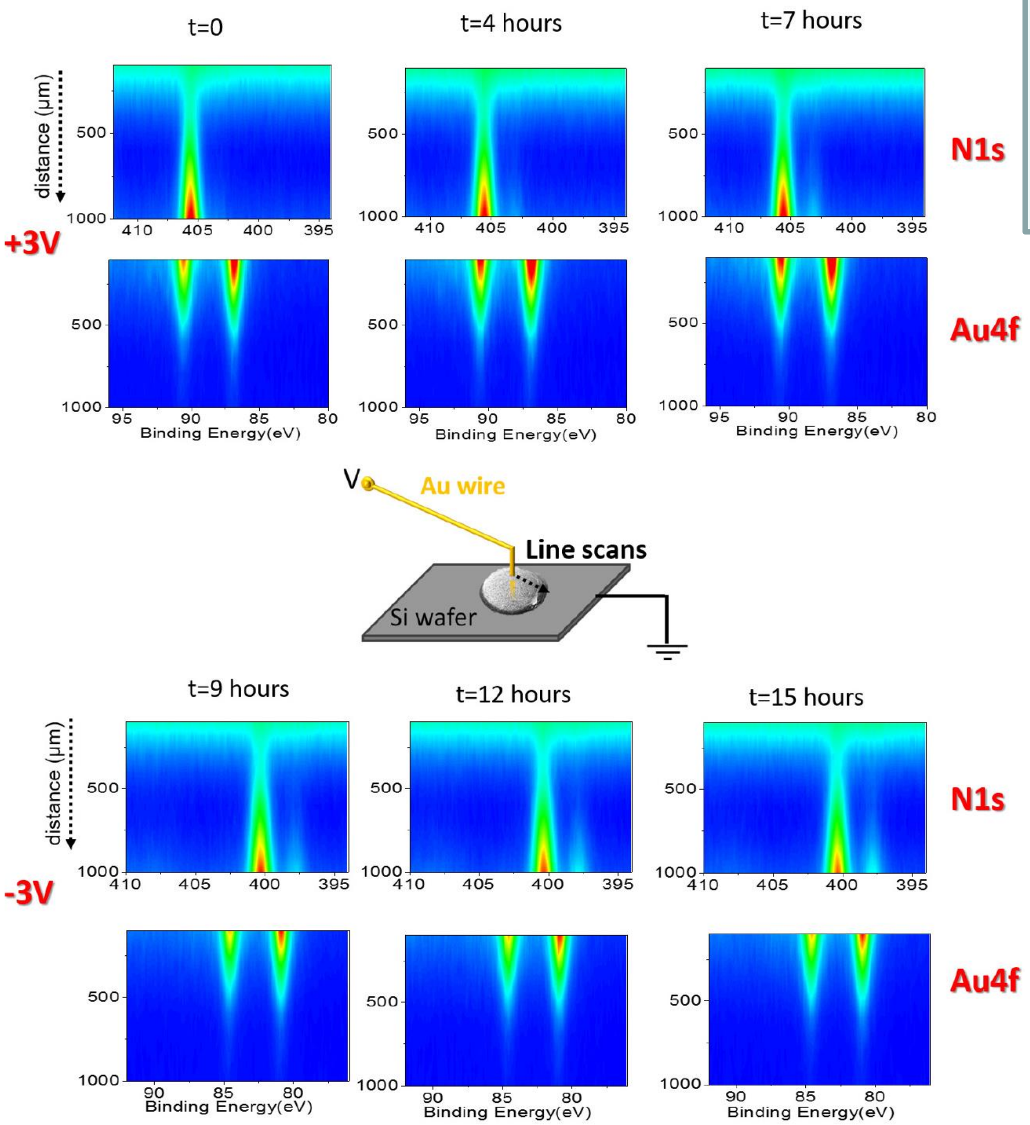
Type II
Drop

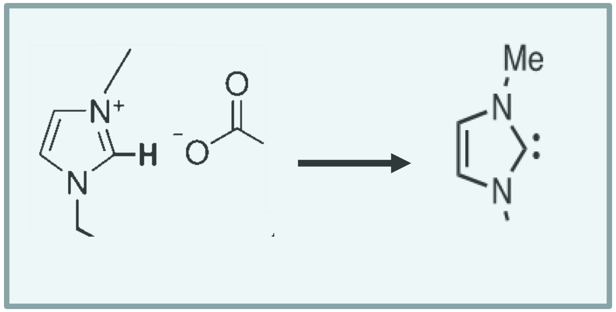


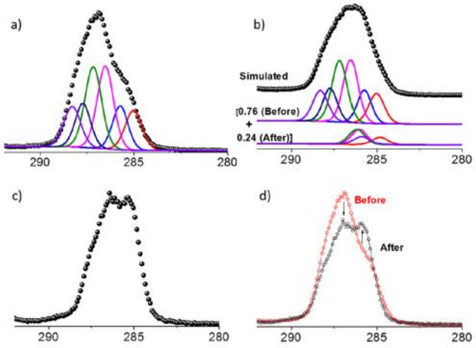




- Electro-Chemical Synthesis of CARBENE







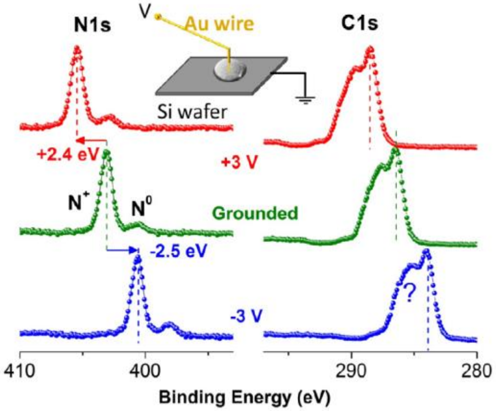
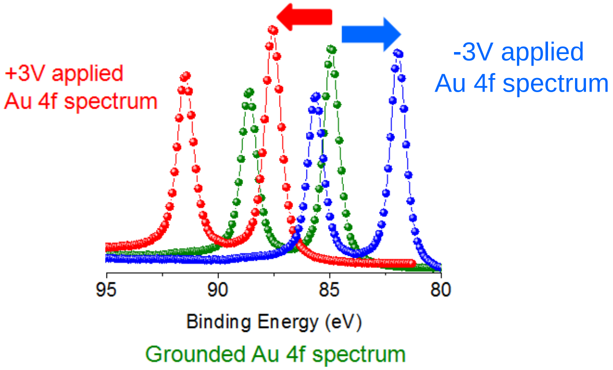
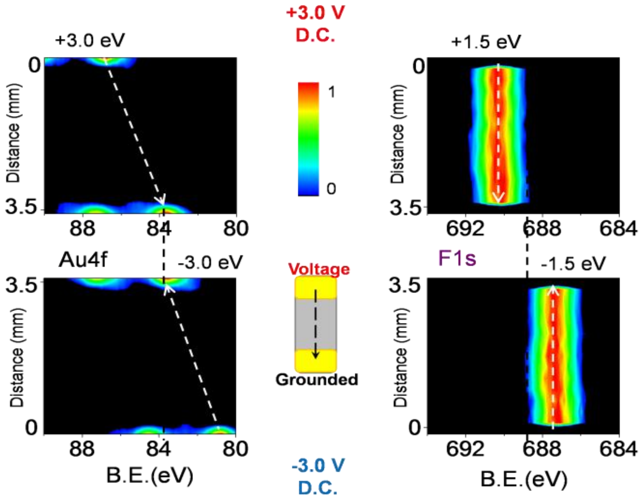


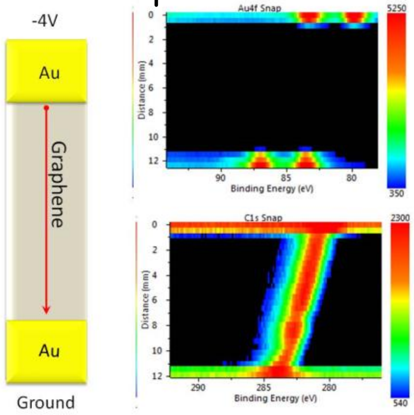
Fig. 3. XP Spectra of theN1s and Au4f regions along the line designated under +3 V and -3 V Bias and in different periods.

DC BIASING

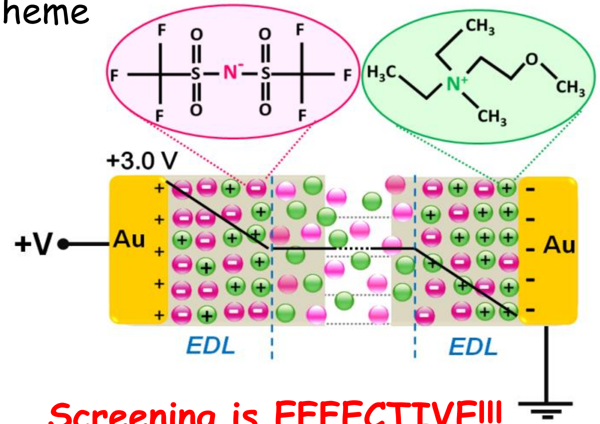




Graphene !!!

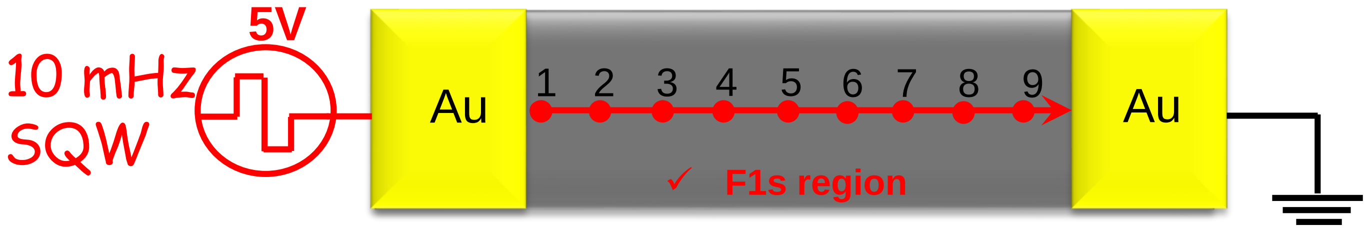


Scheme

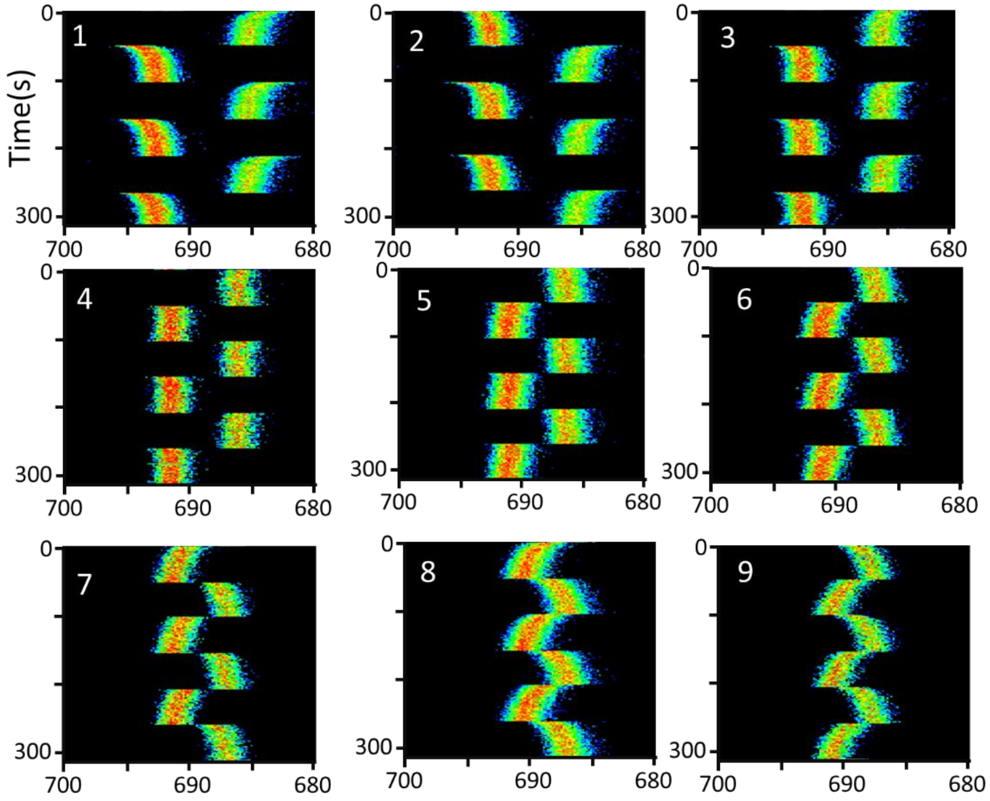


Screening is EFFECTIVE!!!

Dynamics of Ionic-Liquids
COPLANAR CAPACITOR



Line Scan Mode
Step size:
800µm

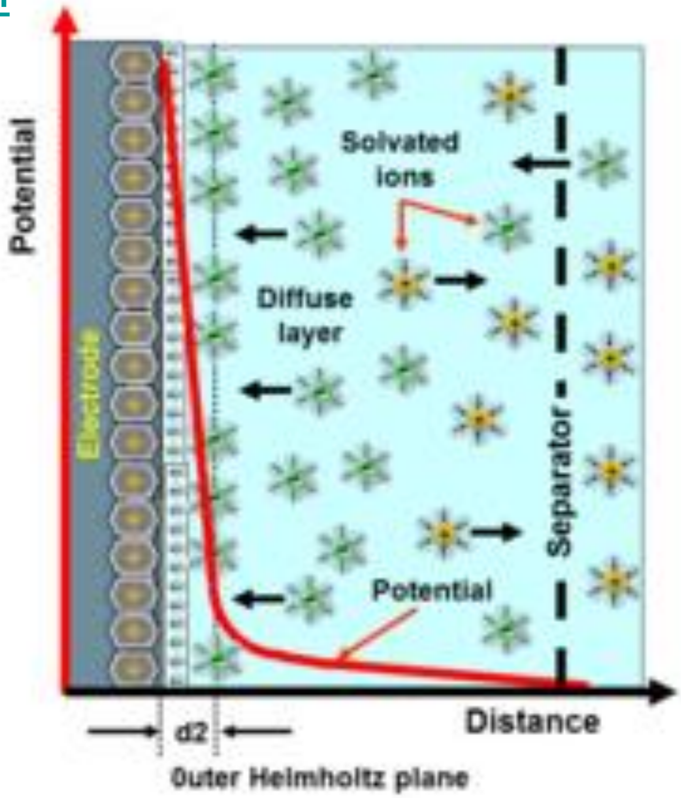


- Position dependent information across the electrodes.

EXTREEMELY SLOW!!!
and
LONG RANGE!!!

Double layer (surface science)
From Wikipedia, the free encyclopedia

When an *electronic* conductor is brought in contact with a solid or iquid *ionic* conductor (electrolyte), a common boundary (interface) among the two phases appears. Hermann von Helmholtz[1] was the first to realize that charged electrodes immersed in electrolyte solutions repel the co-ions of the charge while attracting counterions to their surfaces. Two layers of opposite polarity form at the interface between electrode and electrolyte. In 1853 he showed that an electrical double layer (DL) is essentially a molecular dielectric and stores charge electrostatically.[2] Below the electrolyte's decomposition voltage, the stored charge is linearly dependent on the voltage applied.



Note That DEBYE LENGTH and TIME 1-10 nm and ~1-10 ns !

PHYSICAL REVIEW E **70**, 021506 (2004)

Diffuse-charge dynamics in electrochemical systems

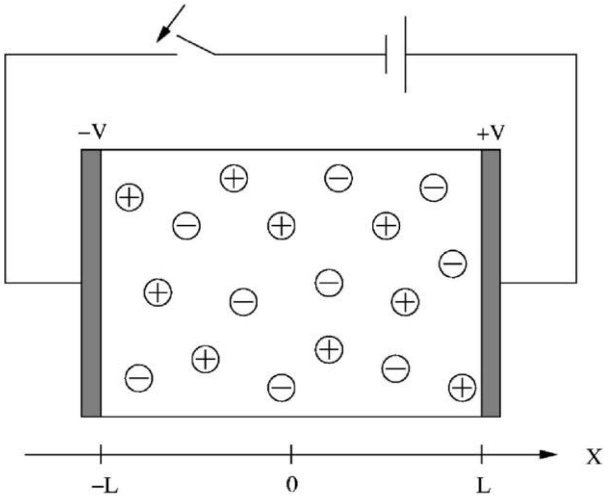
Martin Z. Bazant,[1,2] Katsuyo Thornton,[3] and Armand Ajdari[2]

We describe the concentrations of the charged ions by continuum fields $C_\pm(X,\tau)$ which satisfy the Nernst-Planck equations,

$$\frac{\partial C_\pm}{\partial \tau} = -\frac{\partial}{\partial X}\left(-D\frac{\partial C_\pm}{\partial X} \mp \mu z e C_\pm \frac{\partial \Phi}{\partial X}\right) \qquad (11)$$

from the Einstein relation, $\mu = D/kT$. The total ionic charge density ρ_e controls the spatial variation of the potential Φ through Poisson's equation,

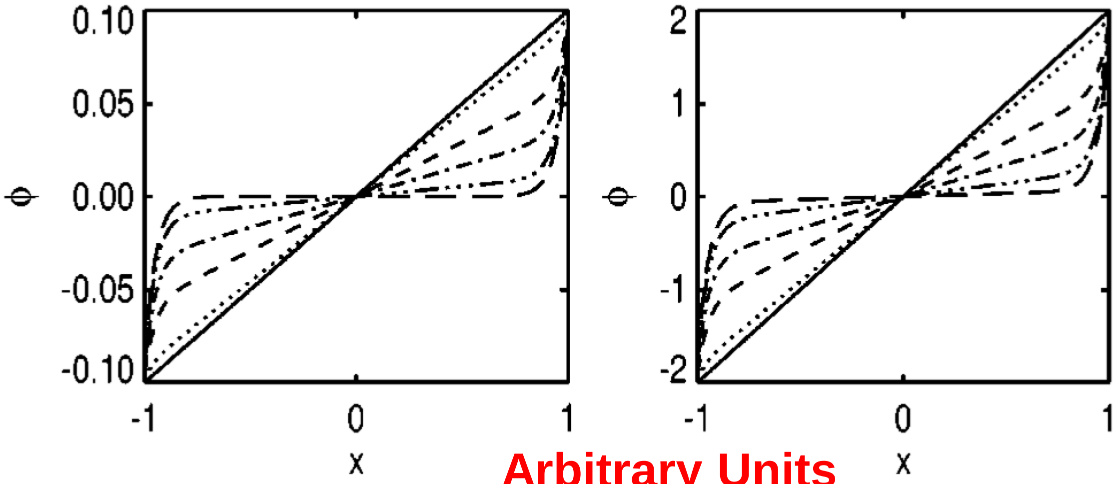
$$-\varepsilon\frac{\partial^2 \Phi}{\partial X^2} = \rho_e = ze(C_+ - C_-), \qquad (12)$$



Defined A New Length and Time Scales

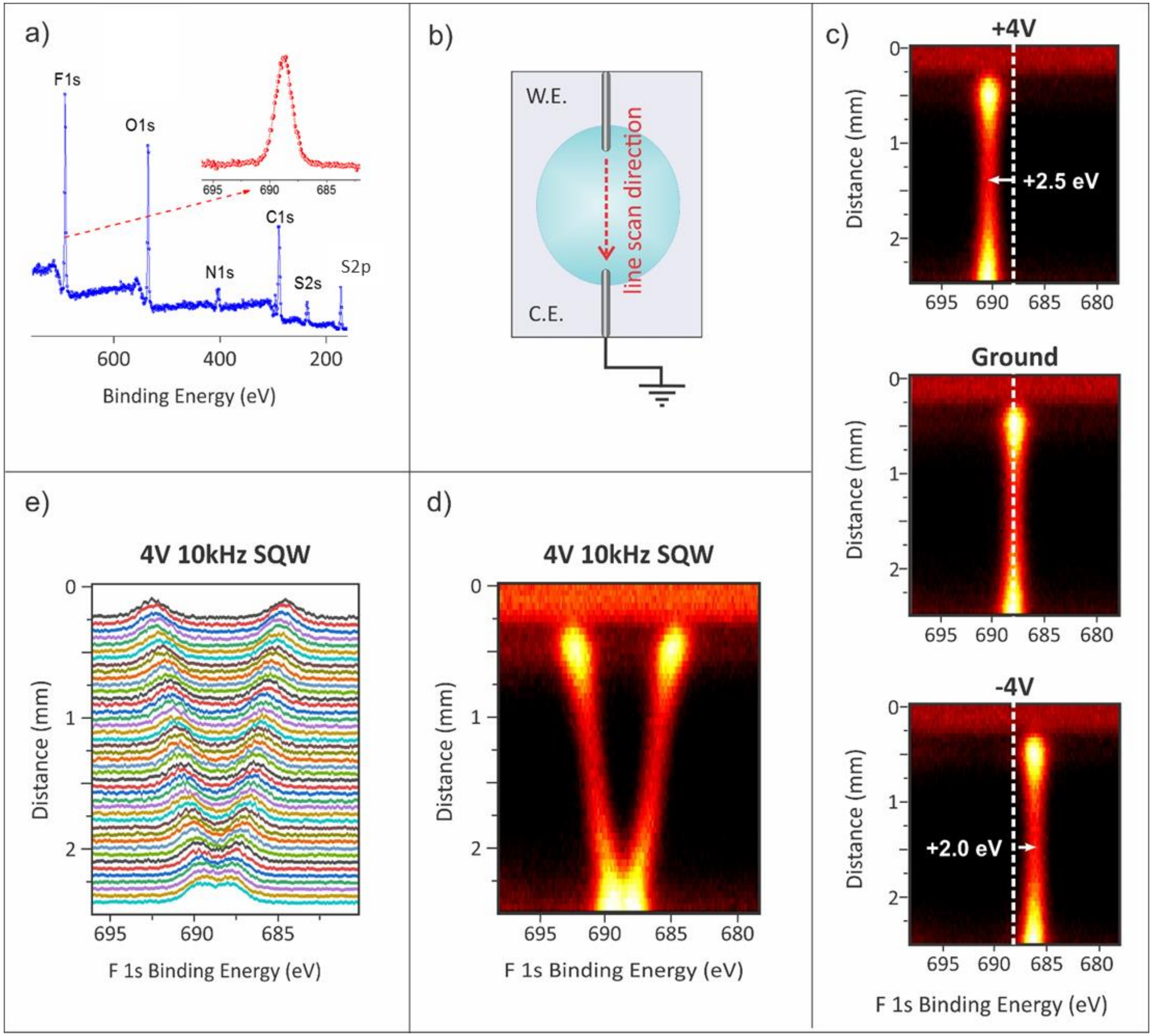
$$\tau_\rho \sim \frac{\lambda_D L}{D} - \frac{\lambda_D^2}{D} -$$

Volts

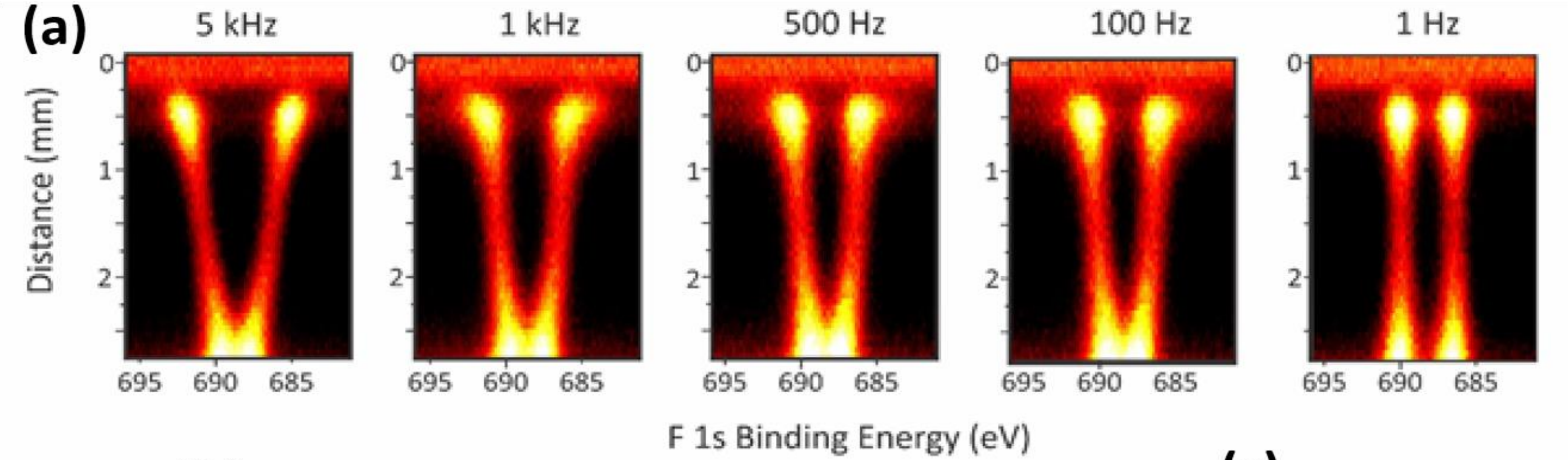


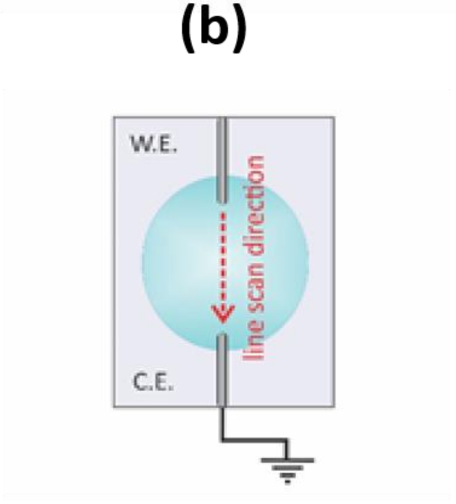
Arbitrary Units

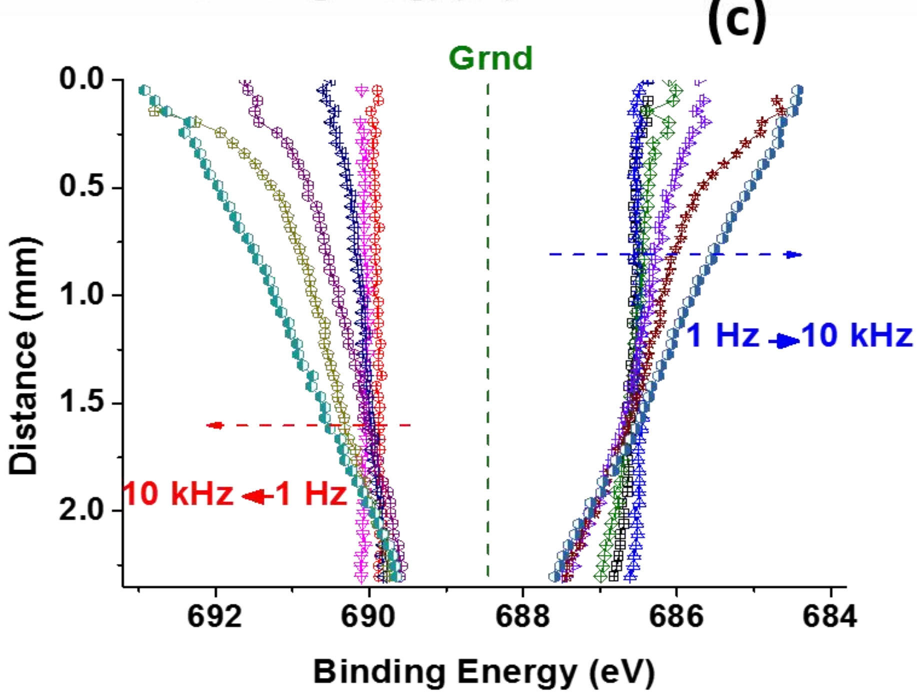
AC BIASING –SQUARE WAVES



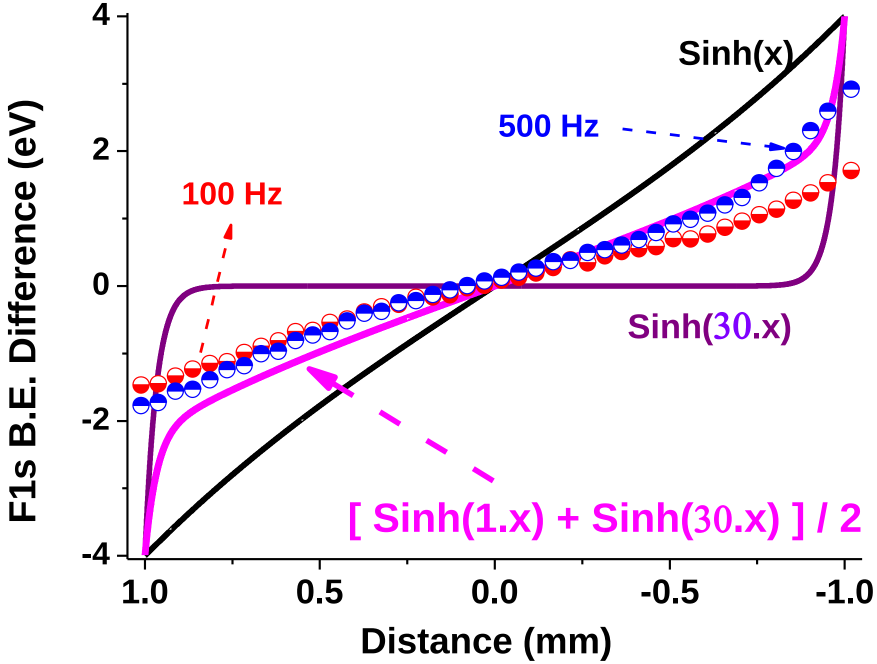
Line-Scans: 1-Dimensional Potential Profiles

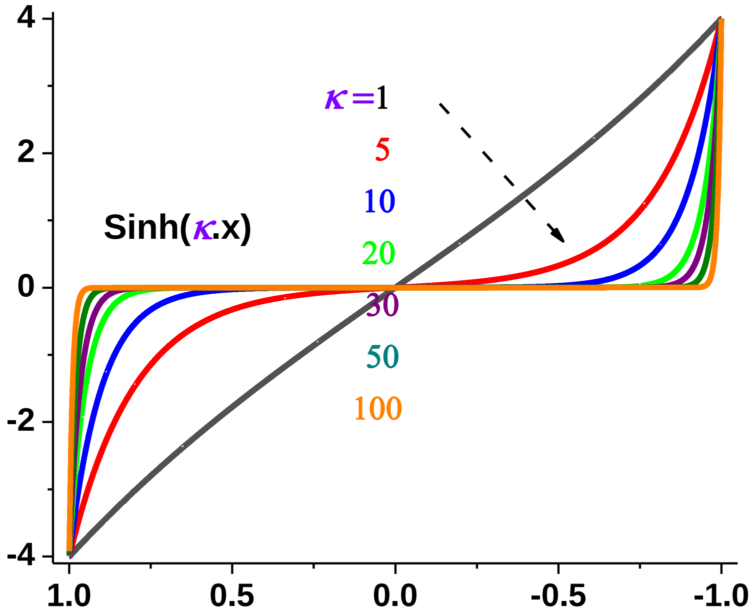


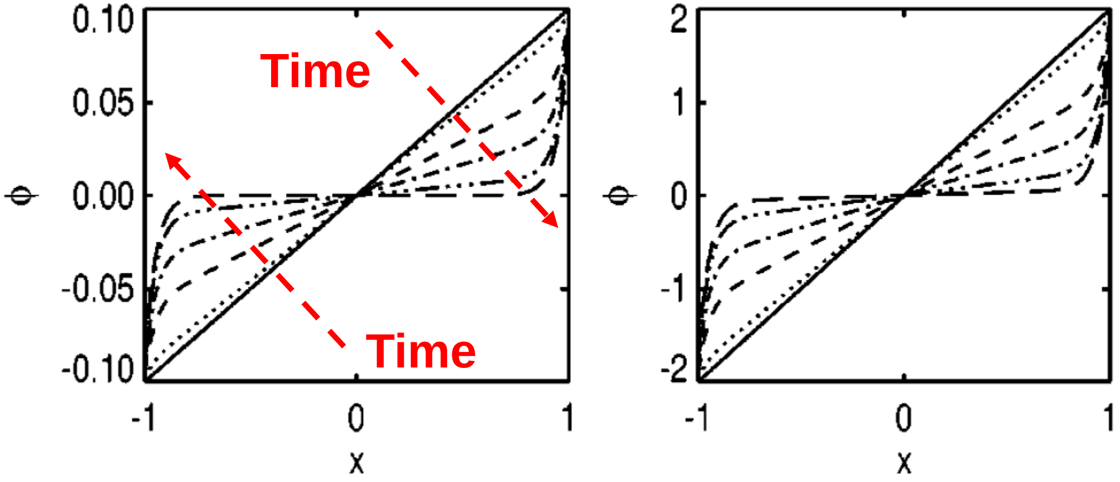




1st Ever Experimental Verification







2 Widely Different Time-Constants

~1:1000 Ratio

κ = 1 and 30

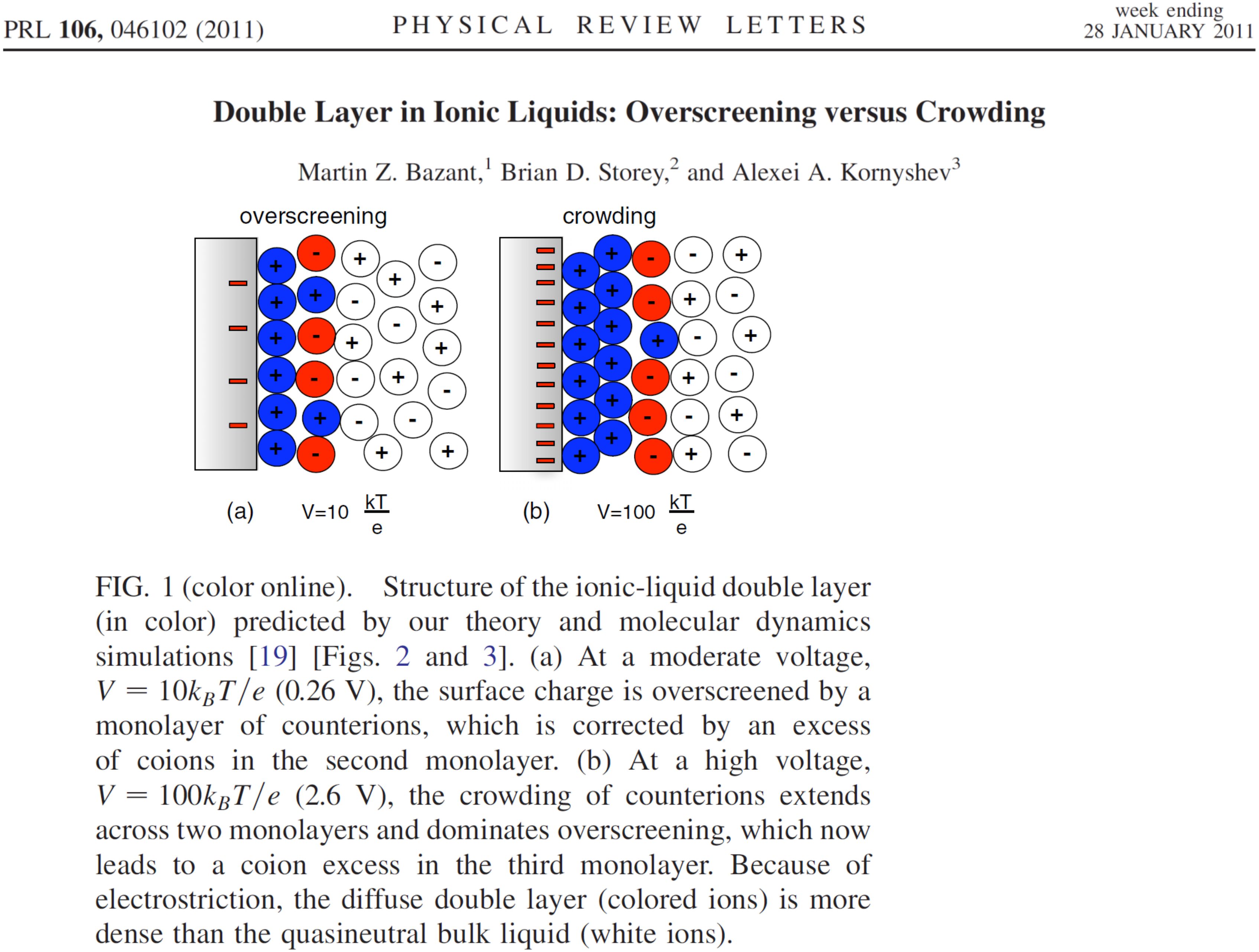
τ = 1^2 and 30^2

$\tau_C = \lambda_D.L/D$ =

10 nm x 1 mm /

2×10^{-11} m^2/s = 0.5 s

New Concepts



PRL 106, 046102 (2011) PHYSICAL REVIEW LETTERS week ending
28 JANUARY 2011

Double Layer in Ionic Liquids: Overscreening versus Crowding

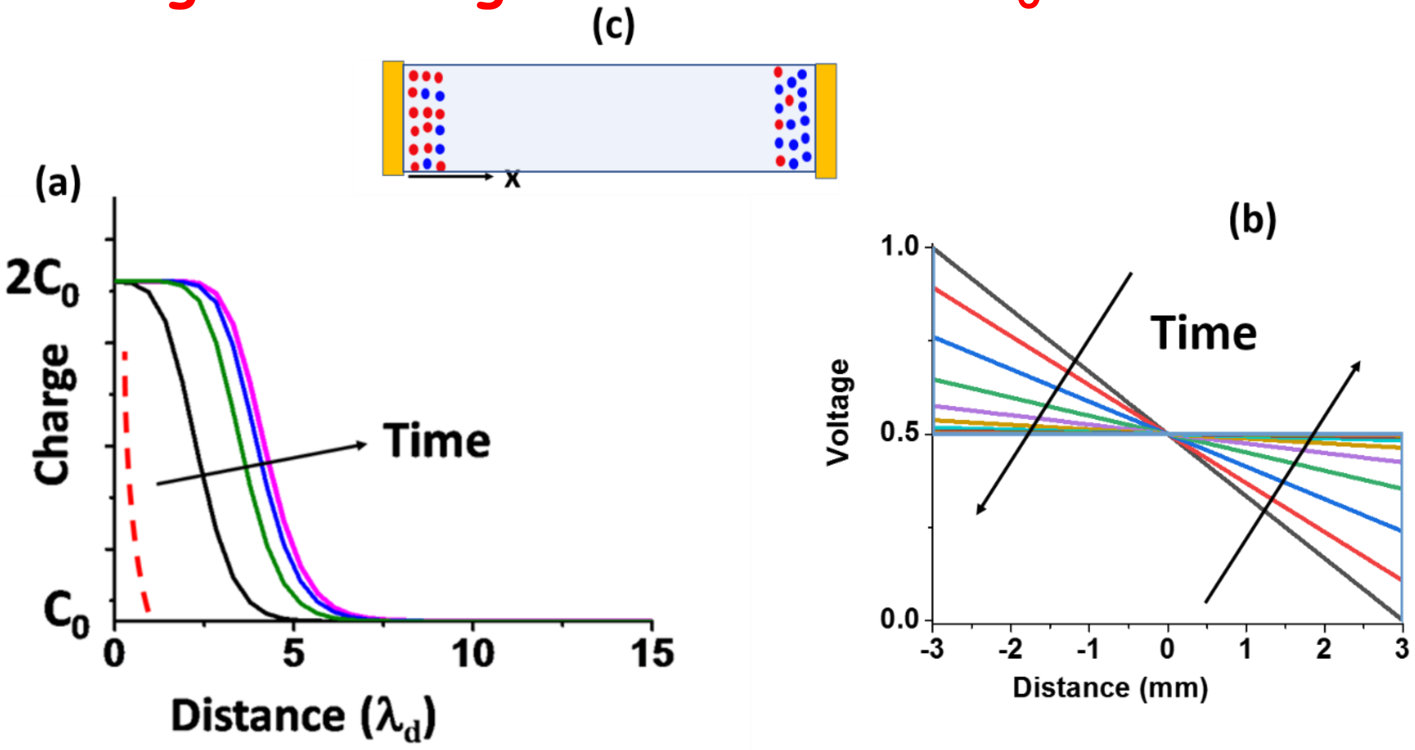
Martin Z. Bazant,[1] Brian D. Storey,[2] and Alexei A. Kornyshev[3]

FIG. 1 (color online). Structure of the ionic-liquid double layer (in color) predicted by our theory and molecular dynamics simulations [19] [Figs. 2 and 3]. (a) At a moderate voltage, $V = 10k_BT/e$ (0.26 V), the surface charge is overscreened by a monolayer of counterions, which is corrected by an excess of coions in the second monolayer. (b) At a high voltage, $V = 100k_BT/e$ (2.6 V), the crowding of counterions extends across two monolayers and dominates overscreening, which now leads to a coion excess in the third monolayer. Because of electrostriction, the diffuse double layer (colored ions) is more dense than the quasineutral bulk liquid (white ions).

Parallel-Plate Capacitor

1-D COMSOL SIMULATION RESULTS

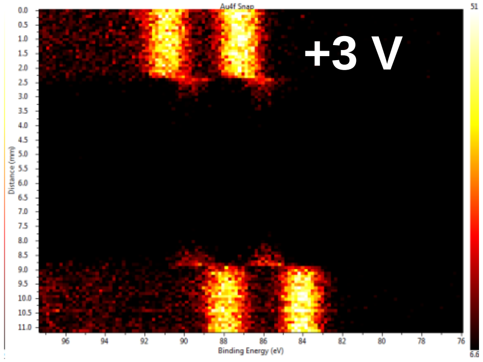
Restricting the Charge Accumulation: C_0=3.3 M

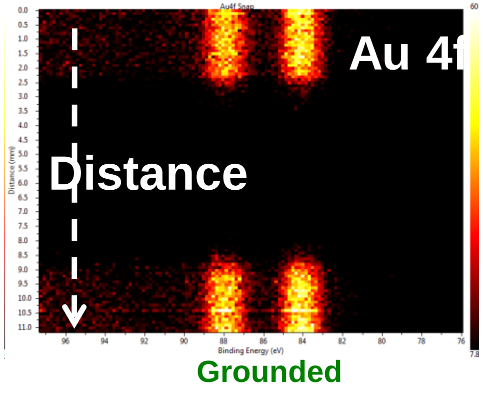


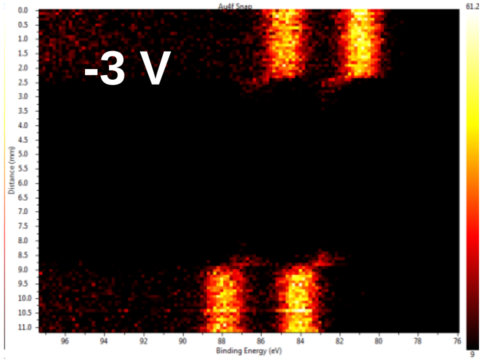
Leeds to Increase in the DL thickness:

0.1 nm to maybe 1 nm

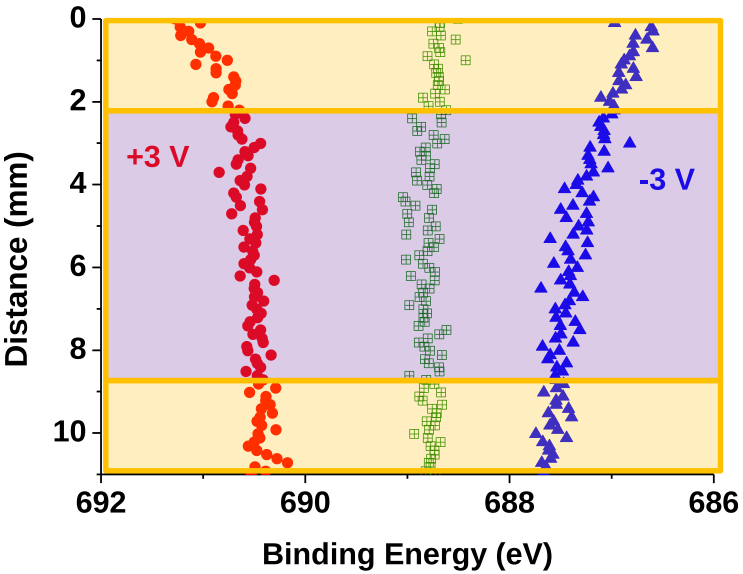
Still TOO SMALL!!!!

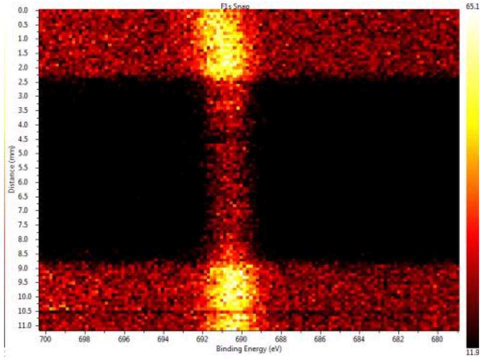


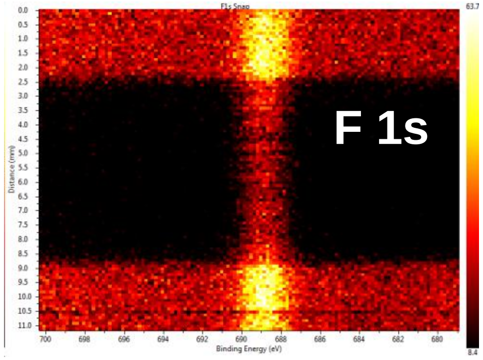


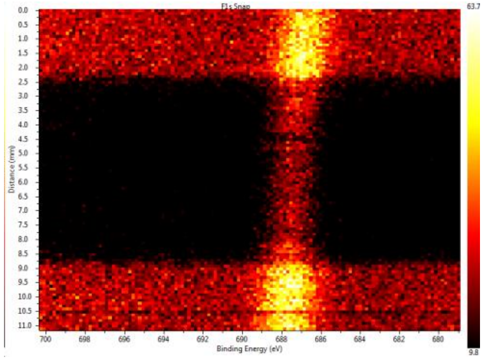


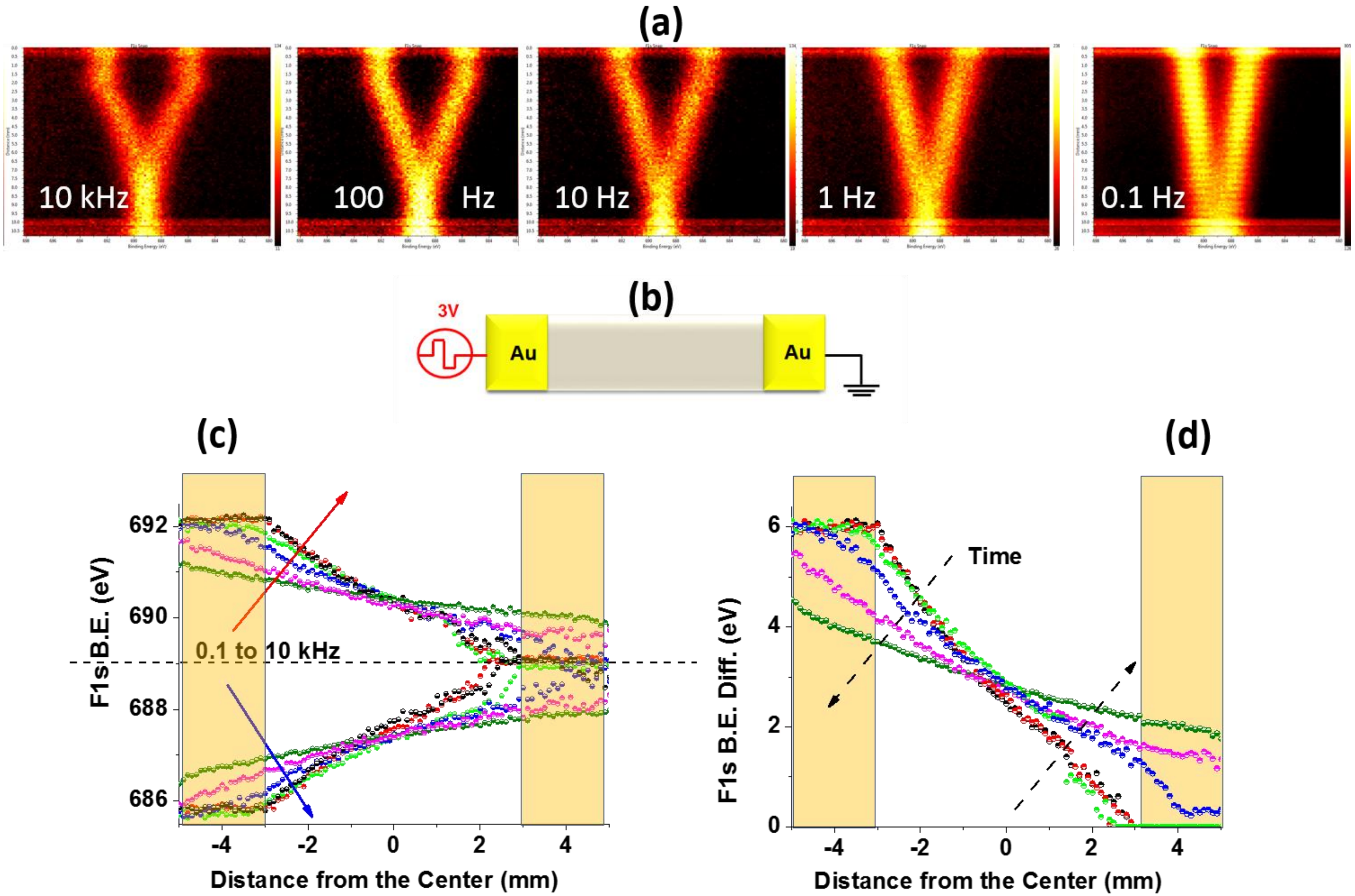
Co-Planar Capacitor



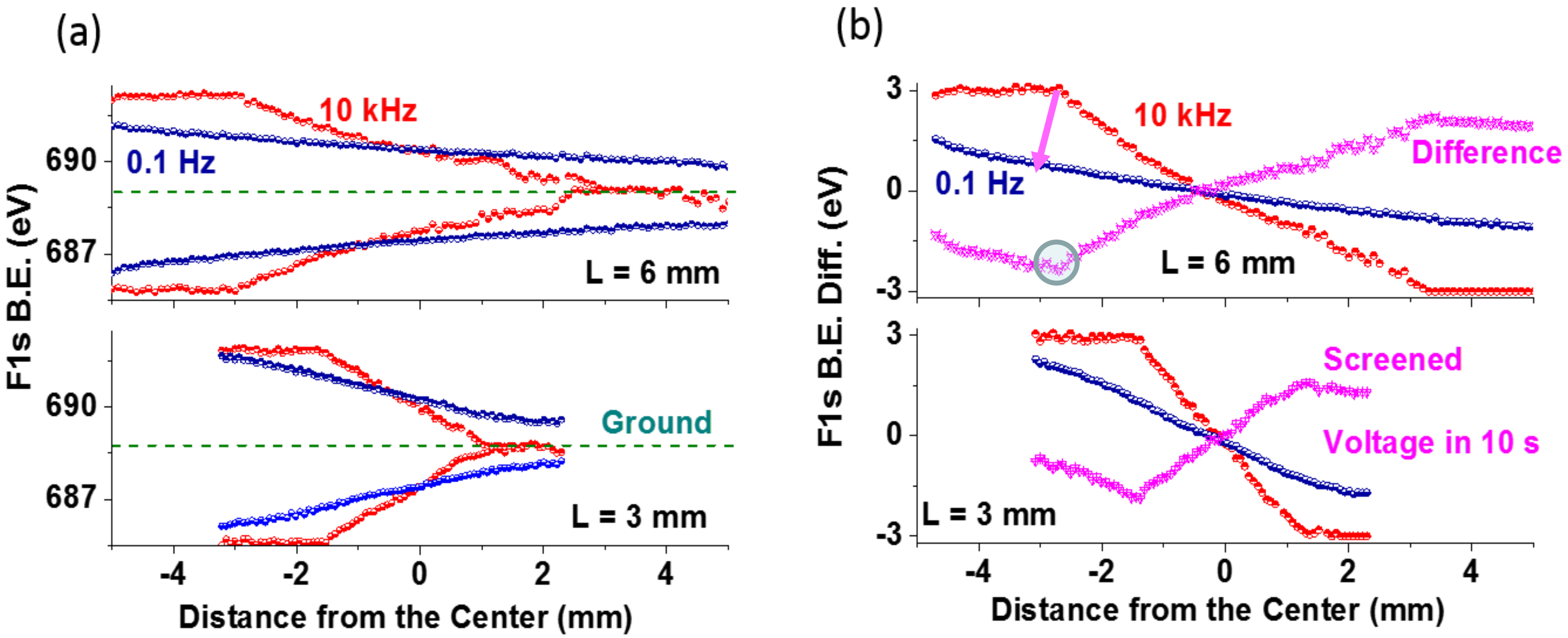







(a)
10 kHz
100 Hz
10 Hz
1 Hz
0.1 Hz
(b)
3V
Au
Au
(c)
692
690
688
686
F1s B.E. (eV)
0.1 to 10 kHz
-4
-2
0
2
4
Distance from the Center (mm)
(d)
Time
6
4
2
0
F1s B.E. Diff. (eV)
-4
-2
0
2
4
Distance from the Center (mm)

2 Different Devices

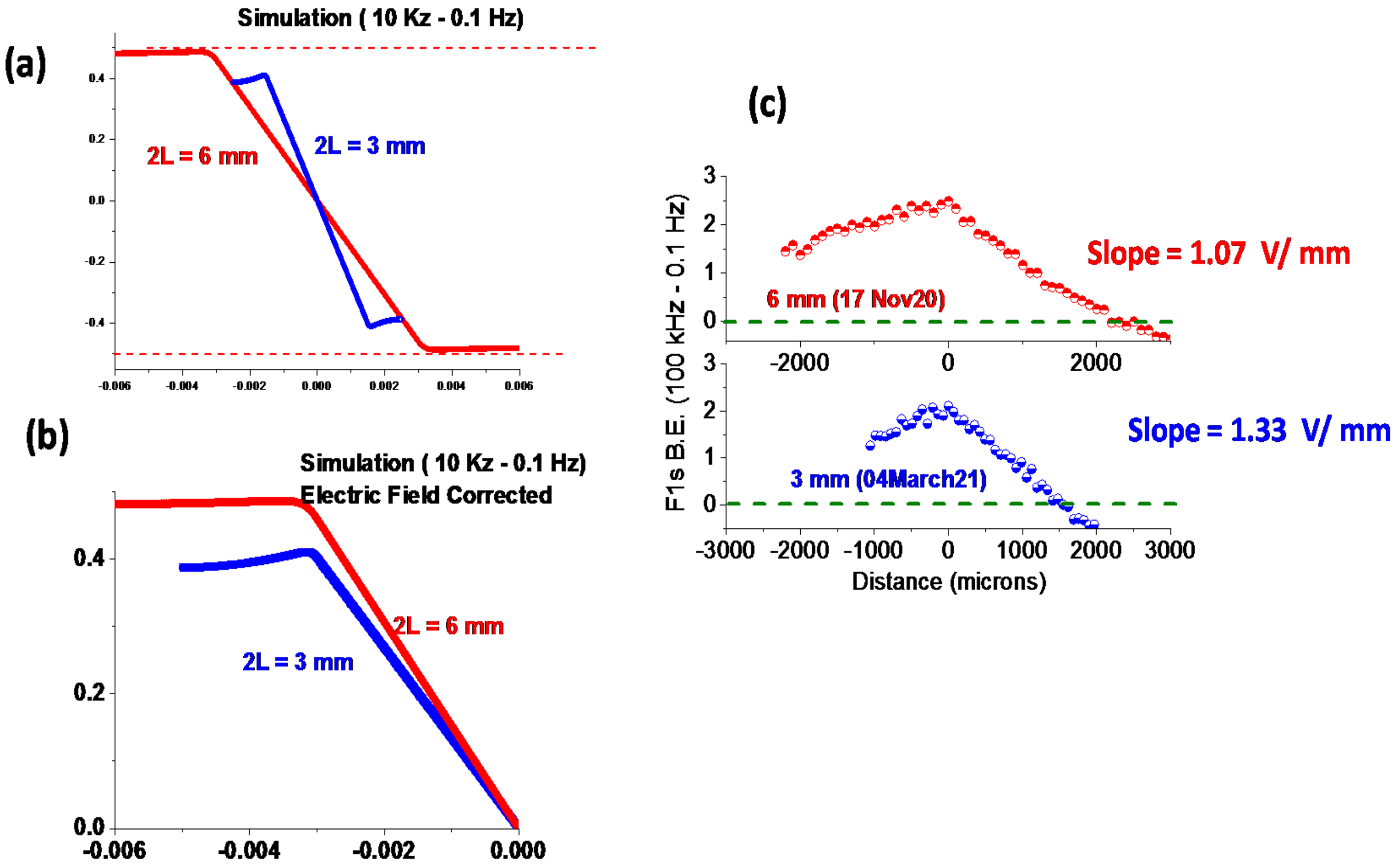


-Using Simple Diffusion Model:

Distance = $(D.\Delta t)^{1/2} = [10^{-11}\ (m^2/s) \times 10\ s]^{1/2} = 10^{-5}$ m

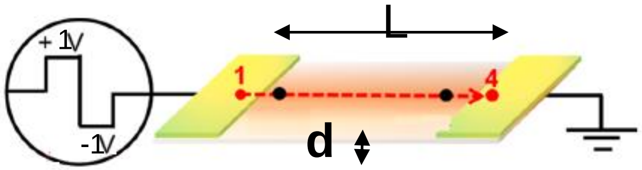
- Drift Velocity (using known viscocity values) = ~ 3 μm/s

Again both are TOO SMALL!!!!

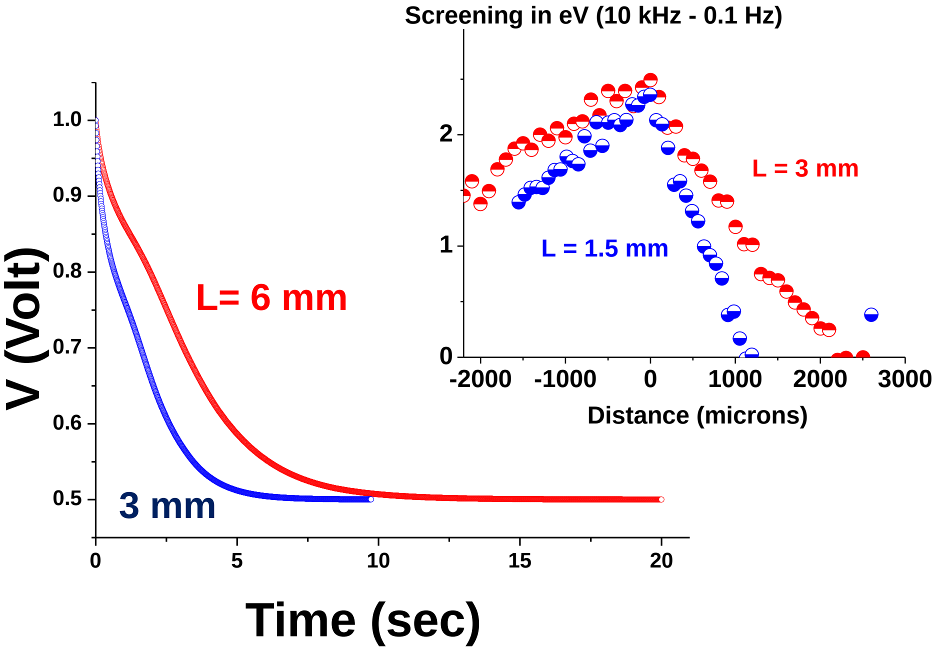

(a)
Simulation (10 Kz - 0.1 Hz)
0.4
0.2
0.0
-0.2
-0.4
2L = 6 mm
2L = 3 mm
-0.006
-0.004
-0.002
0.000
0.002
0.004
0.006
(b)
Simulation (10 Kz - 0.1 Hz)
Electric Field Corrected
0.4
0.2
0.0
2L = 6 mm
2L = 3 mm
-0.006
-0.004
-0.002
0.000
(c)
F1s B.E. (100 kHz - 0.1 Hz)
3
2
1
0
6 mm (17 Nov20)
Slope = 1.07 V/ mm
-2000
0
2000
3
2
1
0
3 mm (04March21)
Slope = 1.33 V/ mm
-3000
-2000
-1000
0
1000
2000
3000
Distance (microns)

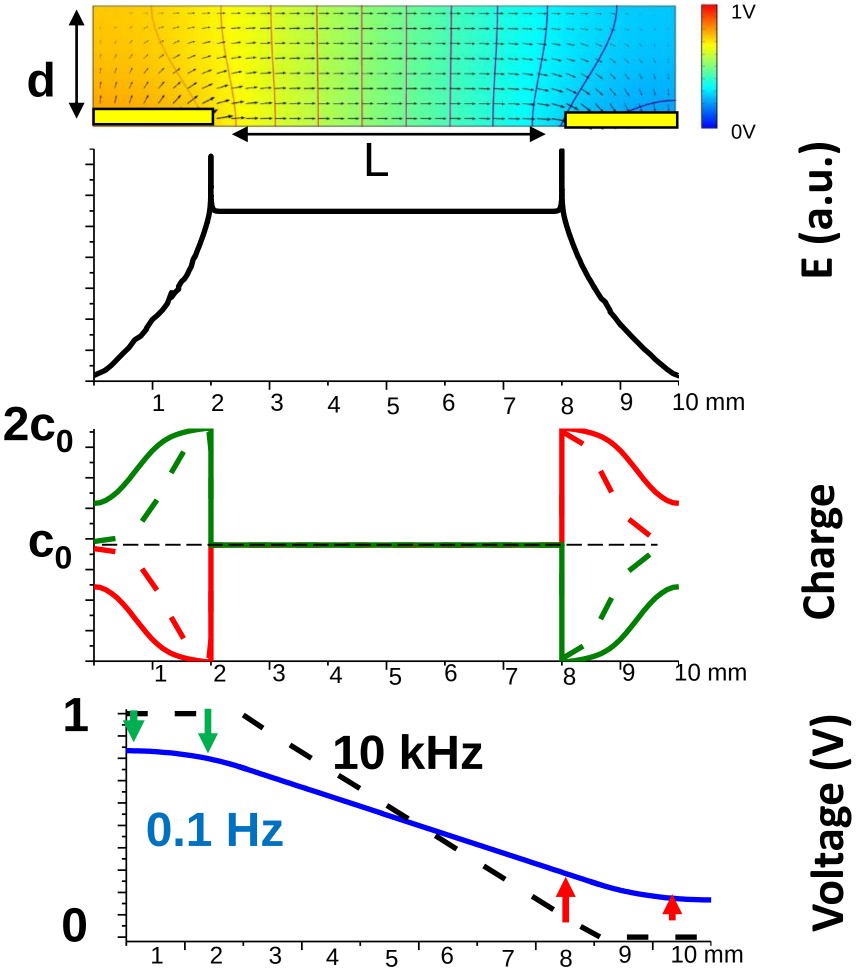
SIMULATIONS USING 2-D COMSOL

Geometric Effects and Nonuniform Double Layer



$\tau \approx RC \approx L/d$





Slow response time τ = 5 sec for XPS measurements

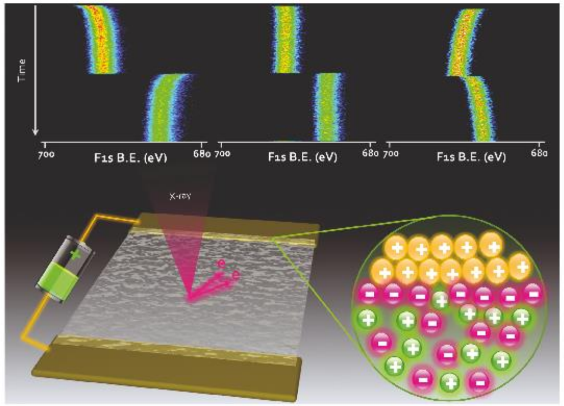
Conclusions

- ✓ D.C. or A.C. Biased XPS
- ✓ Chemical Processes and/or Reactions,
- ✓ Frequency Dependence (Impedance-Like) of Different Liquids on Types of Bonding (Dipolar, and/or Ionic),
- ✓ Validation of Different Models, EDL Formation, etc.,

Can be monitored **in a Chemically Resolved Fashion with** **A BIG HELP from COMSOL**

- ✓ **There is Still Room for INNOVATIVE UTILIZATION of the Old-Lab-Based XPS Technique**

2016



Showcasing research from the surface-science laboratory of Dr Sefik Suzer at the Chemistry Department of Bilkent University, Ankara, Turkey.

Title: XPS enables visualization of electrode potential screening in an ionic liquid medium with temporal- and lateral-resolution

As featured in:

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XPS enables visualization of electrode potential screening in an ionic liquid medium with temporal- and lateral-resolution†

M. T. Camci,[a] P. Aydogan,[a] B. Ulgut,[a] C. Kocabas[b] and S. Suzer*[a]

2018

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Article

Cite This: *Langmuir* 2018, 34, 7301−7308

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DC Electrowetting of Nonaqueous Liquid Revisited by XPS

Pinar Aydogan Gokturk, Burak Ulgut, and Sefik Suzer*

Department of Chemistry, Bilkent University, 06800 Ankara, Turkey

2019

LANGMUIR

Article

Cite This: *Langmuir* 2019, 35, 3319−3326

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AC Electrowetting Modulation of Low-Volatile Liquids Probed by XPS: Dipolar vs Ionic Screening

Pinar Aydogan Gokturk, Burak Ulgut, and Sefik Suzer*

OUR HOLY GRAIL

LIQUID/SOLID INTERFACES

be represented by

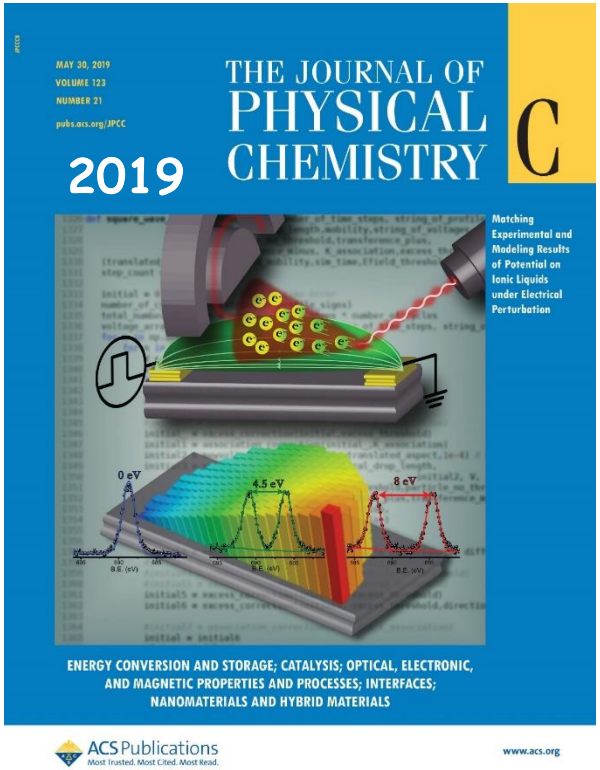
SOLID STATE ELEMENTS

ONLY??

CATIONS & ANIONS

vs

ELECTRONS & HOLES



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Matching Experimental and Modeling Results of Potential on Ionic Liquids under Electrical Perturbation

ENERGY CONVERSION AND STORAGE; CATALYSIS; OPTICAL, ELECTRONIC, AND MAGNETIC PROPERTIES AND PROCESSES; INTERFACES; NANOMATERIALS AND HYBRID MATERIALS

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