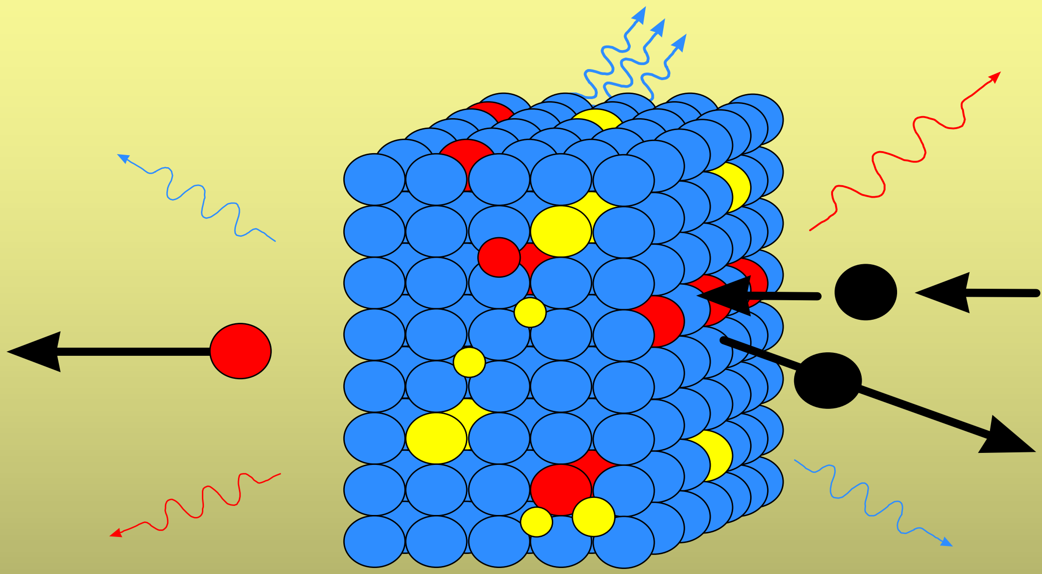
"MeV Ion Beam Assisted Formation of Pseudo-Crystals"



D. ILA, R. L. Zimmerman, and C. I. Muntele

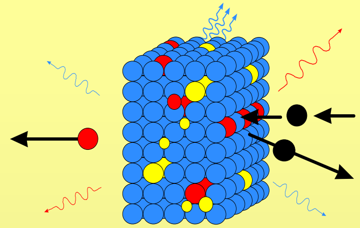
Center for Irradiation of Materials

AAMU – Huntsville, AL USA

http://cim.aamu.edu/

IAEA Meeting - Vienna, Austria 4-9 May 2009

Who are we?



AAMU:

Faculty and staff:

D. ILA, R. L. Zimmerman, A. L. Evelyn, L. R. Holland, C. I. Muntele, D. Nisen (R), Z. Xiao, H. L. Bowman, S. Budak, S. Guner, K. Heidary, M. Saafi, A. Sharma, R. Taylor, M. Alim, T. Kukhtareva, J. Wang, J. Campbell, H. J. Caulfield, J. Fisher (Ind), S. Celaschi (Ind), J. Williams (Ind/ORNL), B. Chhay

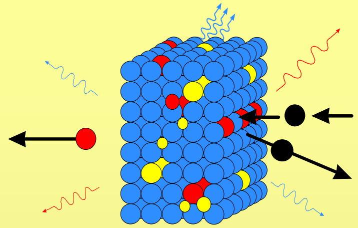
Students:

M. Abunaemeh, I. Giron, B. Sistani, S. Sadat, D. Walker, C. Smith, J. M. Taguenang, L. Wilkinson, R. Gray, P. Arrington & Many more.

Others:

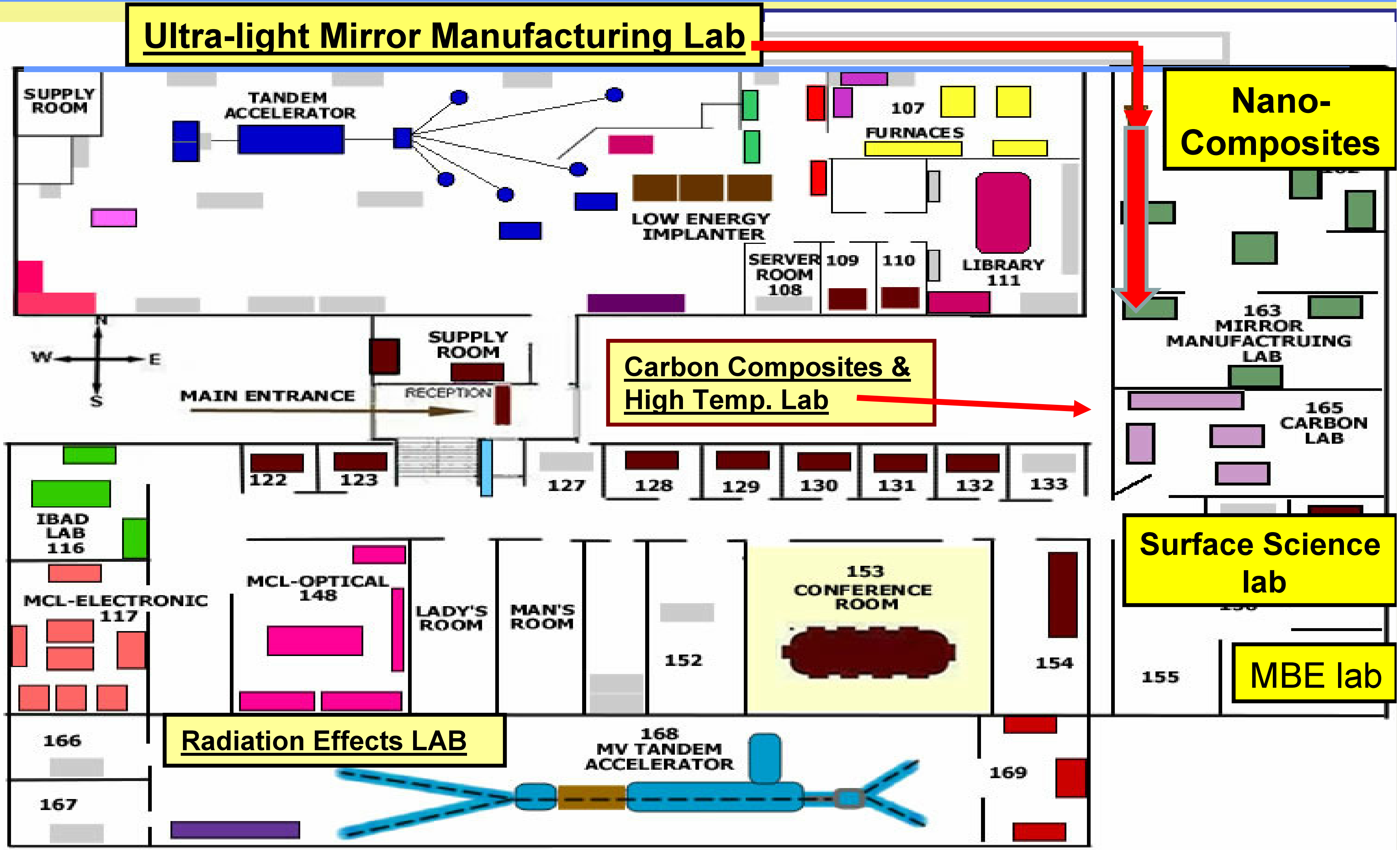
R. Mu (Fisk), A. Elsamadicy (+ UAH Students), I. Gurhan and A. Oztarhan (Ege U, Turkey + students), P. Thevenard (+ UCB Students), A. De Almeida (+USP Students), & Many more.

Partners

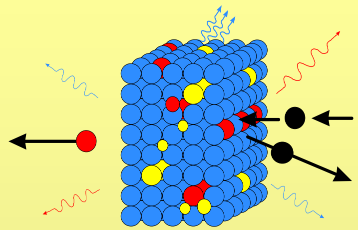


1. **Gov. :** **NRL, ARL, AMRDEC, DOE Labs, AFOSR, AFRL.**
2. **Universities:** ***UAH, UAB, UA, AU, TU, GTRI, UCB, TSU, USP, FU, EU, SU, NU, UA, DELF, UC-Davis, and few more***
3. **Industries:** ***SAIC, Jacobs Eng., BAE, MRC, Raytheon, Boeing, , NG, LM, Brontek, VLOC, II-VI, TBE, SRS, & many more (20 more SB)***

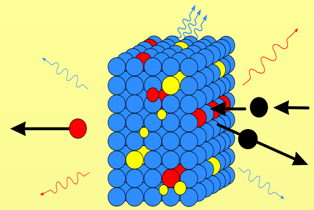
Ctr. for Irrad. of Materials



Past & Present R&D Achievements



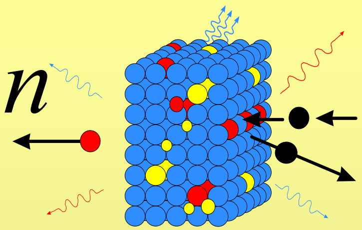
- Separating stopping power effects on thin polymers (early 90s MRS and REI-Japan)
- Formation of Nano-Crystal by Implantation followed by Annealing (early 90s, MRS)
- Formation of Nano-Crystals by Implantation followed by Irradiation (mid 90s US-IBMM and MRS)
- Formation of Nano-Crystals by Co-Deposition, sometime followed by Annealing and/or by MeV Ion Beam Irradiation (Late 90s, MRS, SMMIB & REI 01)

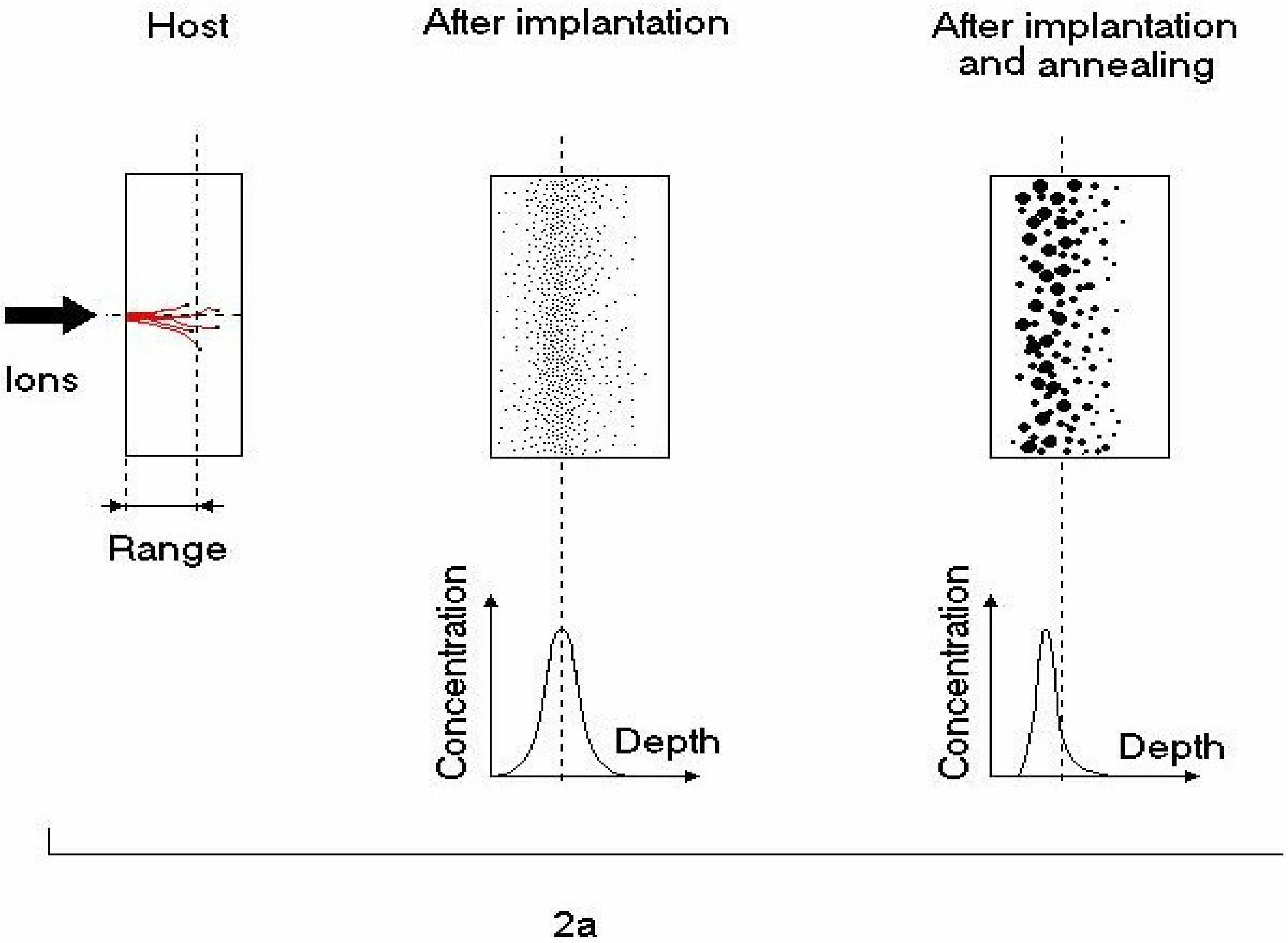


Objective

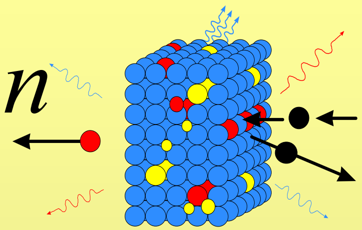
Produce highly dense QDs/NCs in order to take advantage of the new optical, electrical and thermal properties due to formation of QDs/NCs Pseudo-Crystal or due to interaction of QDs/NCs

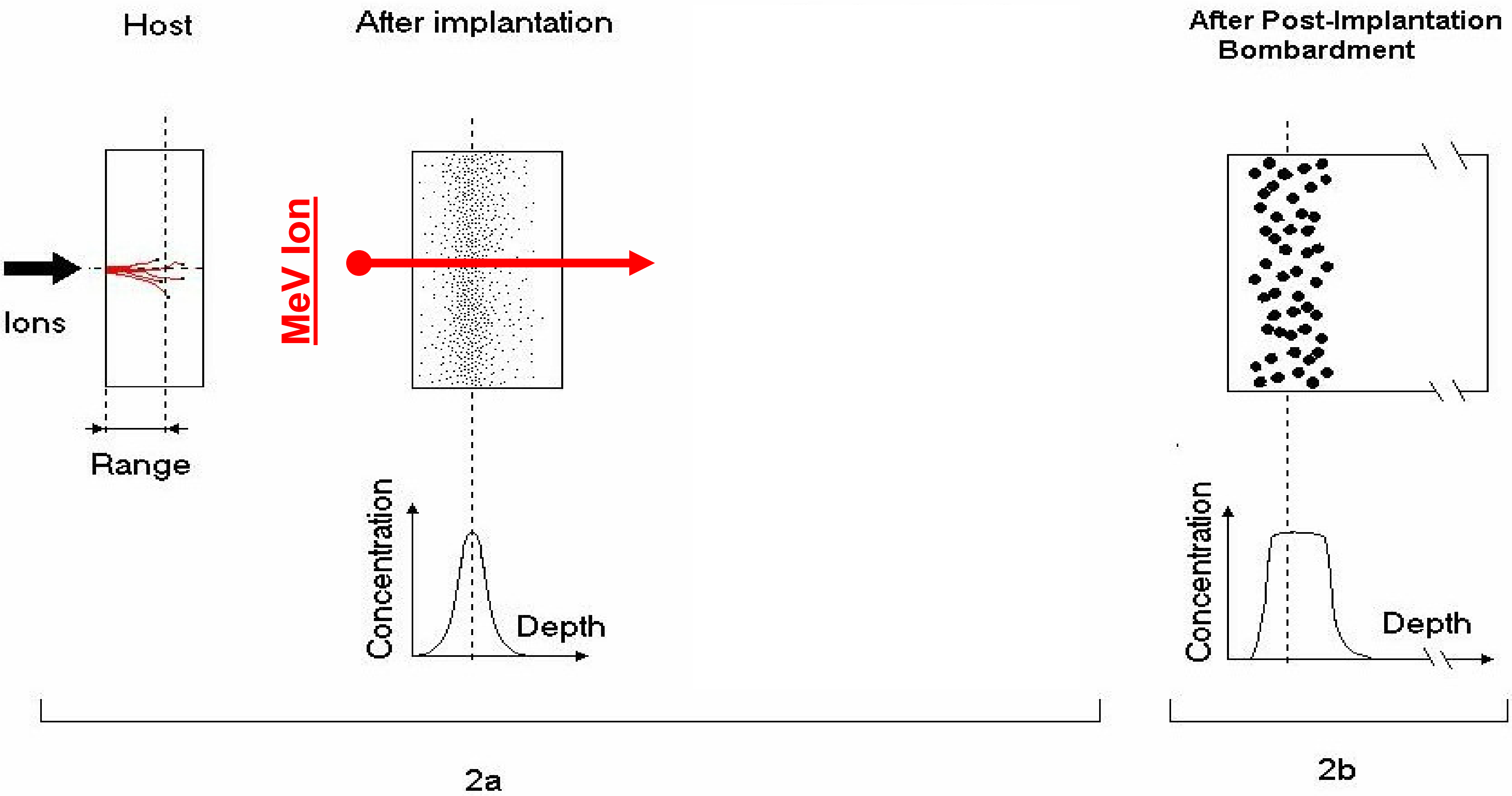
Implantation Followed by Annealing or Post Irradiation (95-2000)



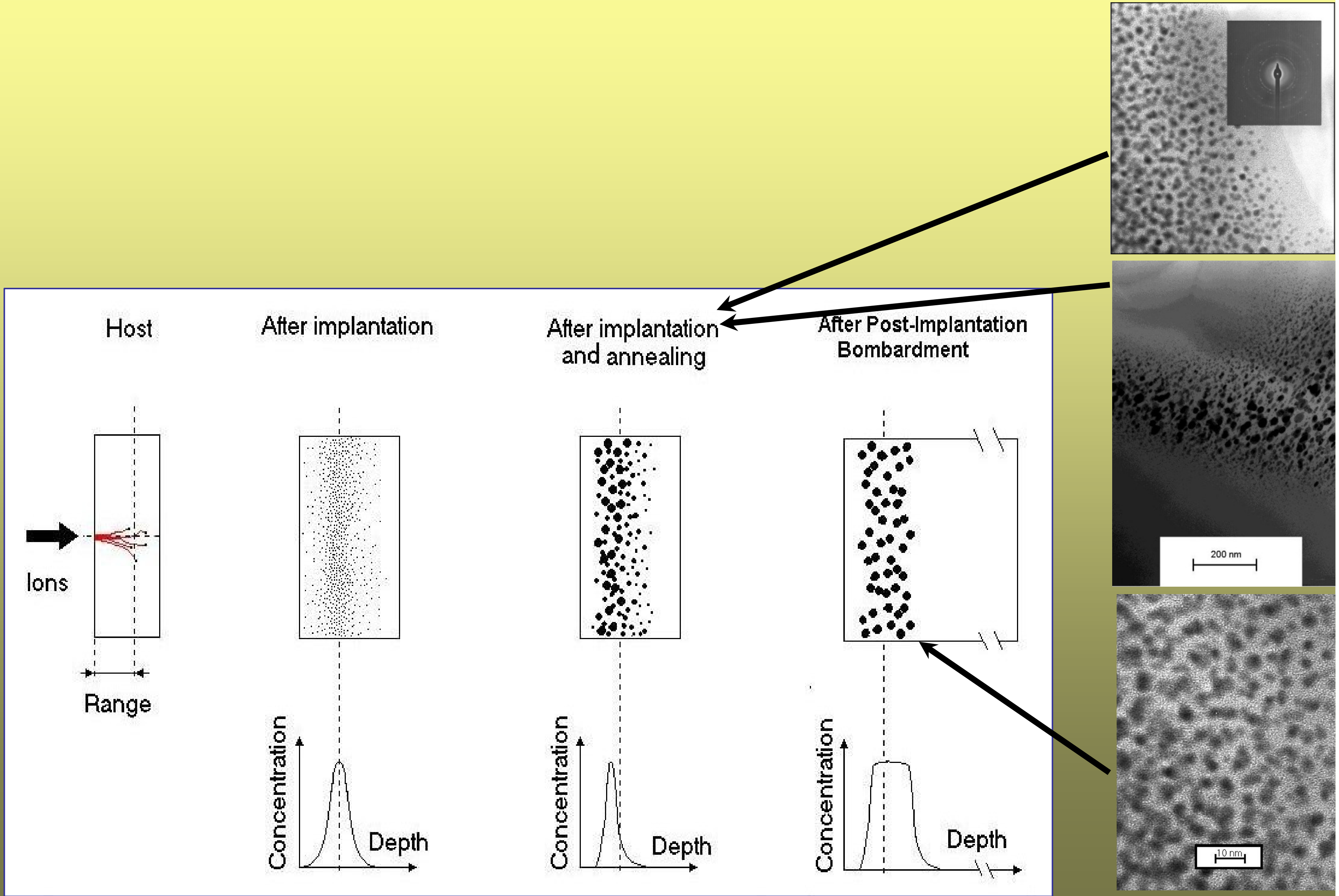


Implantation Followed by Annealing or Post Irradiation (95-2000)



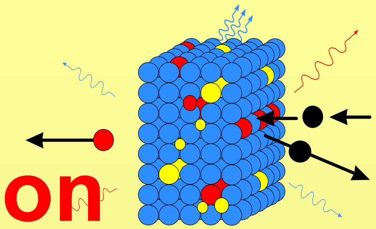


Innovative clustering methods: post-implantation ion bombardment



Advantage

Irradiation induced NC formation



- Producing NC @

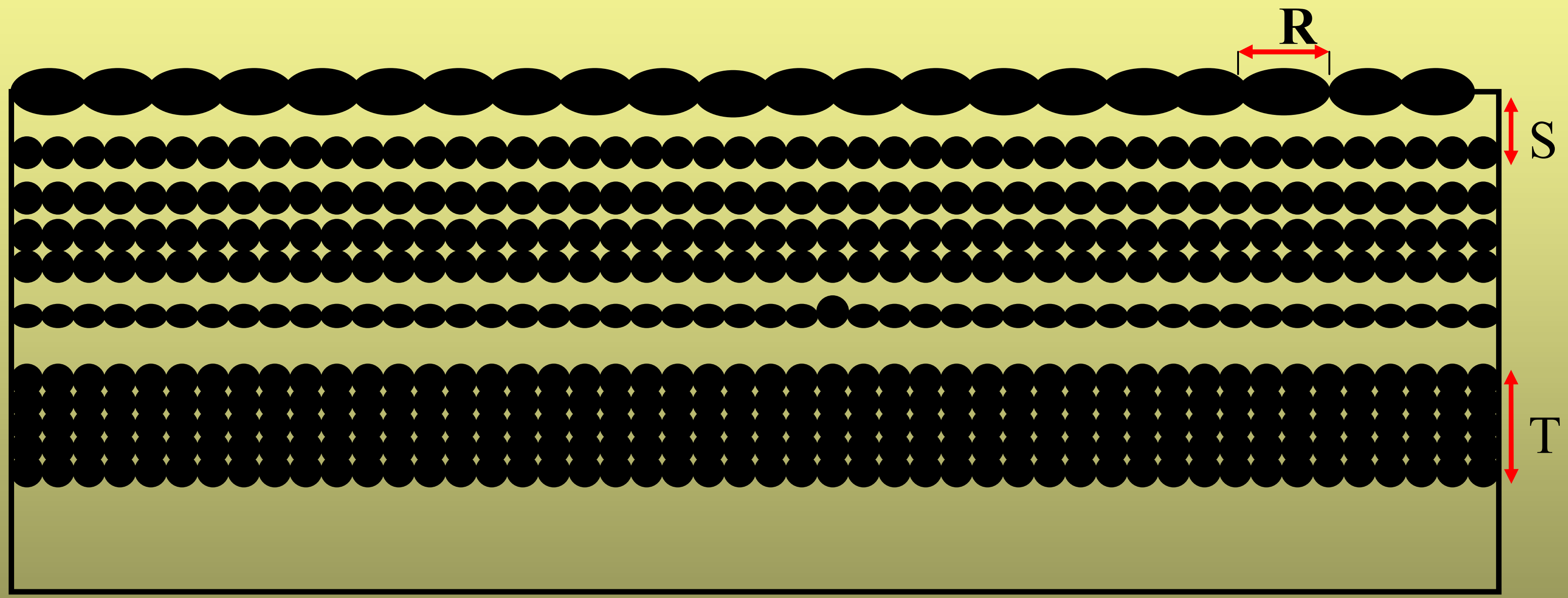
  lower initial implantation fluence

or

  lower concentration in co-deposition

- Uniform NC size
- NC location Control
- Volume Fraction Control

Layered Nano-Structures
Cross section view

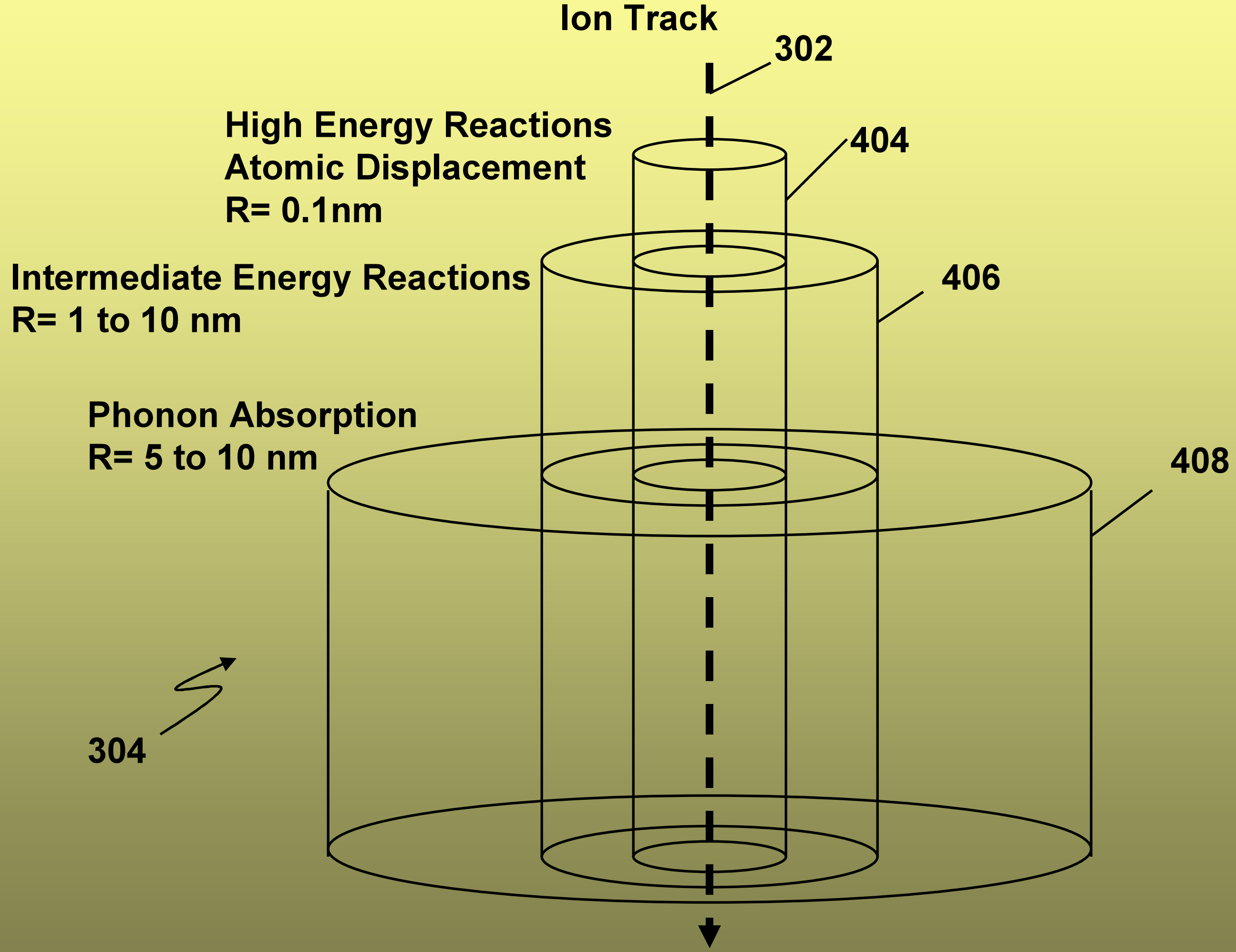


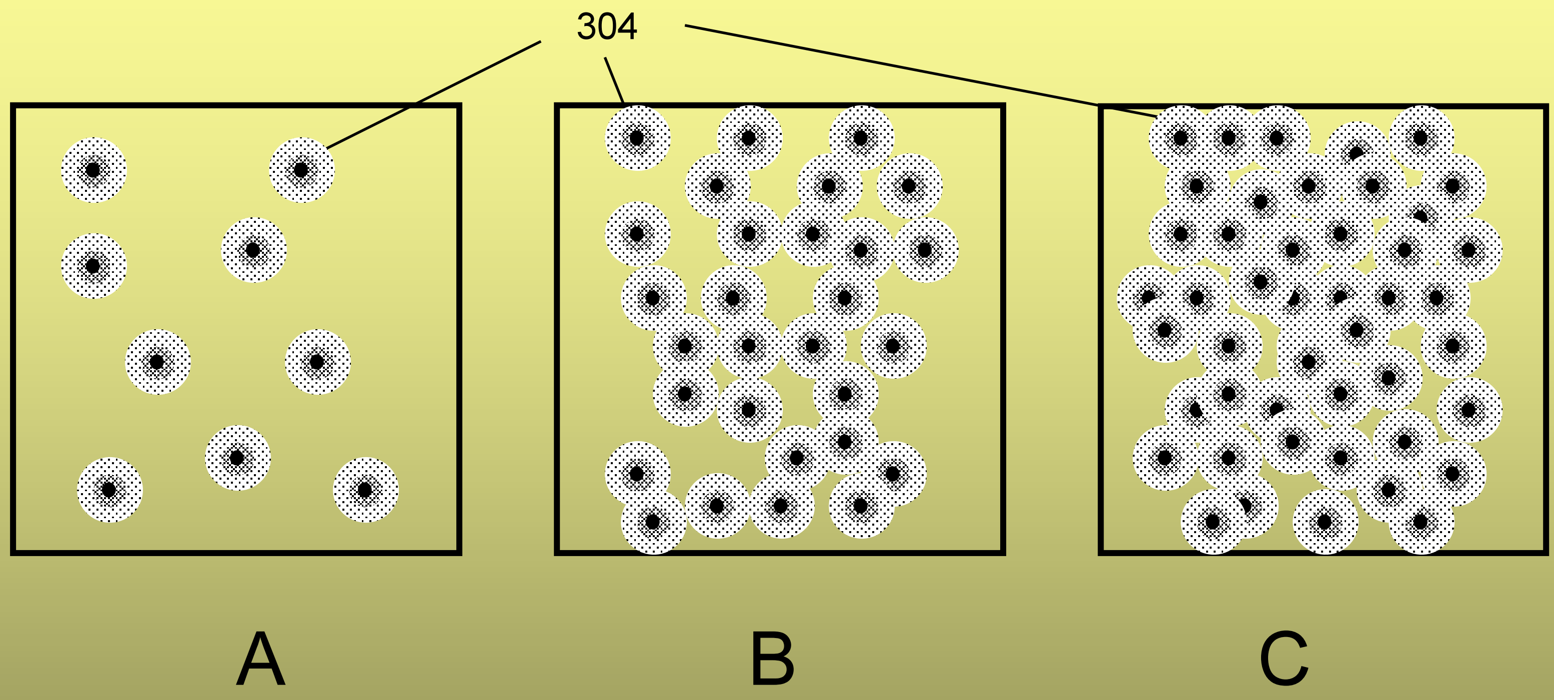
R: QD Radius

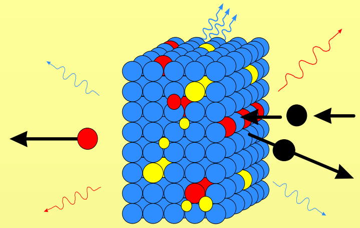
S: Layer Spacing

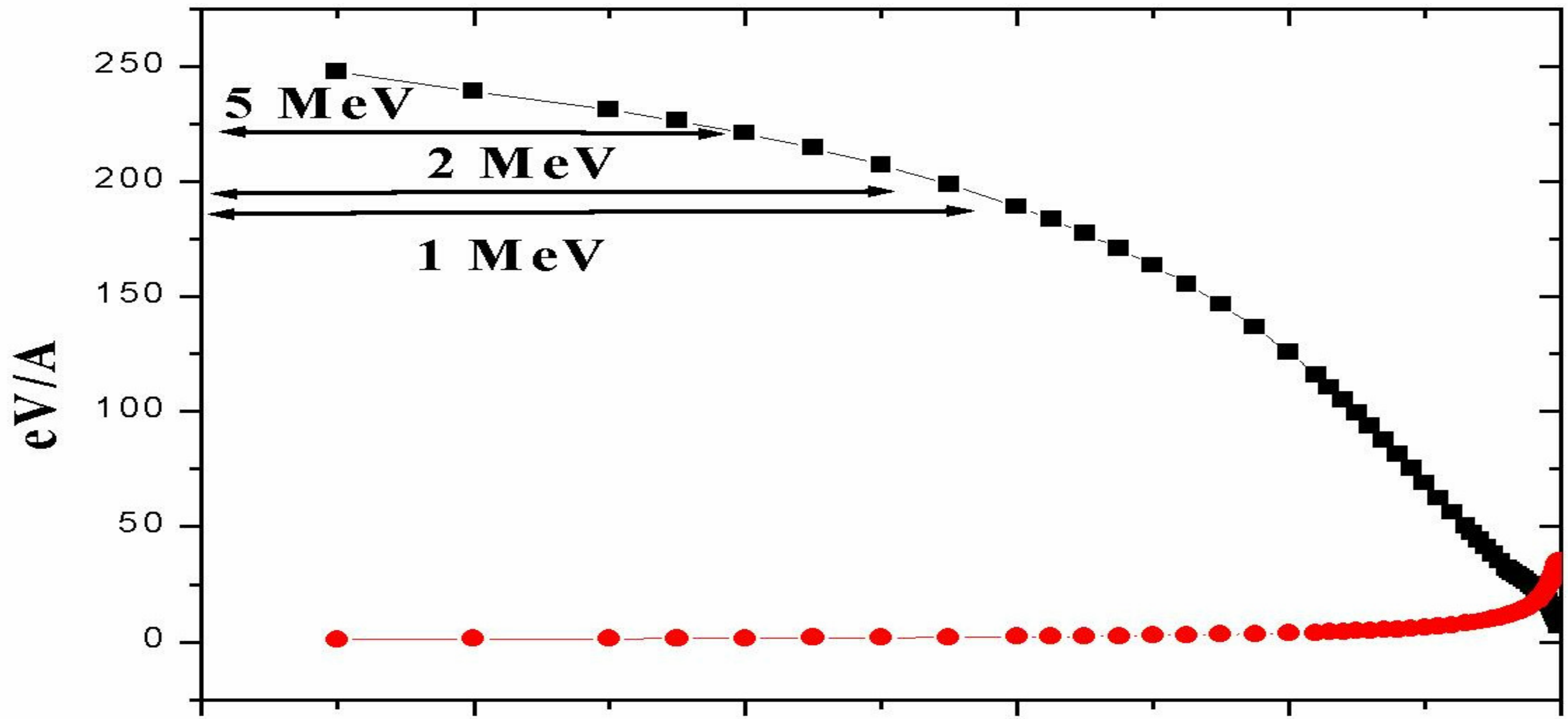
T: Layer Thickness

What is the process?




304
A
B
C





250
200
150
100
50
0
eV/A
5 MeV
2 MeV
1 MeV

Si (MeV)	ΔE (keV) due to ε_e	ΔE (keV) due to ε_n	$\alpha \cdot \lambda$ (nm)
1.2	107	7	4
2	176	5	9
5	373	3	27

Use

Mie theory

to

Detect

the

Nano-cluster formation

Non-destructive approach

Mie Theory a<r<λ

$$\alpha = \frac{18\pi Q n_o^3 \varepsilon_2}{\lambda\left[(\varepsilon_1+2n_o^2)^2+\varepsilon_2^2\right]}$$

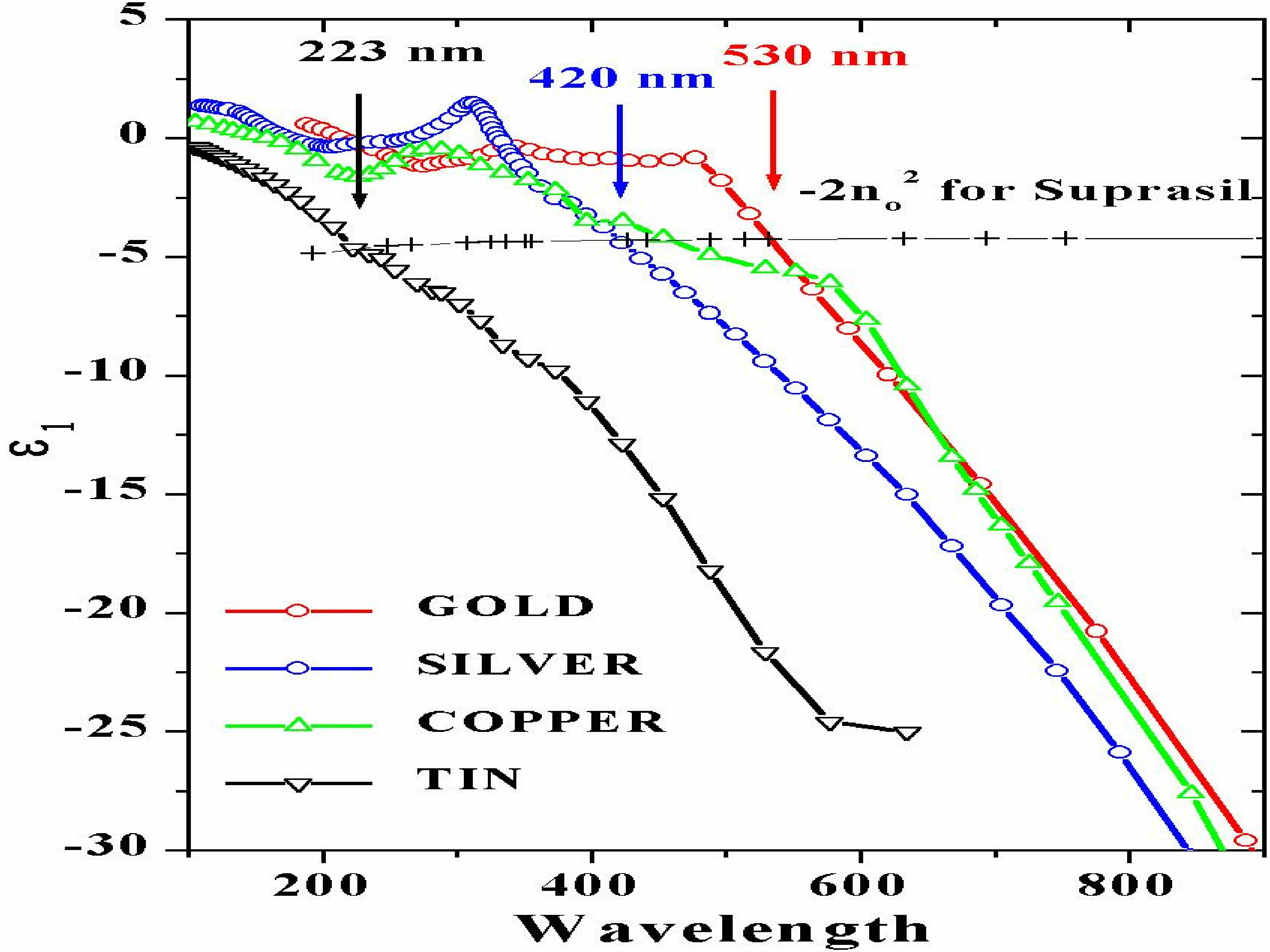
cm^{-1}

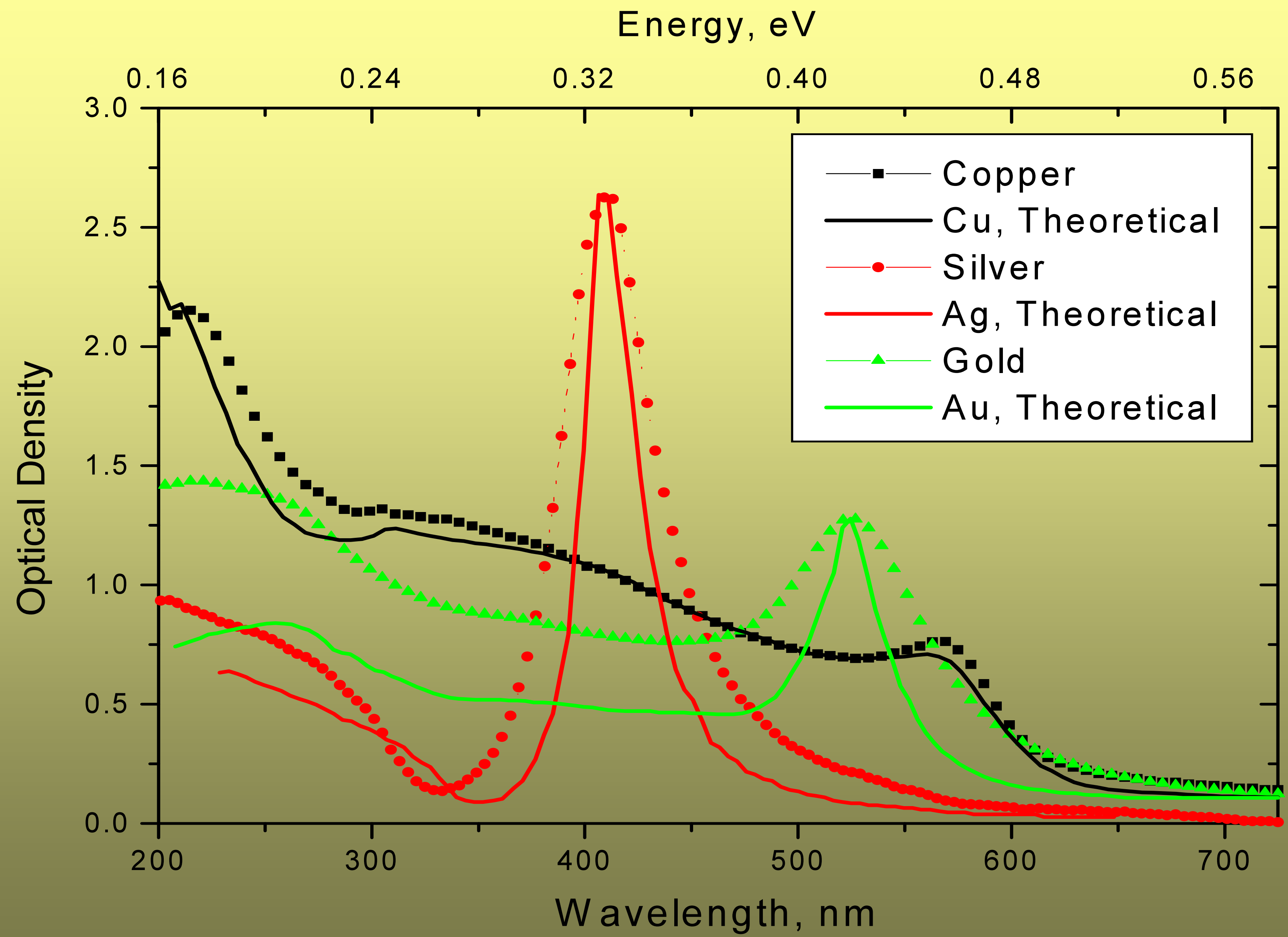
Maximum when

$$\varepsilon_1 + 2n_o^2 = 0$$

α	Linear coefficient of absorption
Q	Volume fraction of metal in insulator host
N_0	Index of refraction of insulator host
$\varepsilon_1 + j\varepsilon_2$	Complex dielectric constant of bulk metal
r	Radius of metal nanocrystal
λ	Vacuum wavelength of incident light
a	Electron mean free path in bulk metal

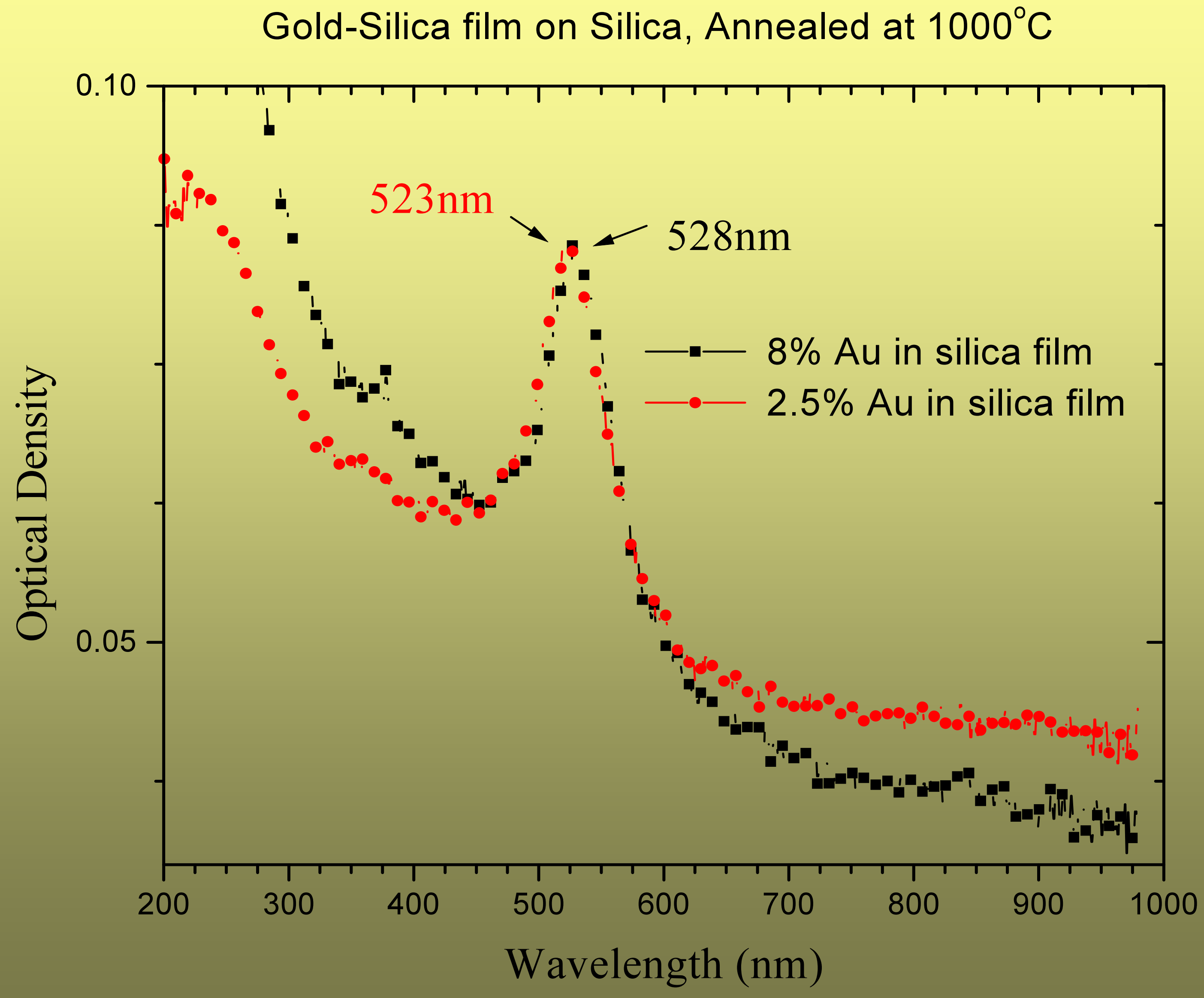
Gustav Mie, *Ann. Physik*, 25, 377 (1908)


223 nm
420 nm
530 nm
$-2n_o^2$ for Suprasil
GOLD
SILVER
COPPER
TIN
5
0
-5
-10
-15
-20
-25
-30
ε_1
200
400
600
800
Wavelength

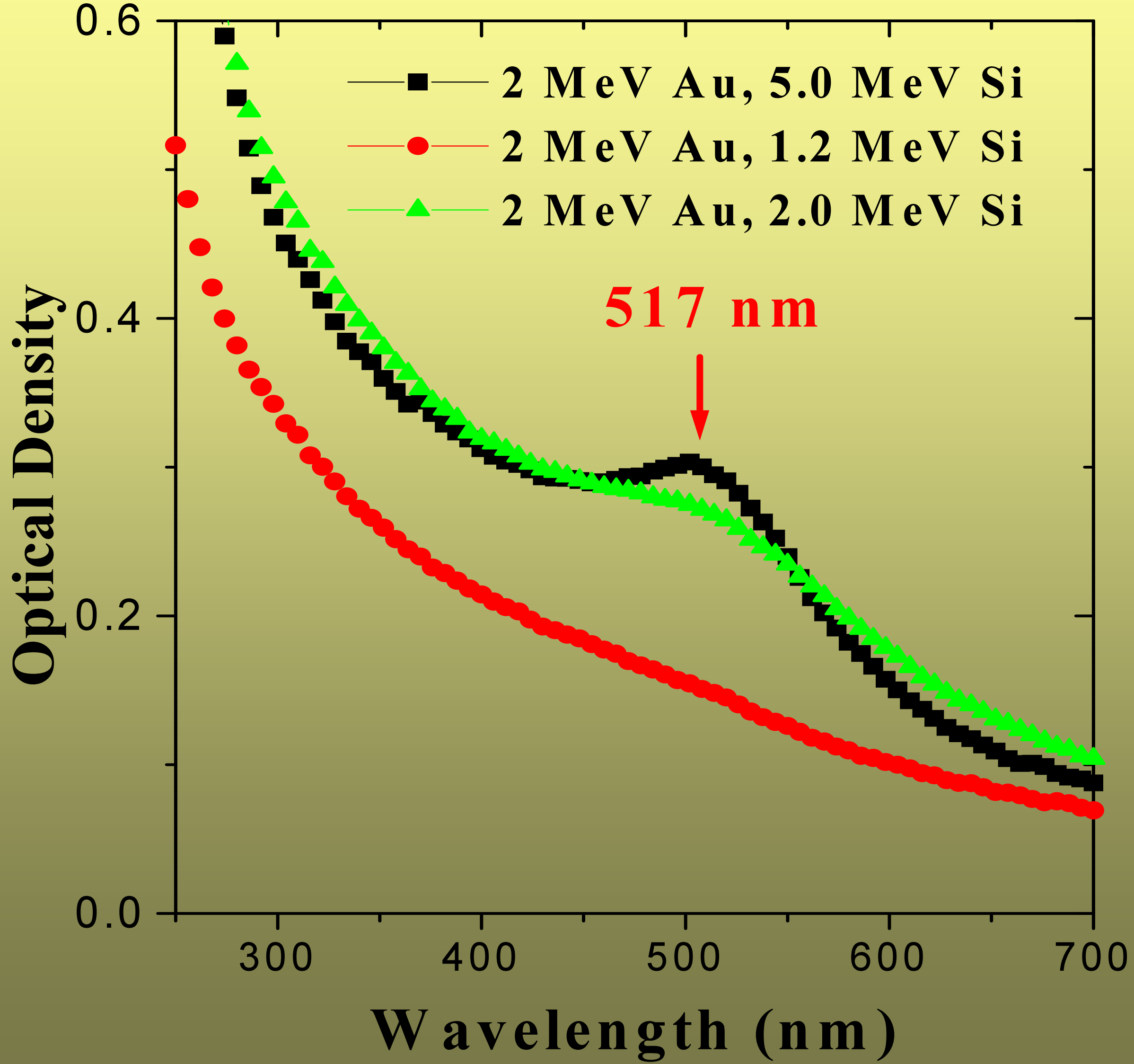

Energy, eV
0.16
0.24
0.32
0.40
0.48
0.56
Optical Density
3.0
2.5
2.0
1.5
1.0
0.5
0.0
200
300
400
500
600
700
Wavelength, nm
Copper
Cu, Theoretical
Silver
Ag, Theoretical
Gold
Au, Theoretical

Examples

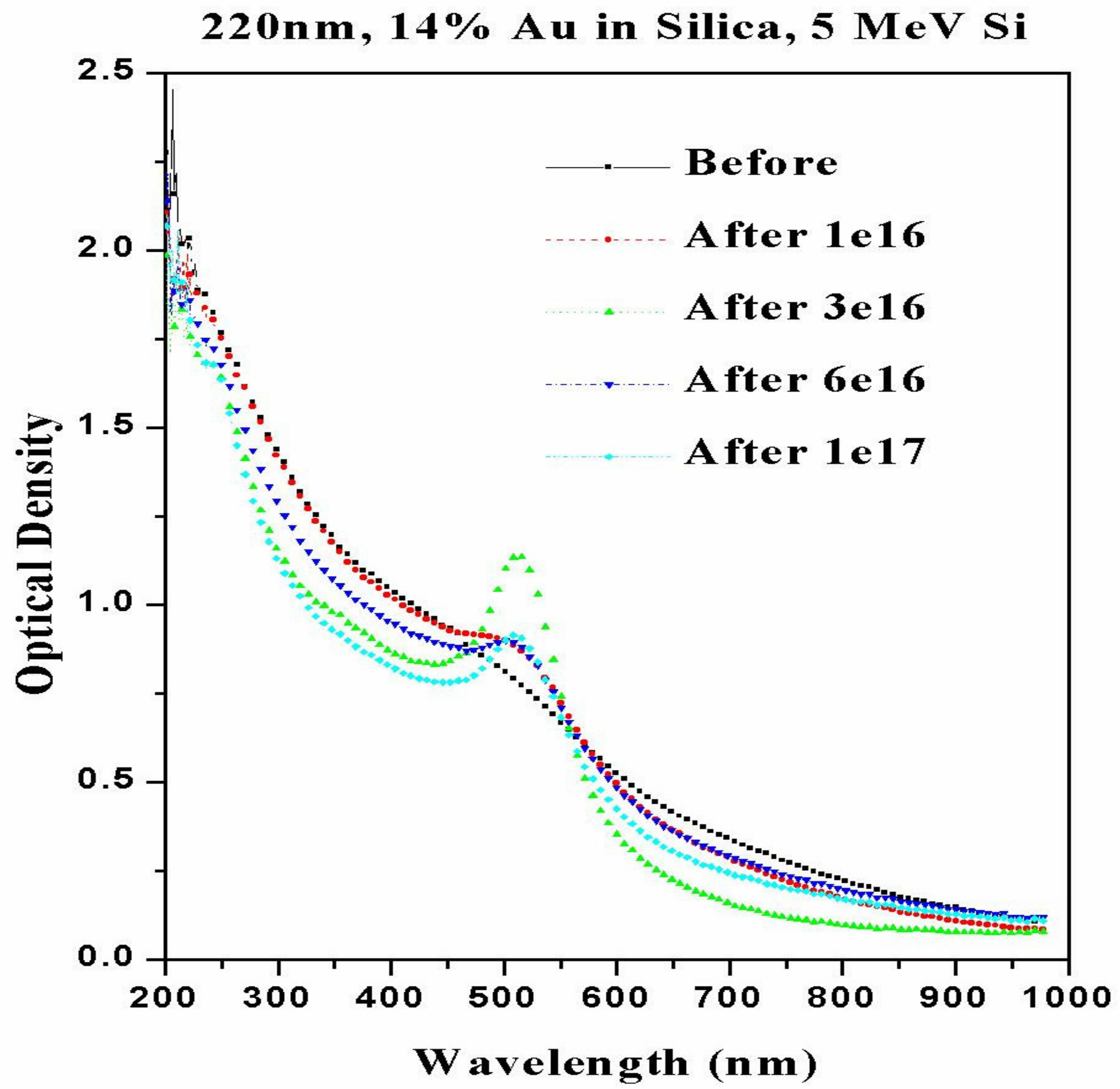
Example: Co-Deposition of Au and Silica, then annealed



Example: Au implanted in Silica, then bombarded by Si Ions



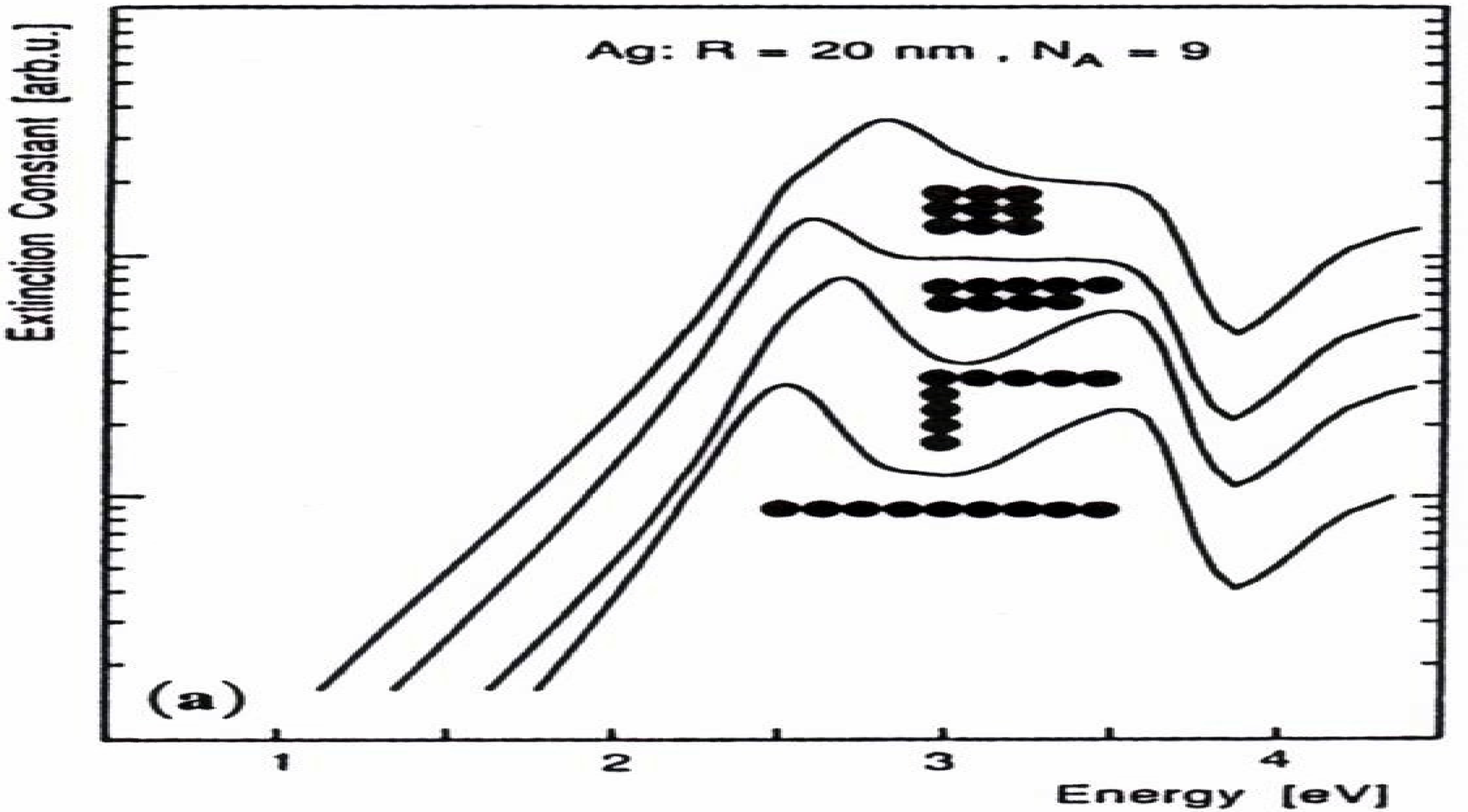
Example: Co-Deposition of Au and Silica, then bombarded



How do you know if the QDs/NCs are interacting?

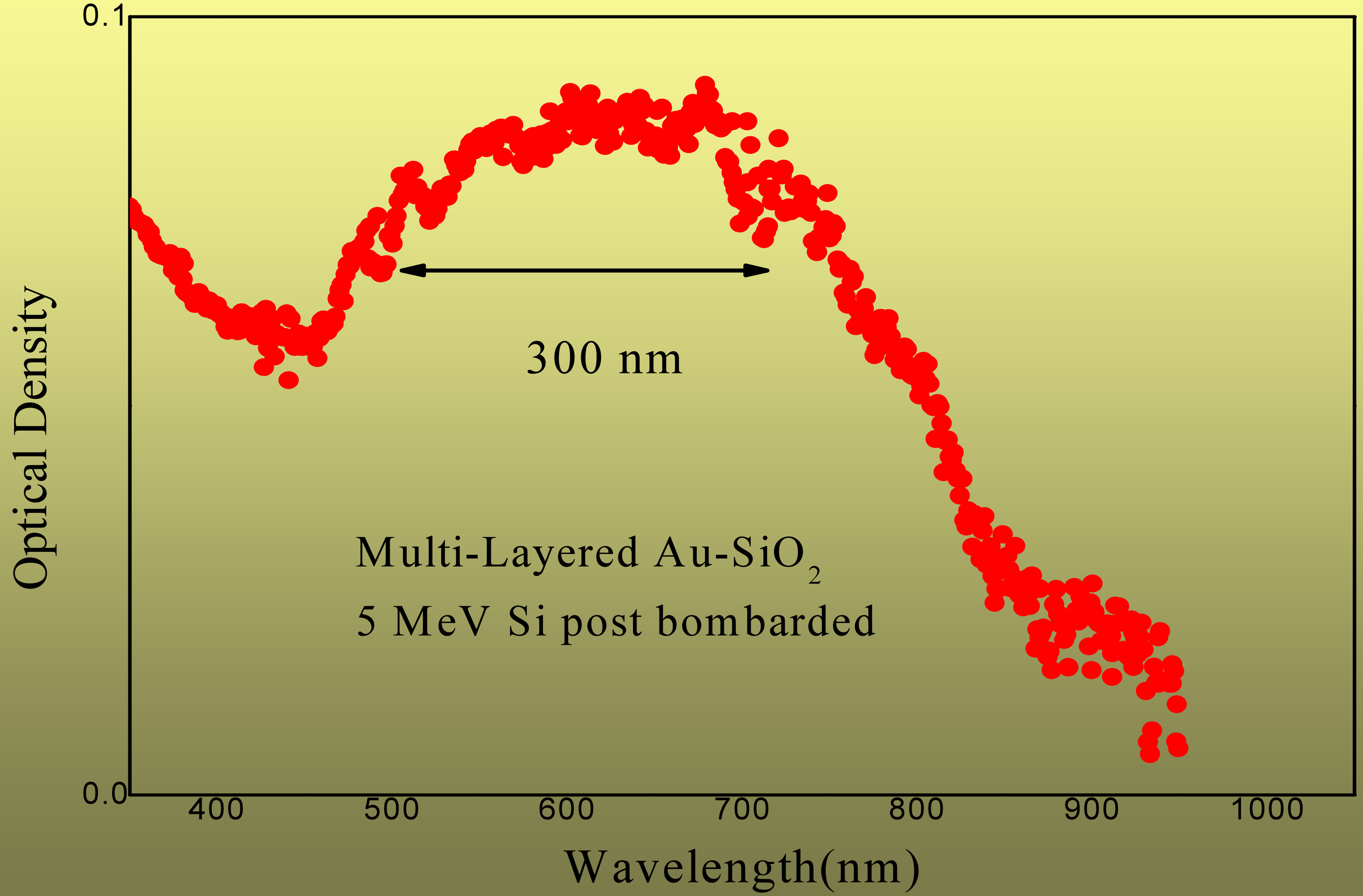
Shape of α as QDs/NCs interact through thin layers of SiO_2 Buffers

Kreibig, U. and Vollmer, M., Optical Properties of Metal Clusters, (Springer-Verlag, Berlin Heidleberg, 1995), p. 167.



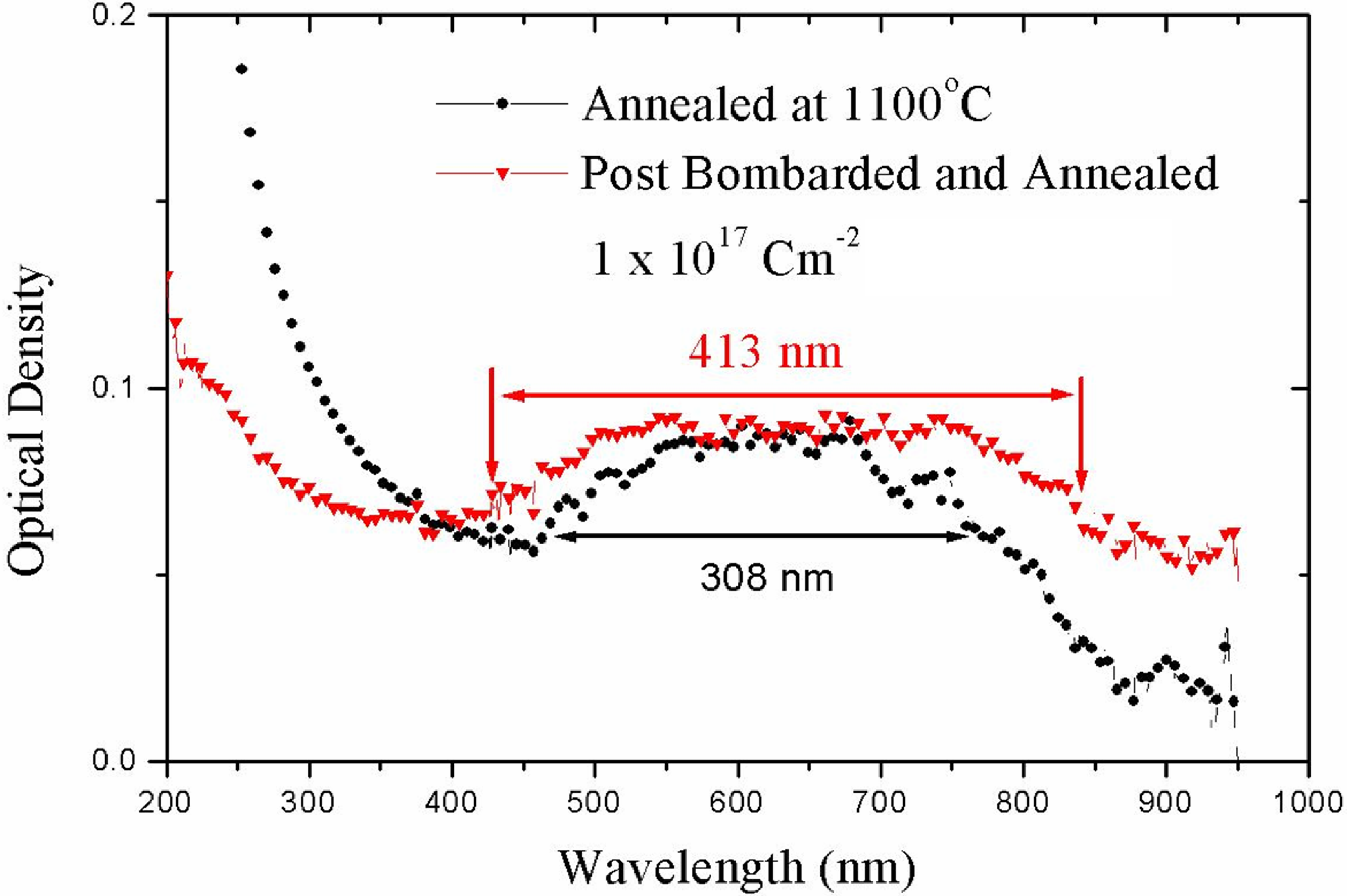
Example:

Five periods of SiO_2/SiO_2+Au on SiO_2 Substrate



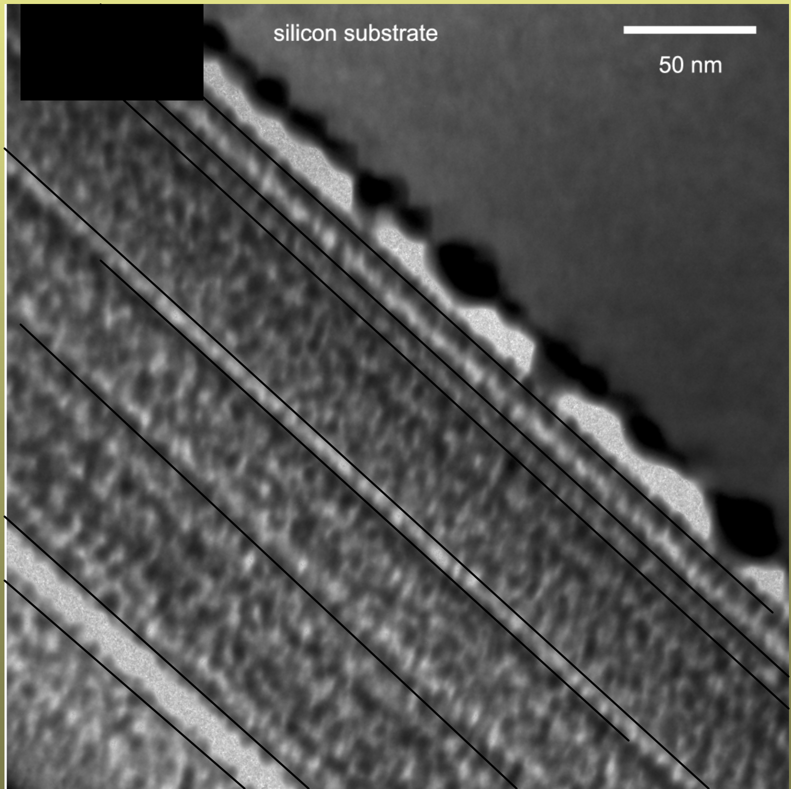
Example:

Many periods of SiO_2/SiO_2+Au on SiO_2 Substrate

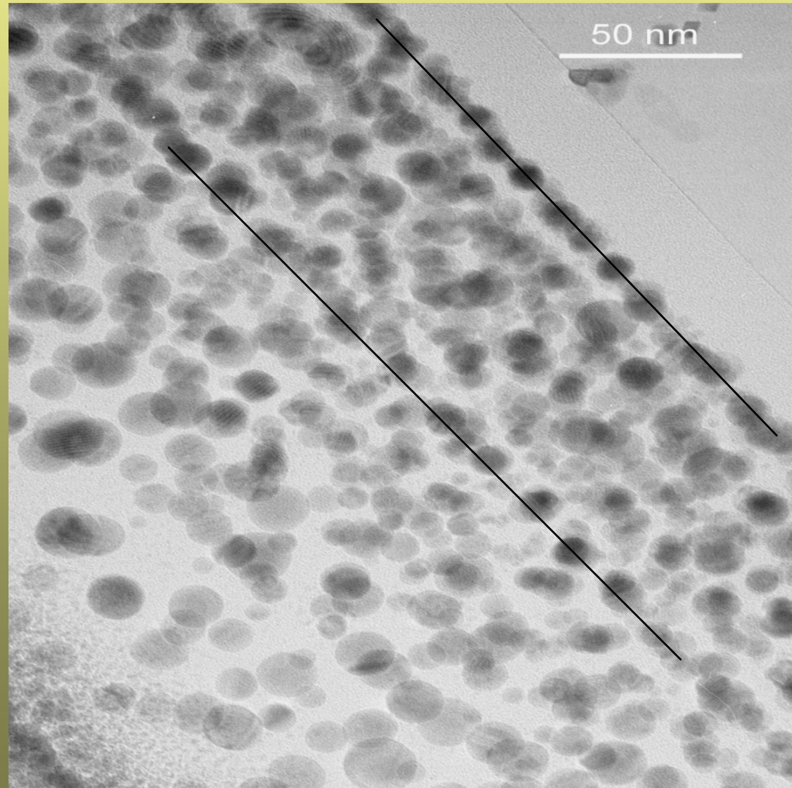


Gold dots in Silica
“Cross section view”

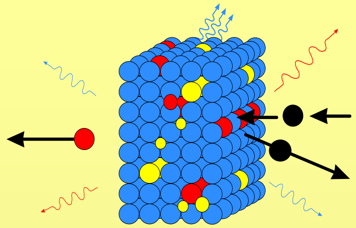
Prep Parameters XXX



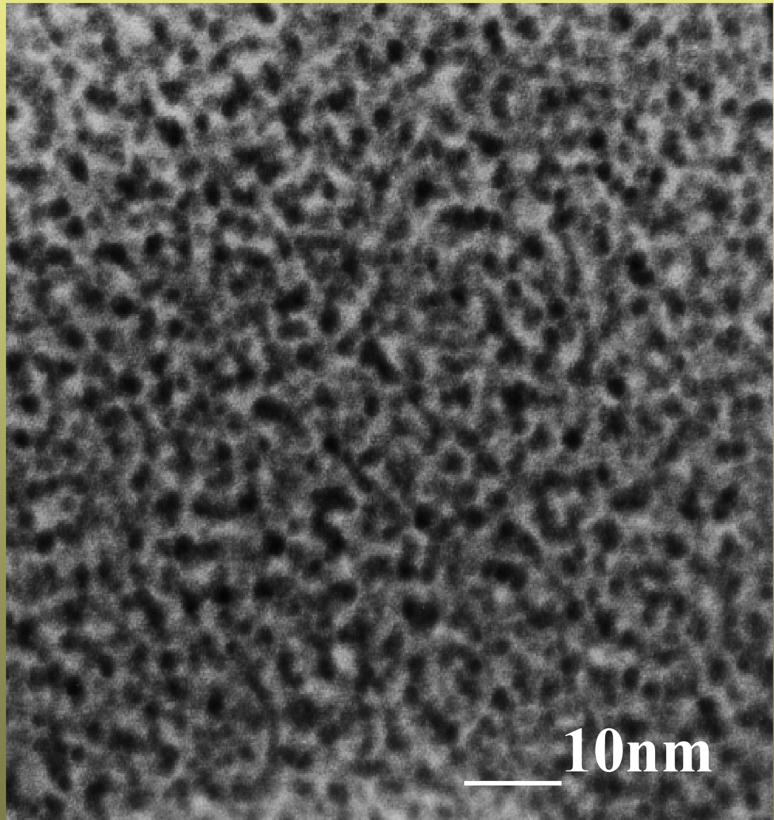
Prep Parameters XXX

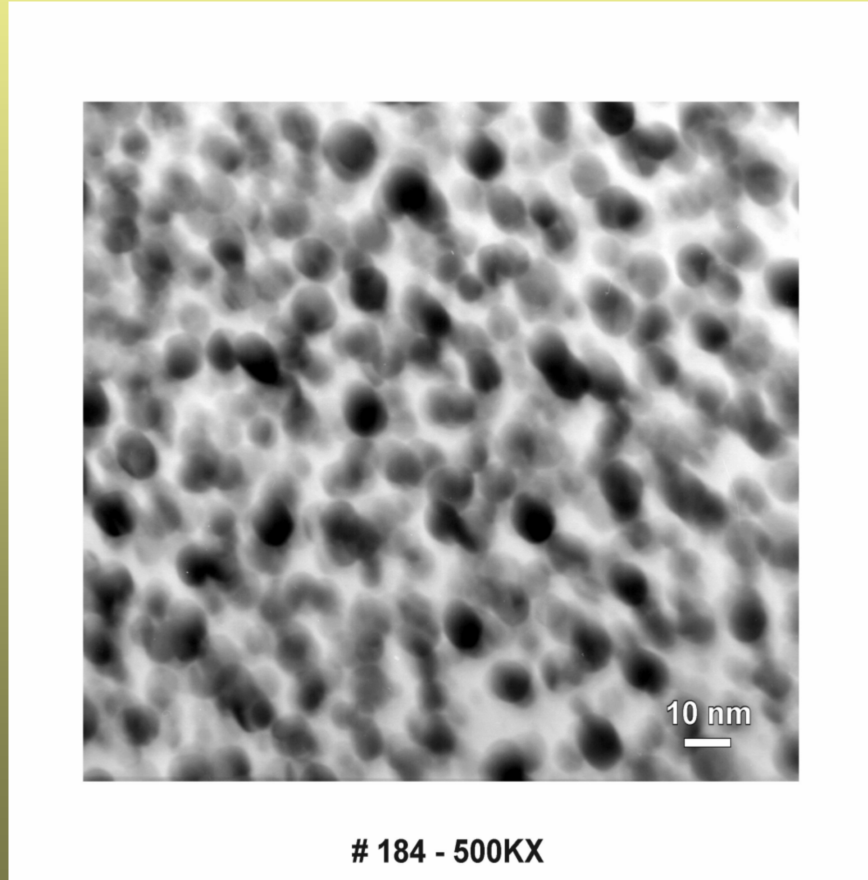


Au nanocrystal in Silica
Au-Silica Co-deposited



Low Au Concentration	High Au Concentration





Sample Preparation process

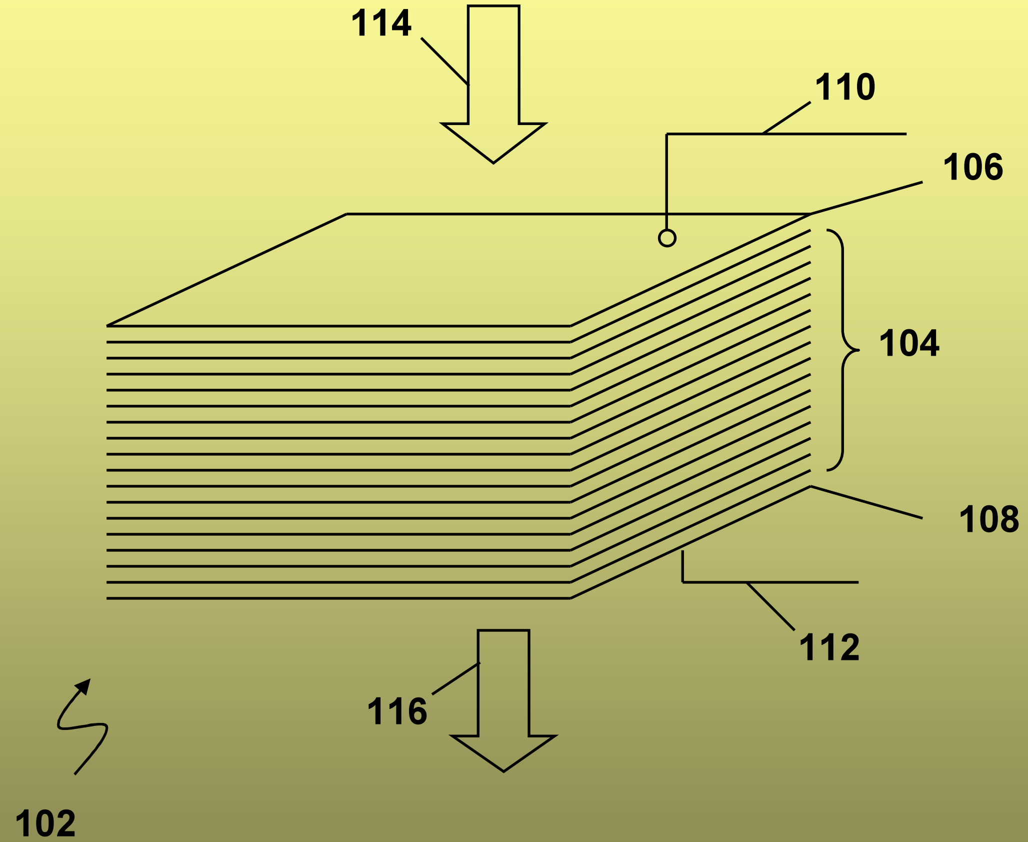
Generate multilayer structure
Comprising alternate layers of insulator
And co deposited metal plus insulator

↓

Irradiate structure through the layer plane
with ionizing radiation to generate
QDs/NCs

↓

Prepare surfaces
for the desired device


114
110
106
104
108
112
116
102

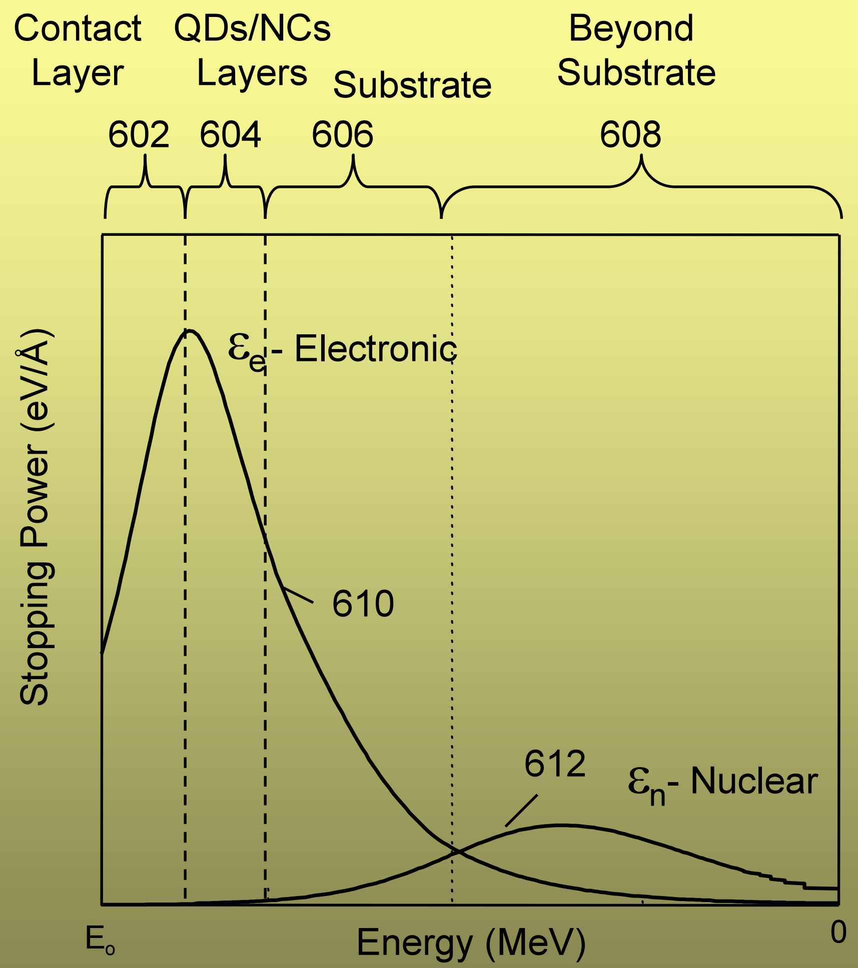
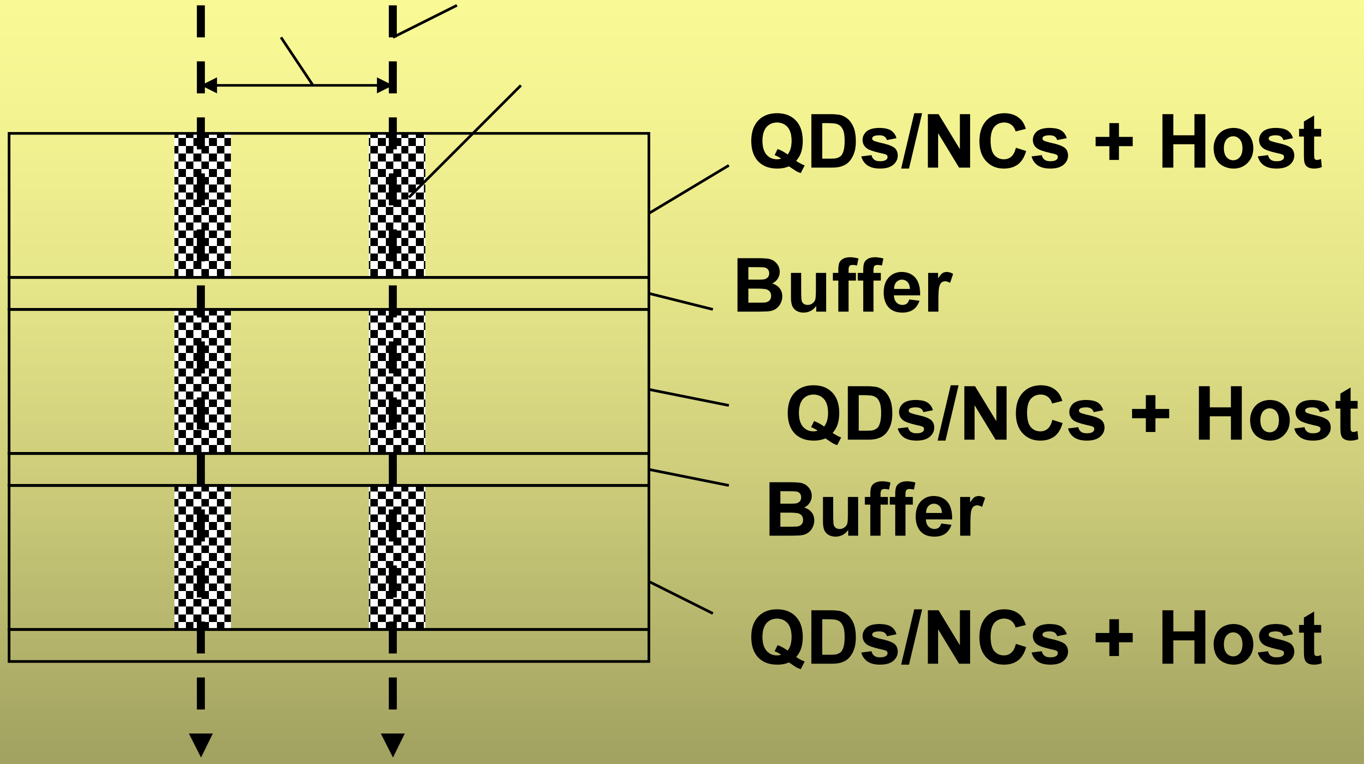
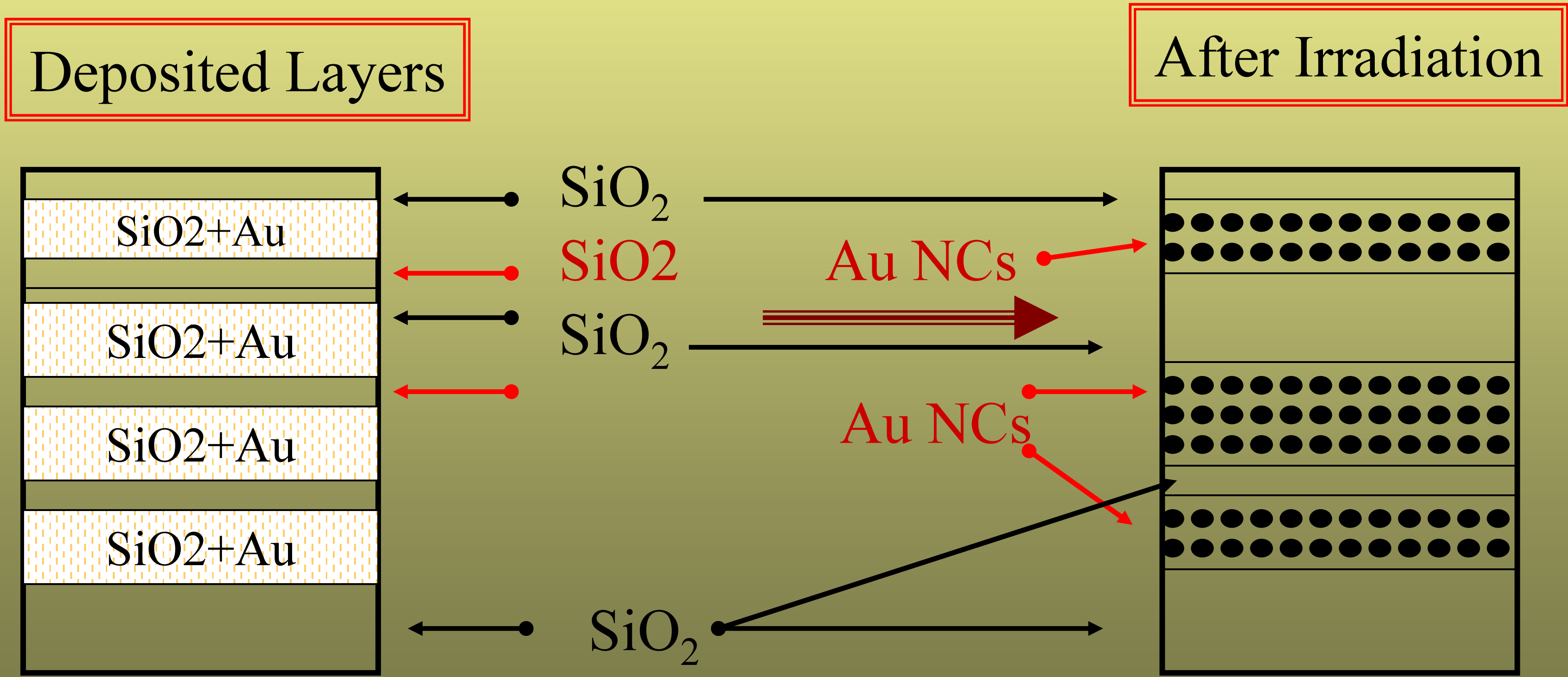

Contact Layer
QDs/NCs Layers
Substrate
Beyond Substrate
602
604
606
608
ε_e- Electronic
610
612
ε_n- Nuclear
Stopping Power (eV/Å)
E_o
Energy (MeV)
0

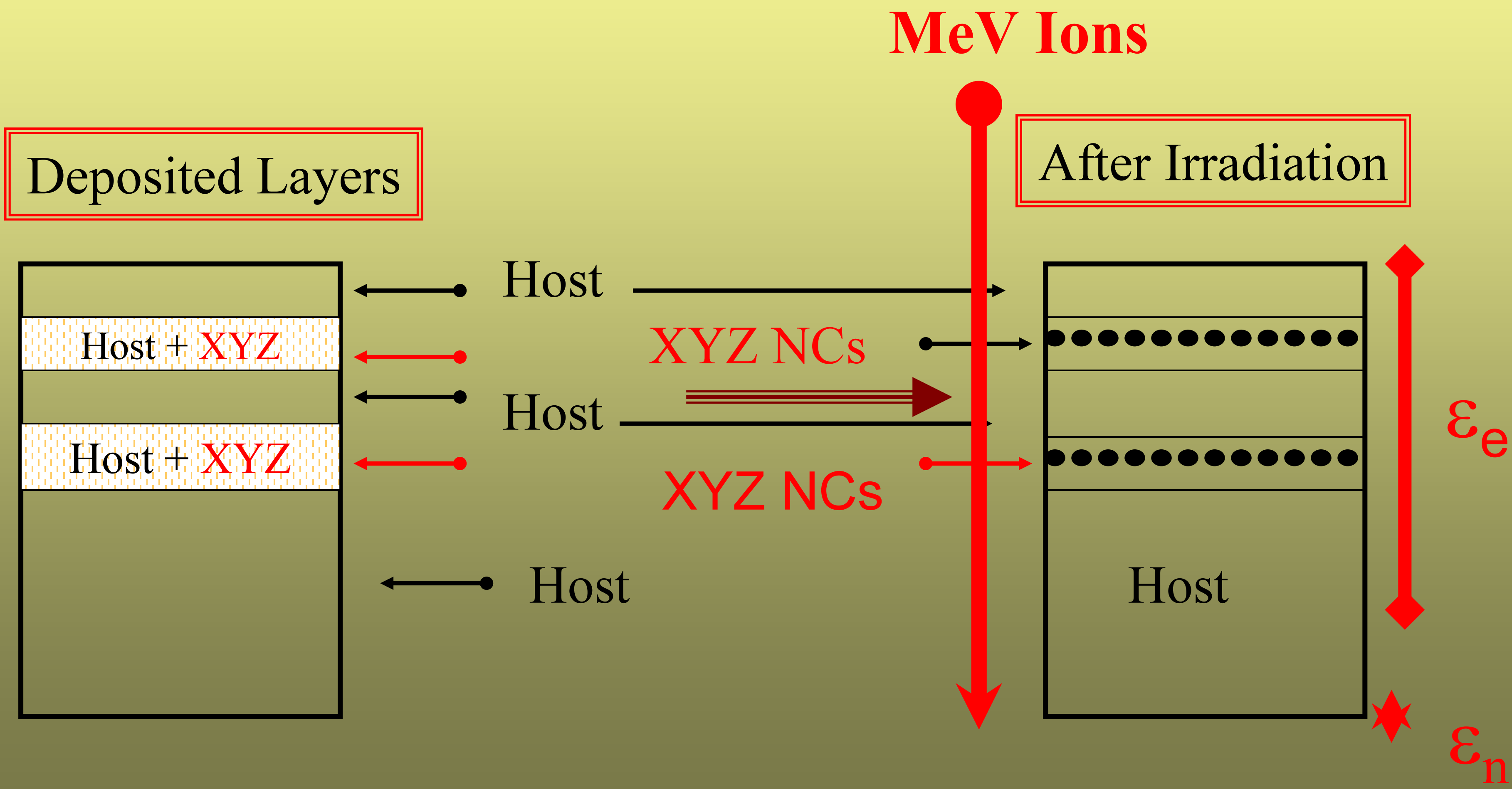
Fig. 6


QDs/NCs + Host
Buffer
QDs/NCs + Host
Buffer
QDs/NCs + Host

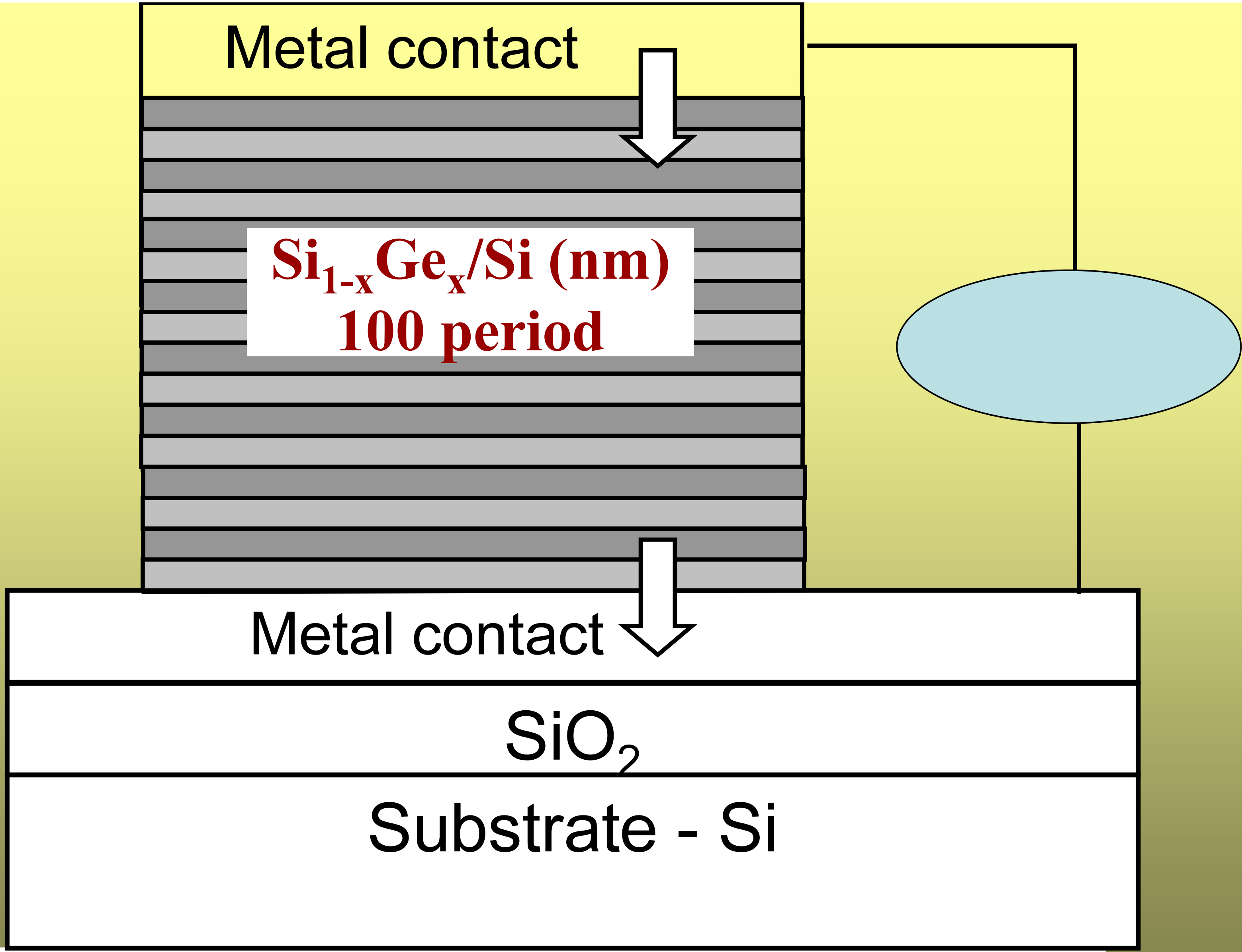
Layered Au NCs Formation by Deposition and Post Irradiation



Layered (any)- QDs/NCs Formation by Deposition and Post Irradiation

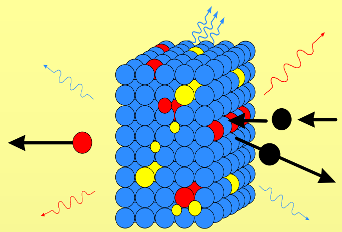


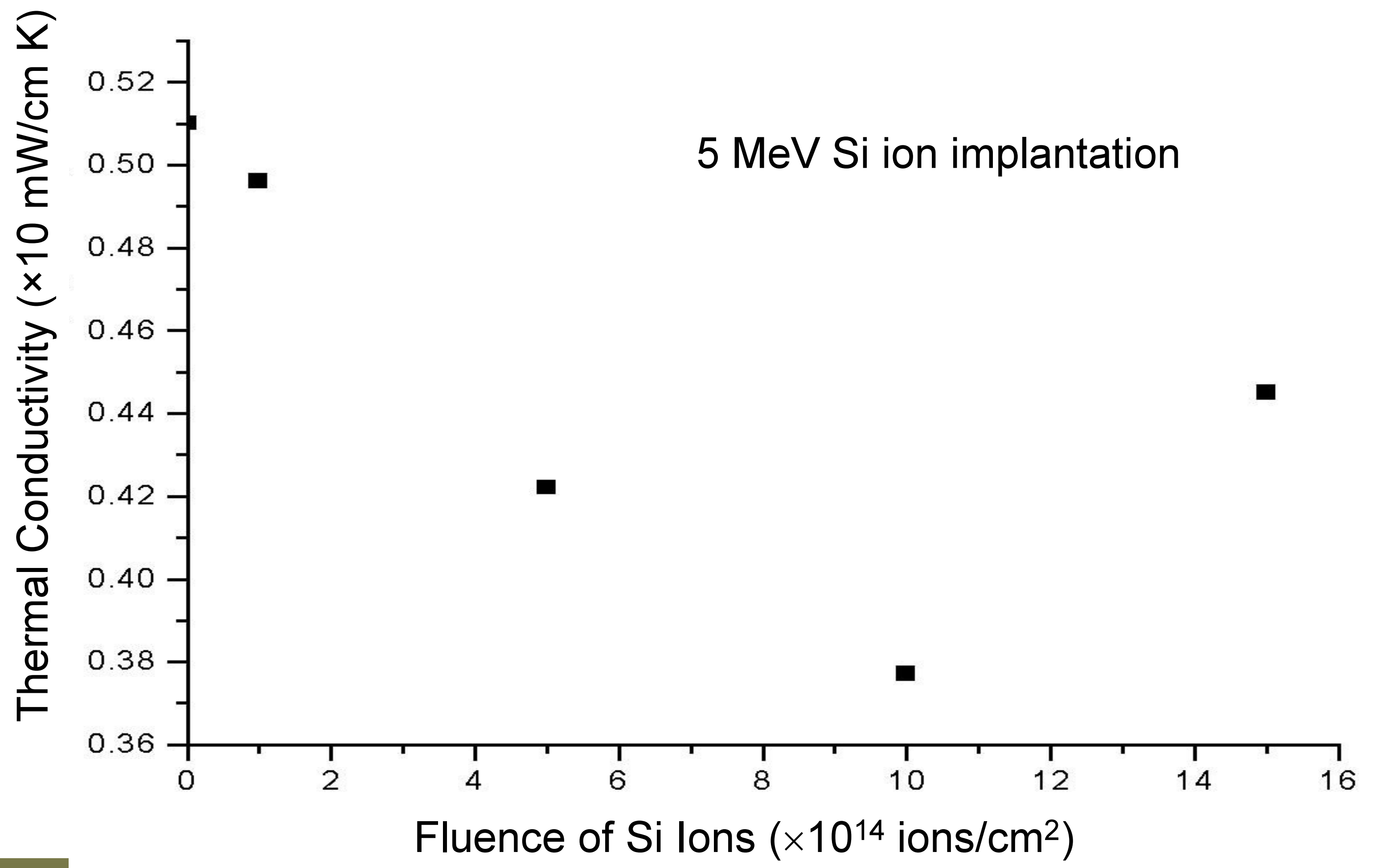
Design of NL/NC (QW/QD) Device using Ion Beam



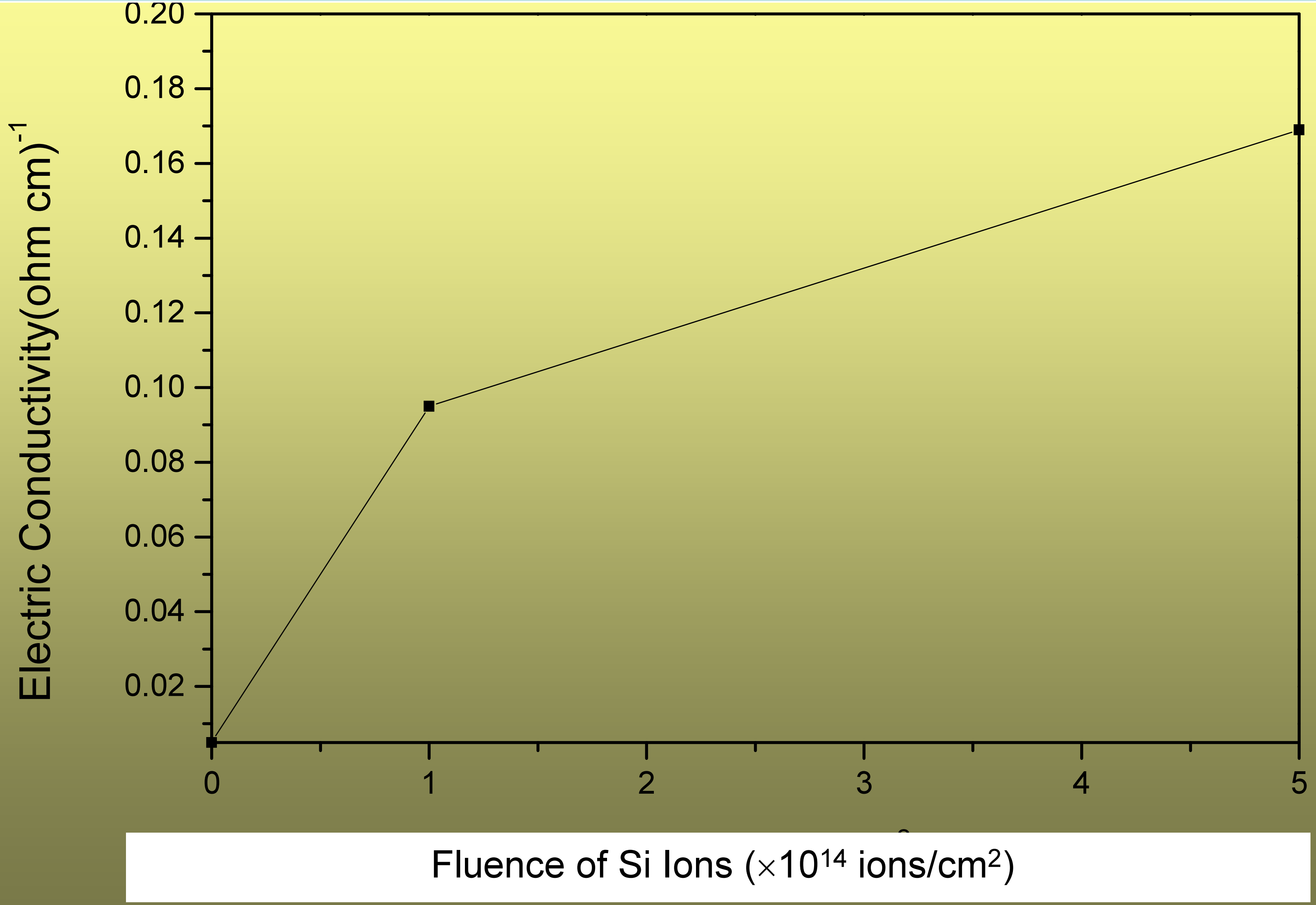
Schematic of $Si_{1-x}Ge_x/Si$ Superlattice TE device

Example of the Thermal Conductivity

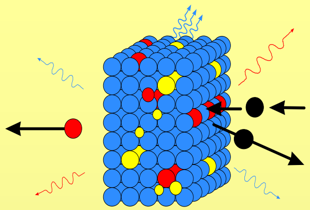




Example of the Electrical Conductivity

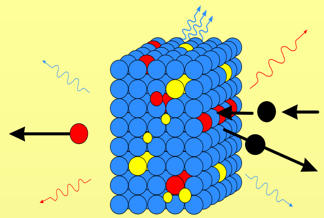


Summary



Produced highly dense and localized QDs/NCs taking advantage of the short pulses of the highly localized electronic energy deposited per unit volume due to ionization combined with layered deposition of desired species.

Applications



- Optical filters
- Sensors (Chem/Bio)
- Highly Efficient Thermoelectric Generators (Patent filed)
- Peltier devices
- ……