Magnetron-Based Nanocluster Source: Capabilities, Limitations and Future Possibilities

(A recent Invited University presentation)

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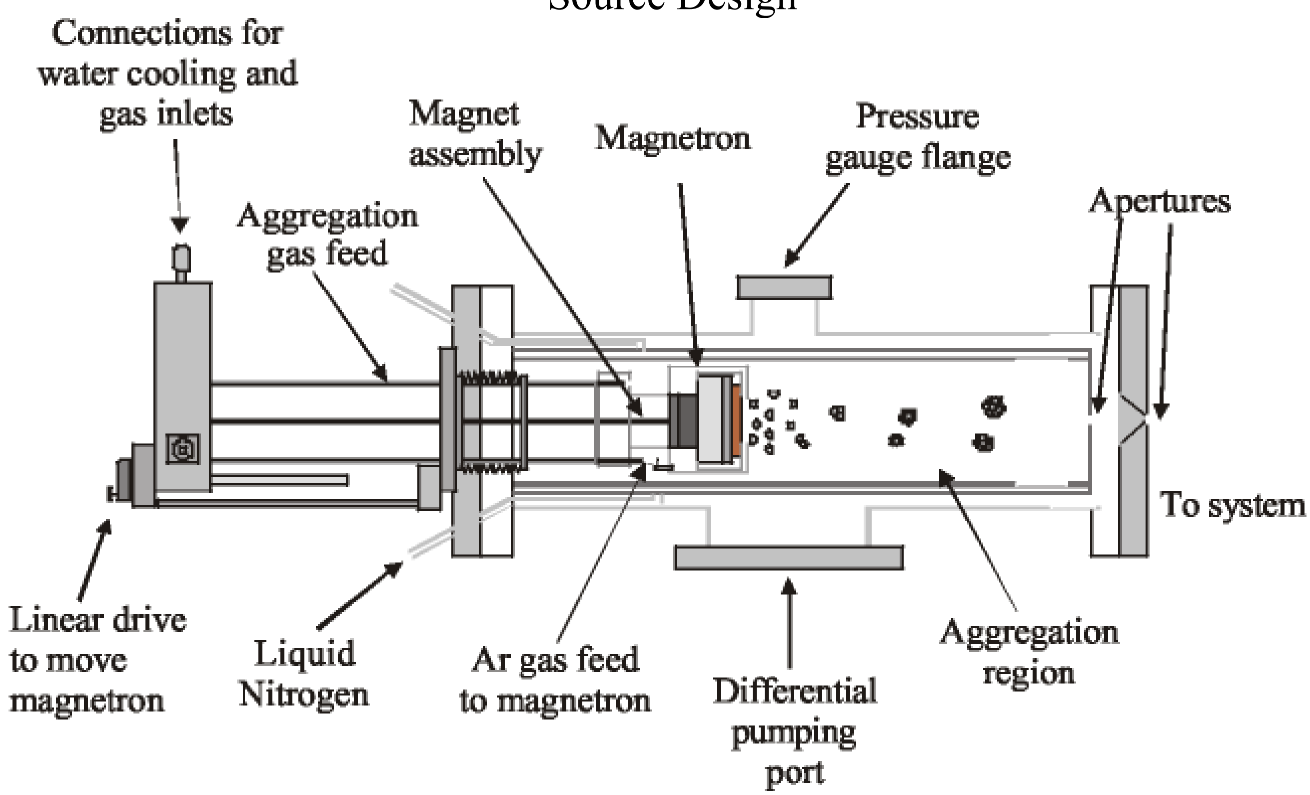
OUTLINE

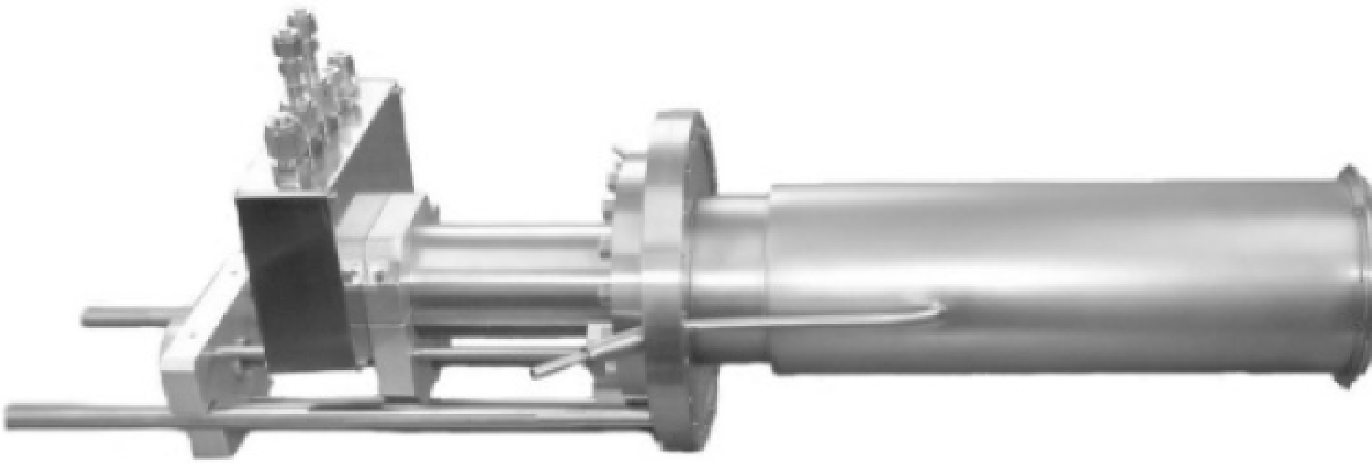
- Design
1. Cluster source
2. Quadrupole Mass Filter (QMF)
- Test data
- Case studies
- Future possibilities
-

History

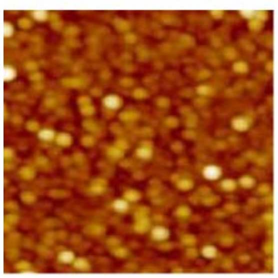
- First developed by Professor H. Haberland, Freiburg University, Germany in early 90's

Source Design





OAR Nanocluster Source



Materials

Why Magnetron Sputtering

<u>Wide Range of Materials</u>

- Metals and semiconductors via DC sputtering
- Insulators via RF sputtering
- Core+shell structures using non inert carrier gases
- Significant portion of clusters already ionized:
  - Al 60-80%
  - Mo 20-60%
  - Cu 20-50%

(Haberland, J. Vac. Sci. Tech. A 12(5) P 2925, 1994)

Why Ions?

- Ion manipulation
  - Separation of neutrals from ions
  - Acceleration /deceleration of ions
- For negative clusters, no unintended Ar+ sputtering
- Mass Spectrometry without an ionizer

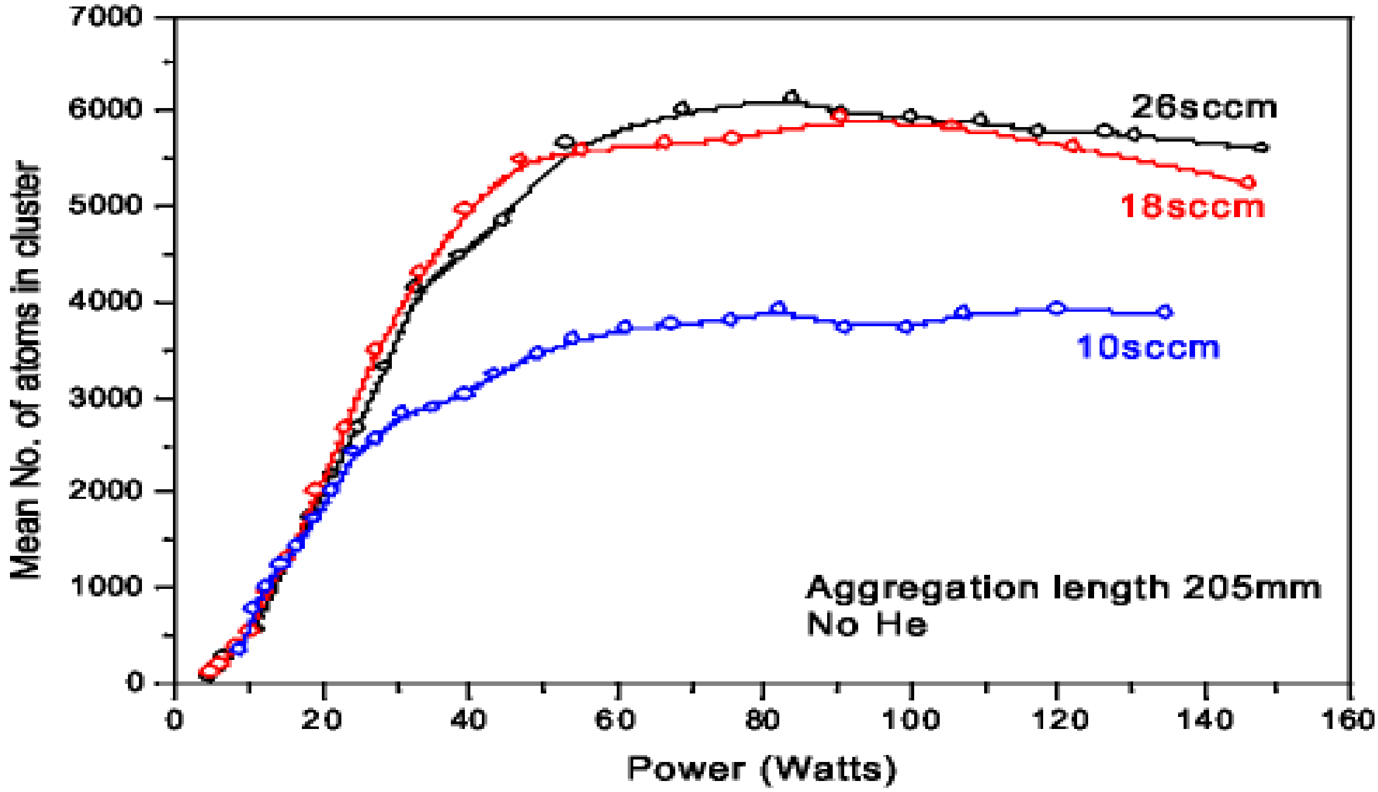
Cluster Size Control

- Magnetron power
- Sputter gas flow rate (Ar)
- Carrier gas flow rate (He)
- Aggregation length
- Aggregation region temperature
- Aperture size

Size Control

S.A. Koch et.al, Appl. Phys. Lett. Vol.84, No.4, 26, Jan 2004)

Cluster Size vs. Power



Cluster size increases with power initially and then levels off

Cluster Size vs. Ar Flow Rate

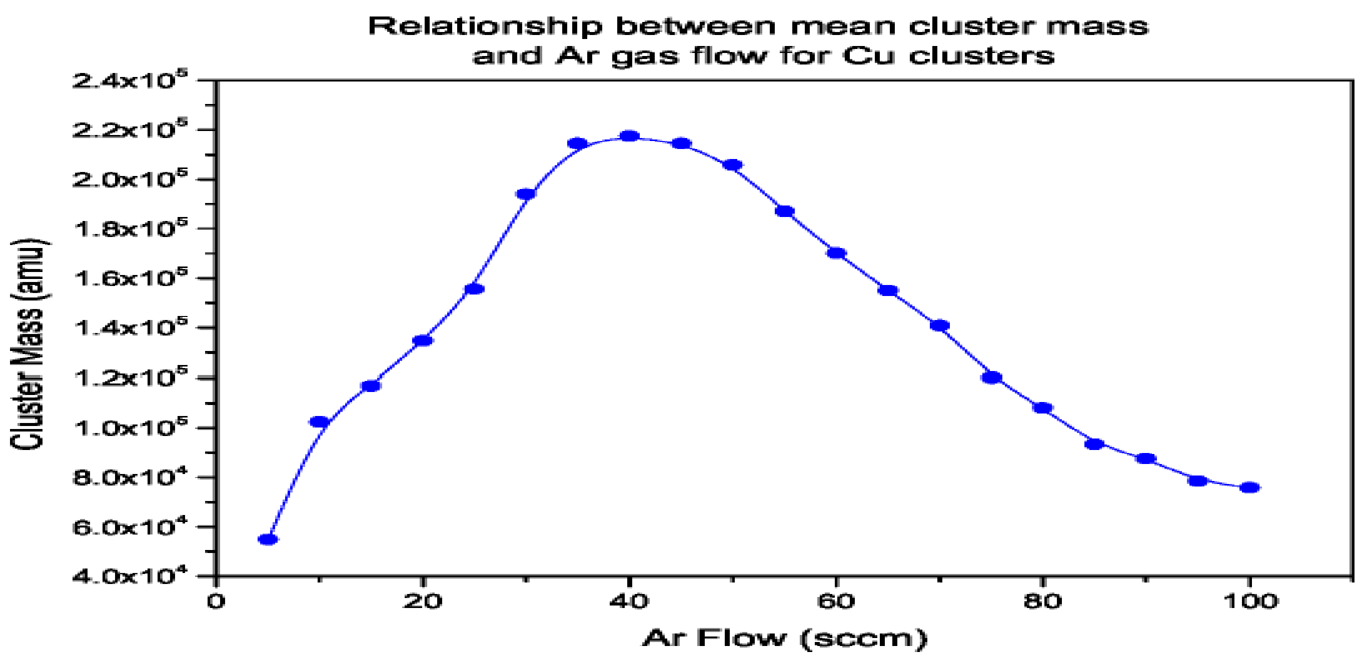


Figure 5

Cluster Size vs. He Flow Rate

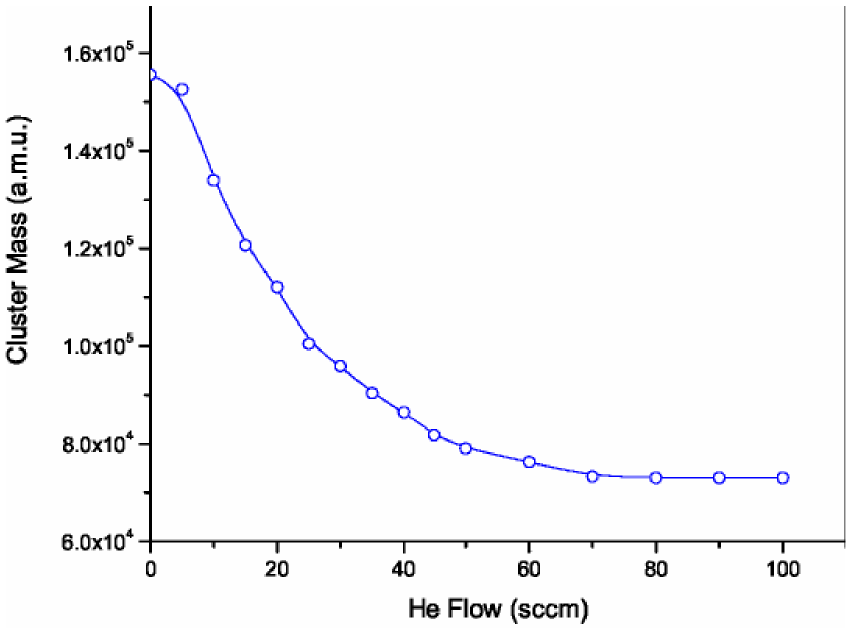


Figure 7

Increase in the carrier gas flow decreases the cluster size

Cluster Size vs. Ar Flow Rate

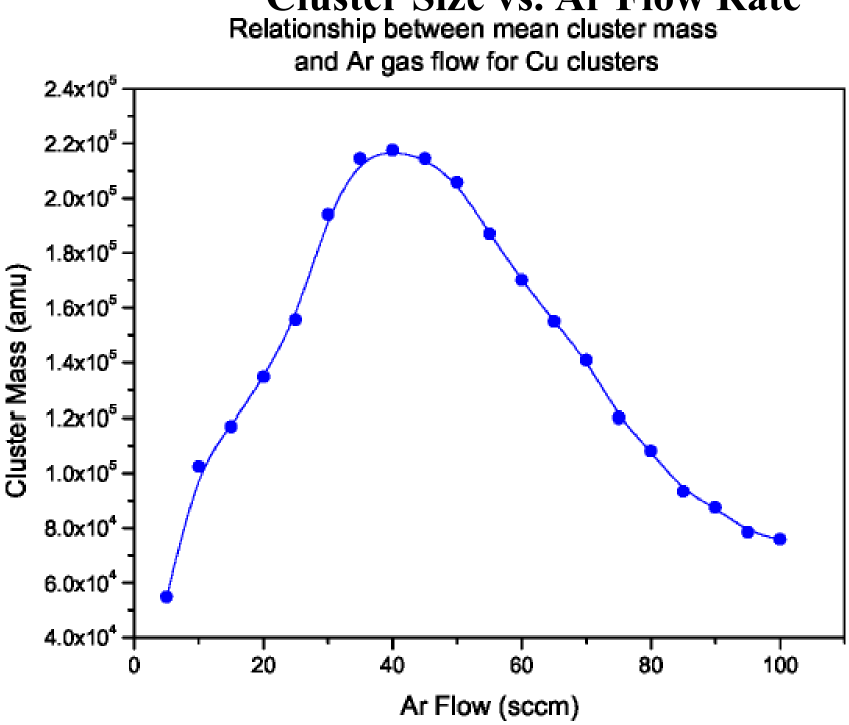
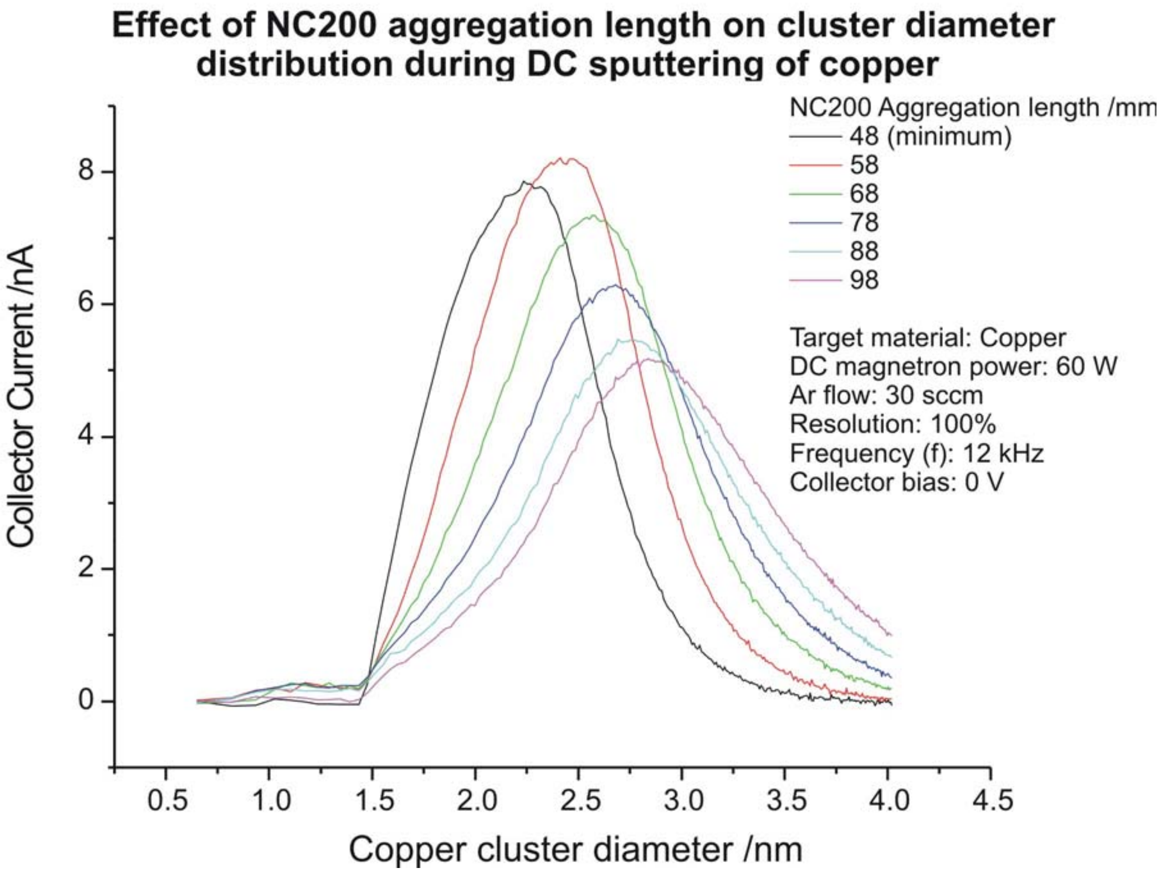
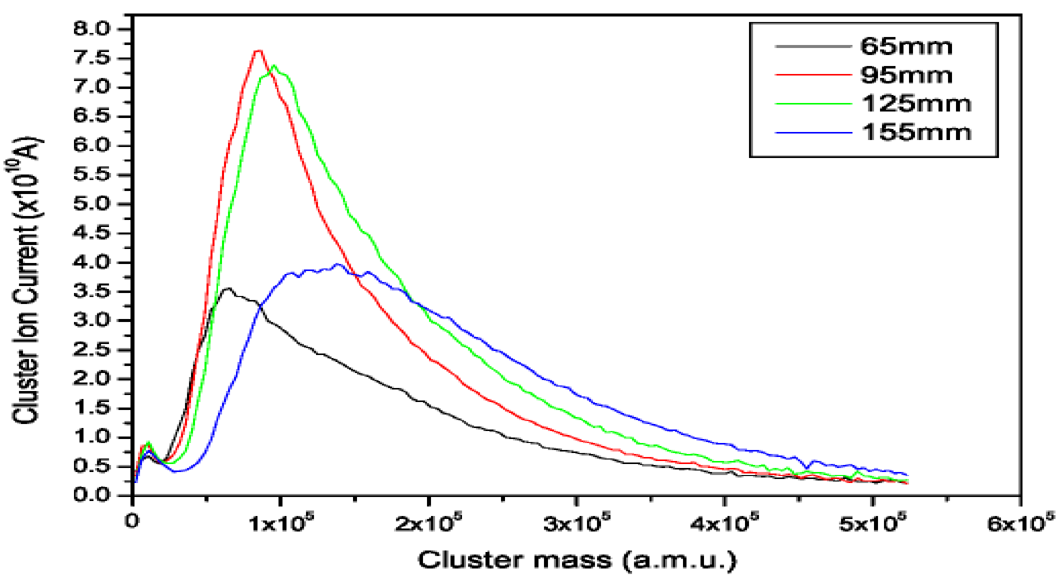


Figure 5

Cluster Size (Aggreg. Length)

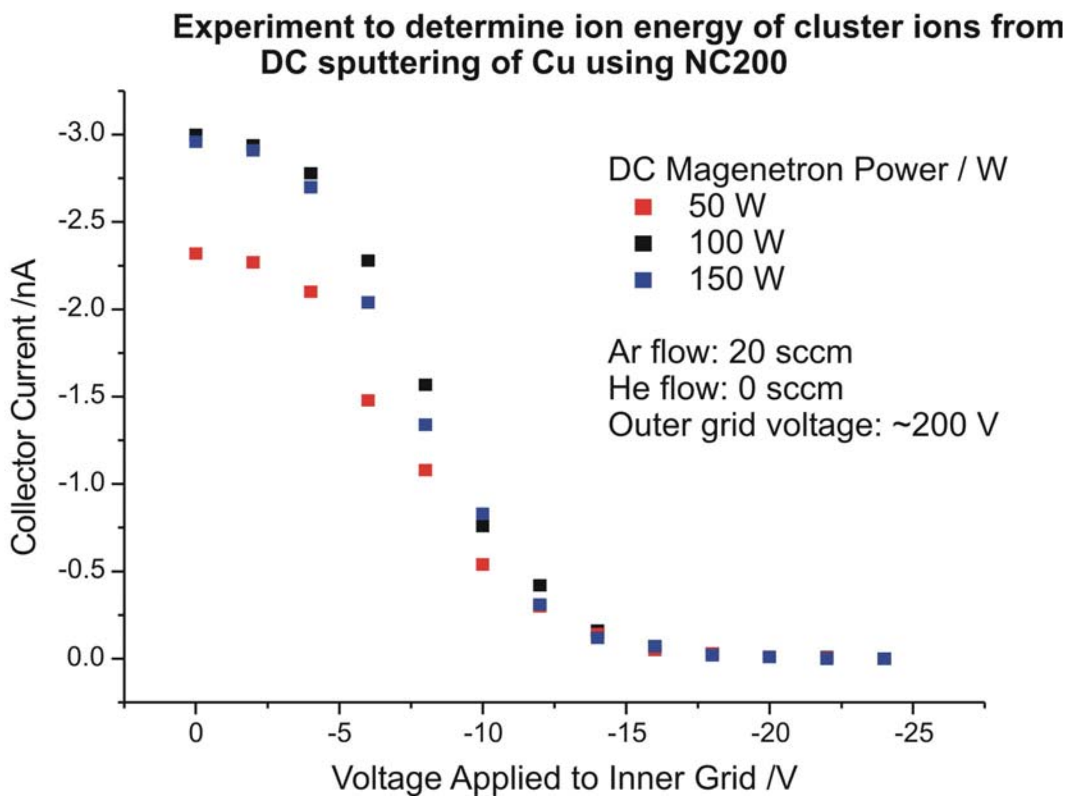


Effect of Aggregation Length

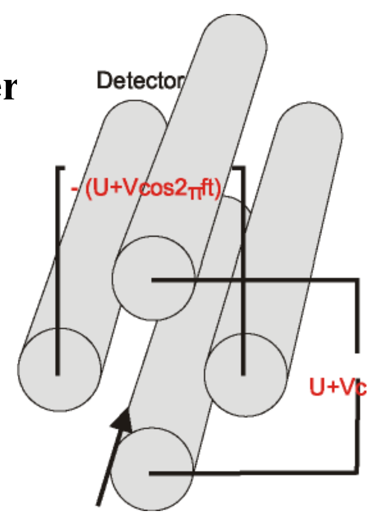


Longer aggregation length increases the cluster size

Cluster Energy



Quadrupole Mass Filter



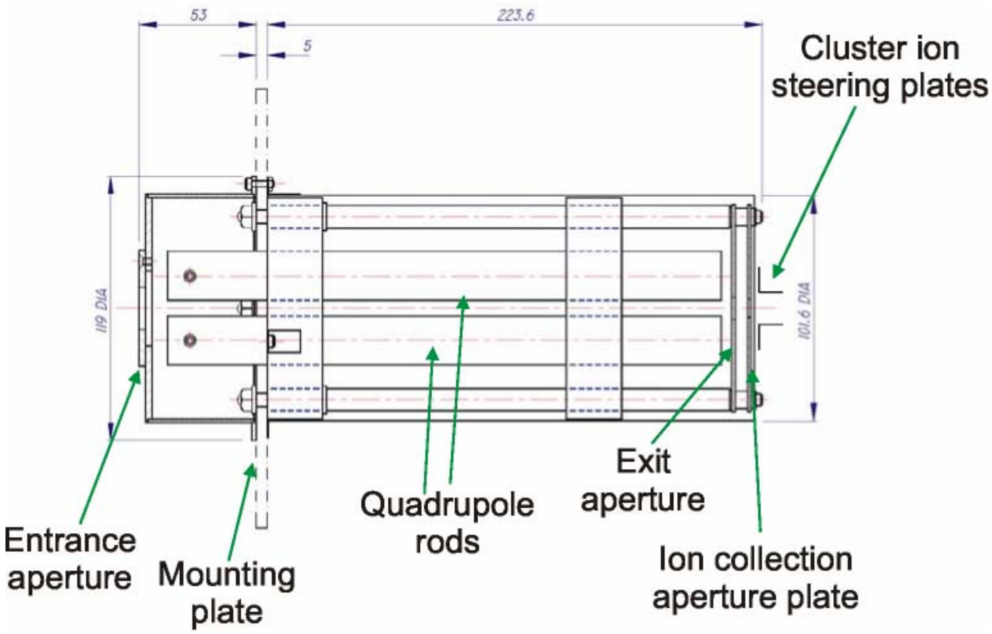
In-situ monitor + band pass filter

<u>Need to achieve a very wide scanning range (>105 amu)</u>

Binns, C et al Rev. Sci. Instrum., Vol 68, No. 4 April 1997

- The opposite rods electrically connected.
- Apply: DC (U) and AC (V with freq. f) voltages
- Filtering of clusters of specific mass/ charge ratio
- Scanning Range: Mm =7x107 (Vmax / f2 d2)
  d = rod diameter
- Theoretical Resolution: ΔM/M= 7.936 (0.16784 – (U/V))
- Optimum Resolution: ΔM= 4x109 (Vz/f2L2)
  Vz =ion energy L = length of the rods

OAR QMF



Operational Modes

<u>Scan Mode</u>

- scan V (cluster mass) while monitoring ion current
- U/V ratio is kept constant

<u>Filter Mode</u>

- V (cluster mass) is fixed
- Adjust U/V (resolution)

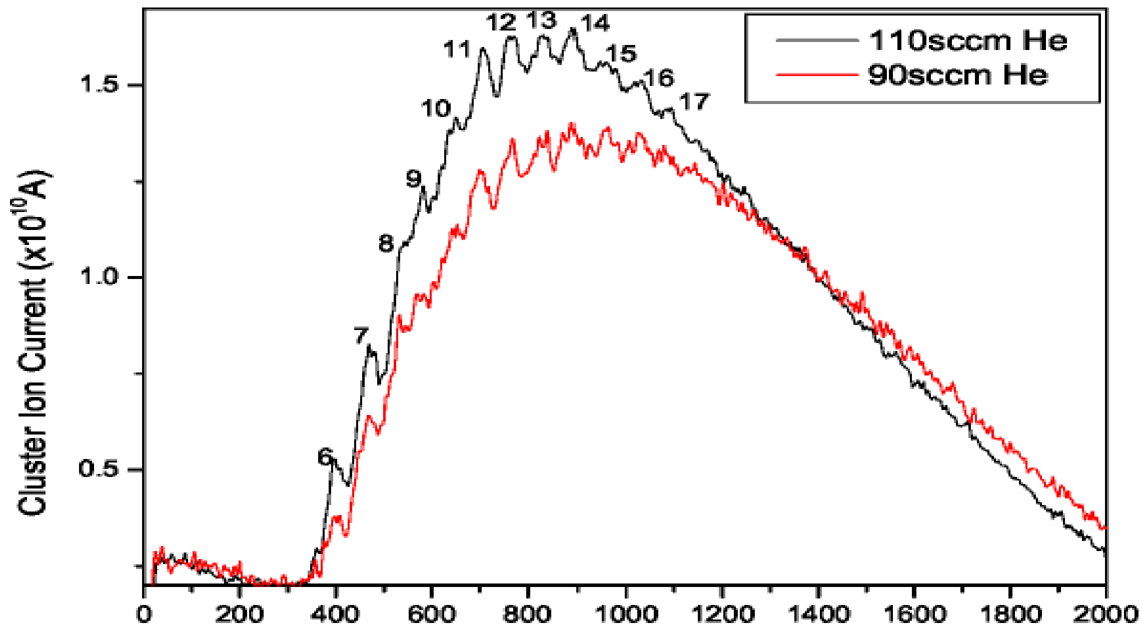
<u>Scanning Range</u>

- 30 AMU to 3x106 AMU

<u>Resolution</u>

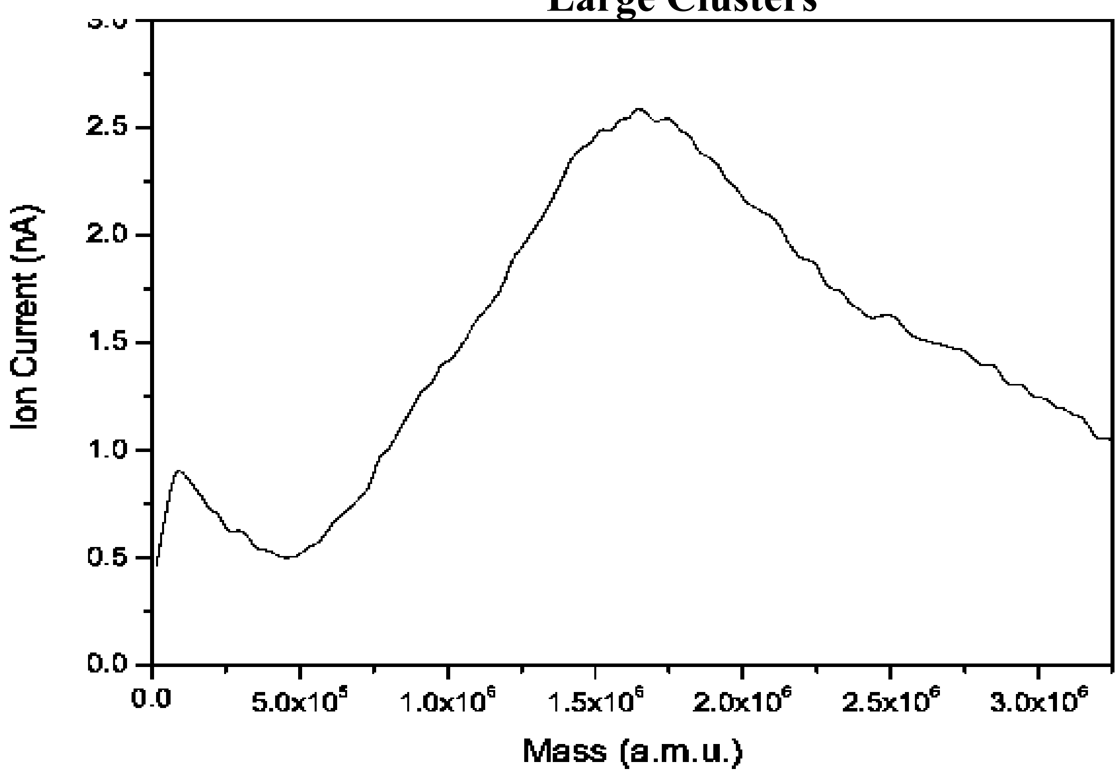
- Theoretical : significantly less than 1% assuming perfect machining of the rods, uniform ion energy, etc.
- +/- 2% resolution possible
- Useful flux obtainable with +/- 5% resolution

Small Clusters

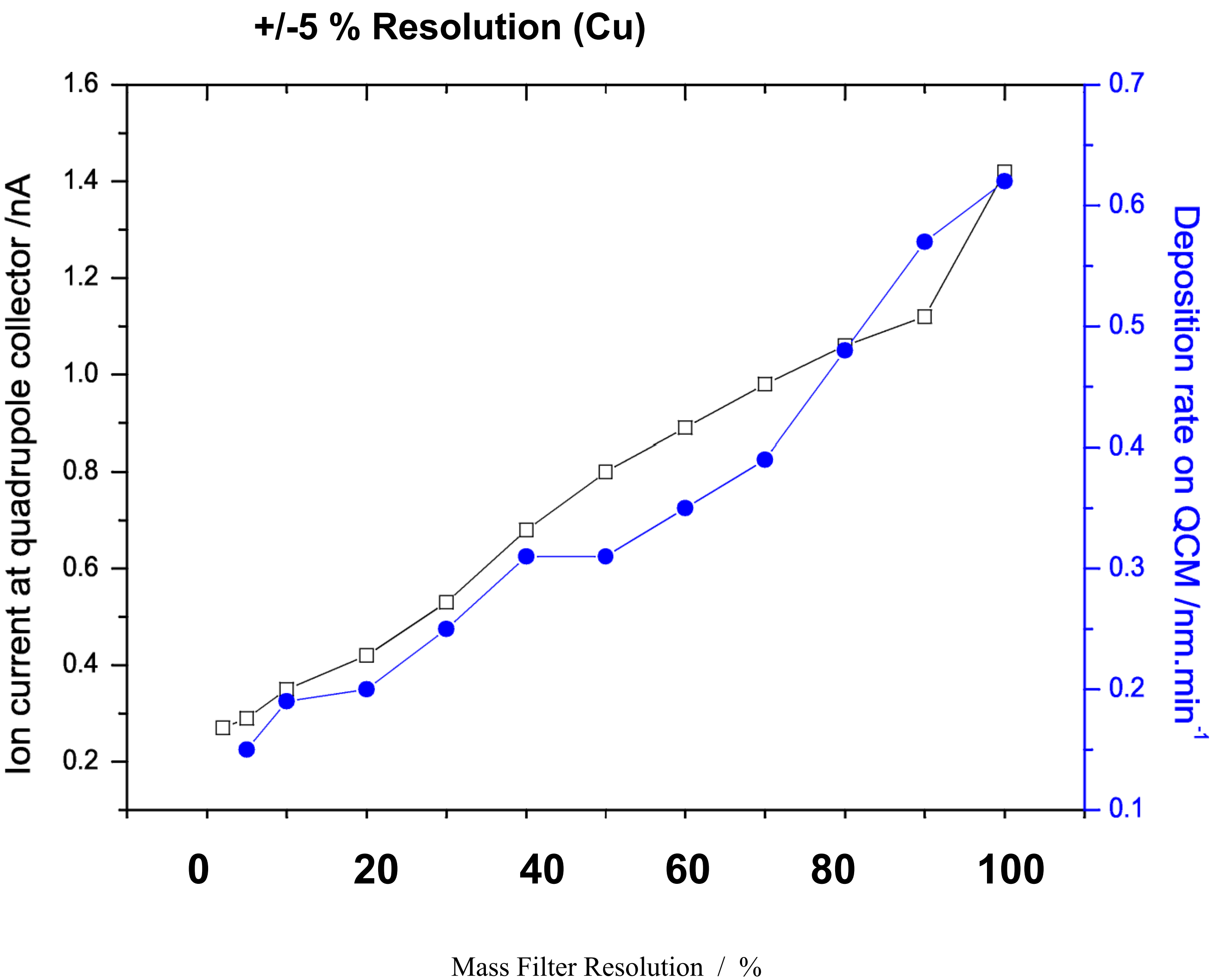


Power : 10W, Ar flow: 35sccm, He flow:110sccm, 90sccm
Aggregation length: minimum

Large Clusters

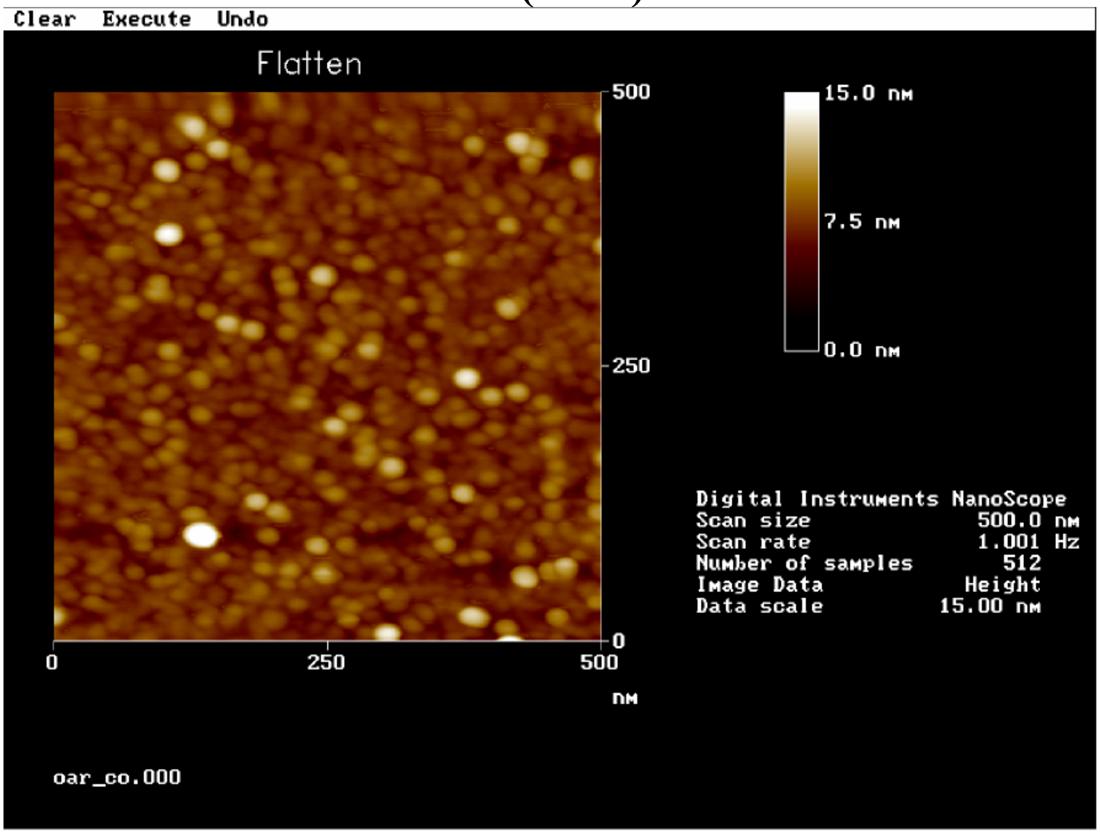


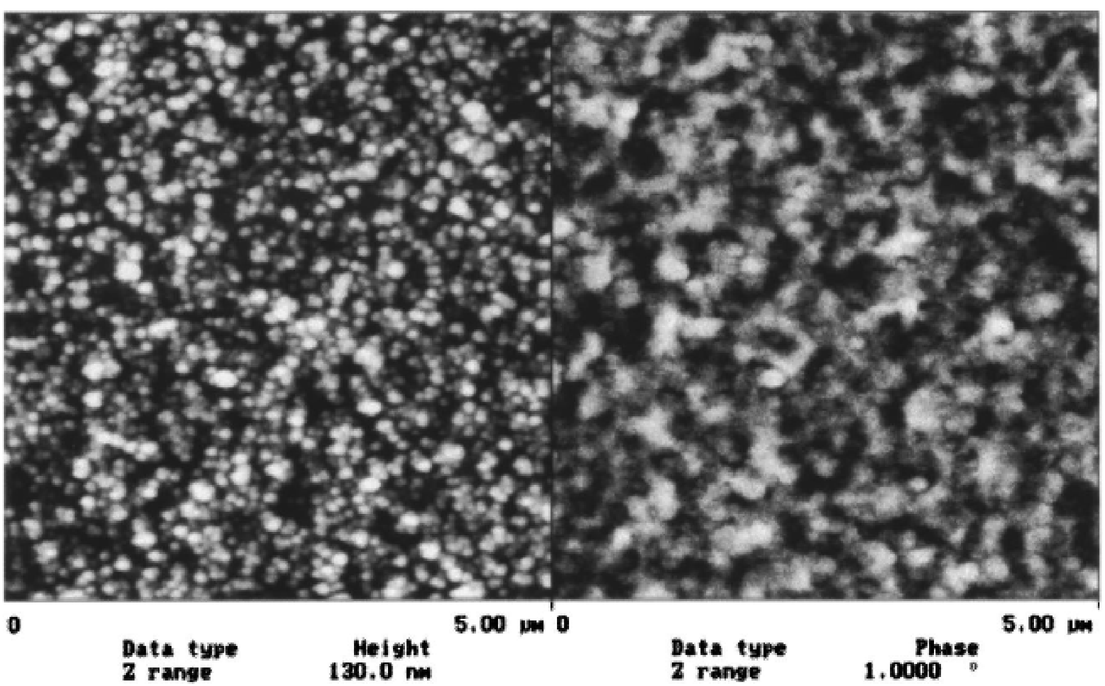
Power : 95W, Ar flow: 65sccm, He (:0), Aggregation length: maximum.



+/-5 % Resolution (Cu)
Ion current at quadrupole collector /nA
Deposition rate on QCM /nm.min-1
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
Mass Filter Resolution / %

Co (AFM)

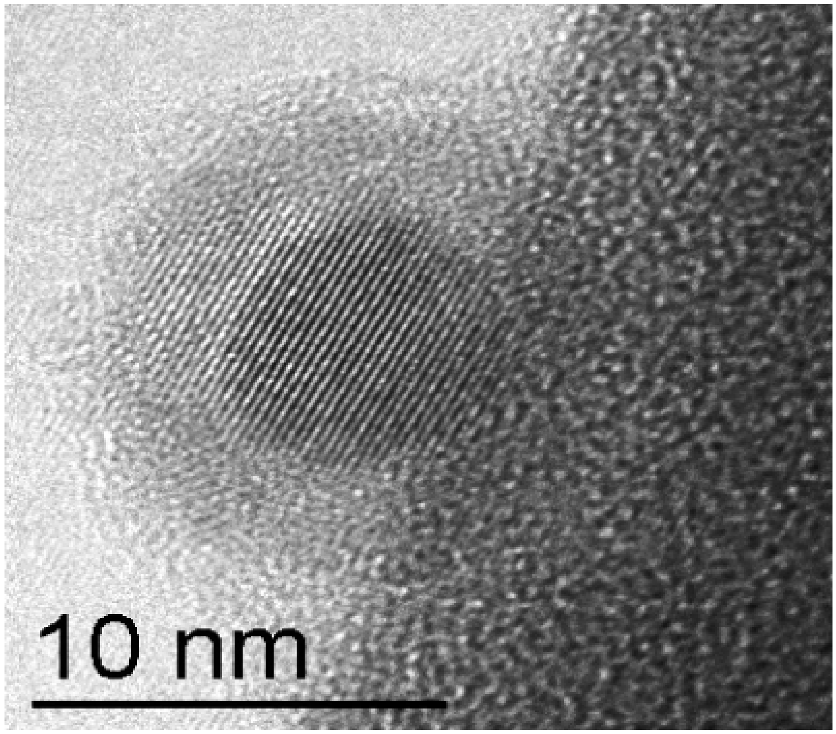




Height Phase

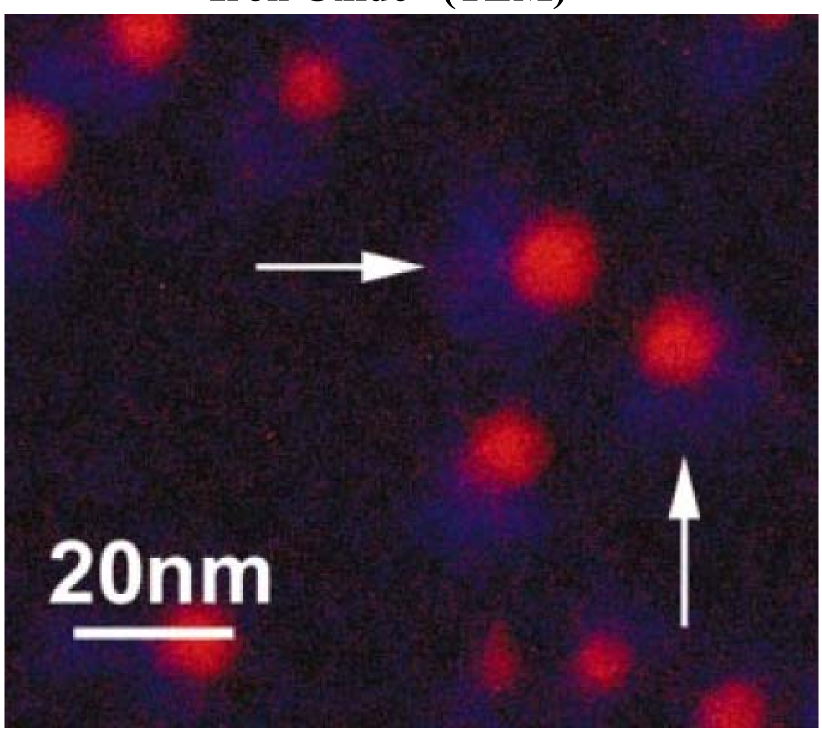
S.A. Koch et. al, APL. Vol. 84, No.4 , 2004

Fe (5 nm Core) + 2nm O shell



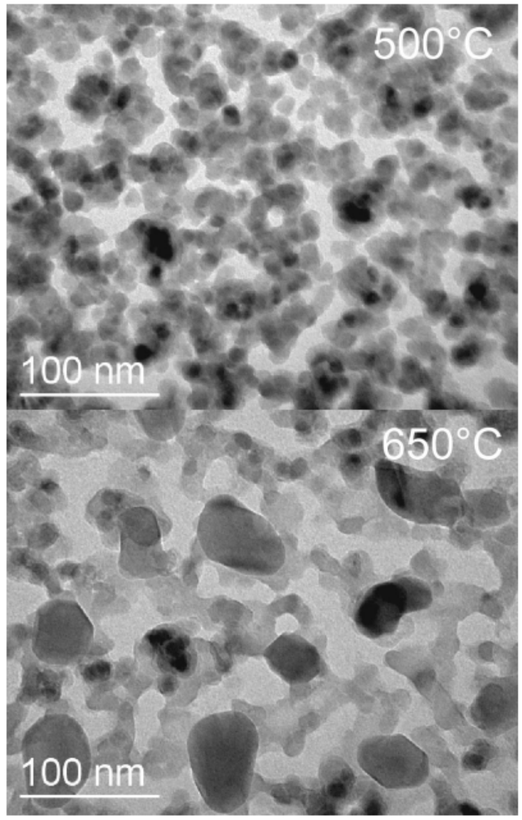
Vystavel et.al, APL, Vol.82, No.2 2003

Iron Oxide (TEM)



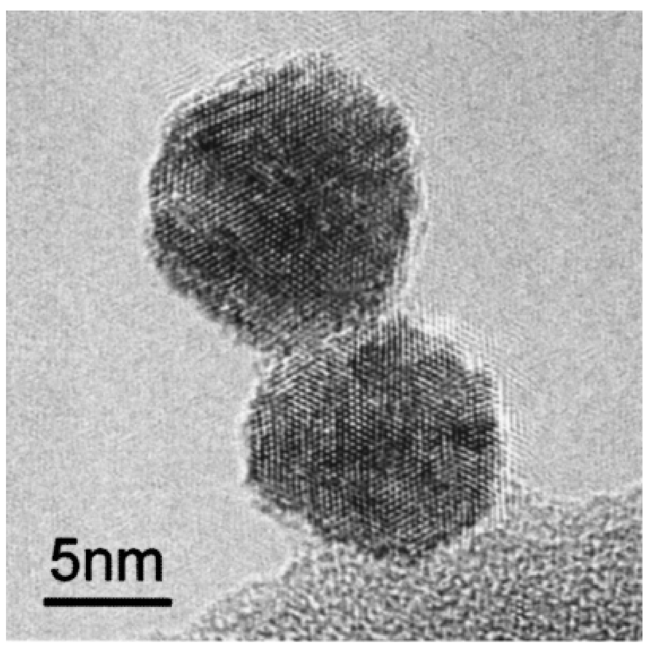
Vystavel et.al, APL, Vol.82, No.2 2003

Fusion of Fe clusters



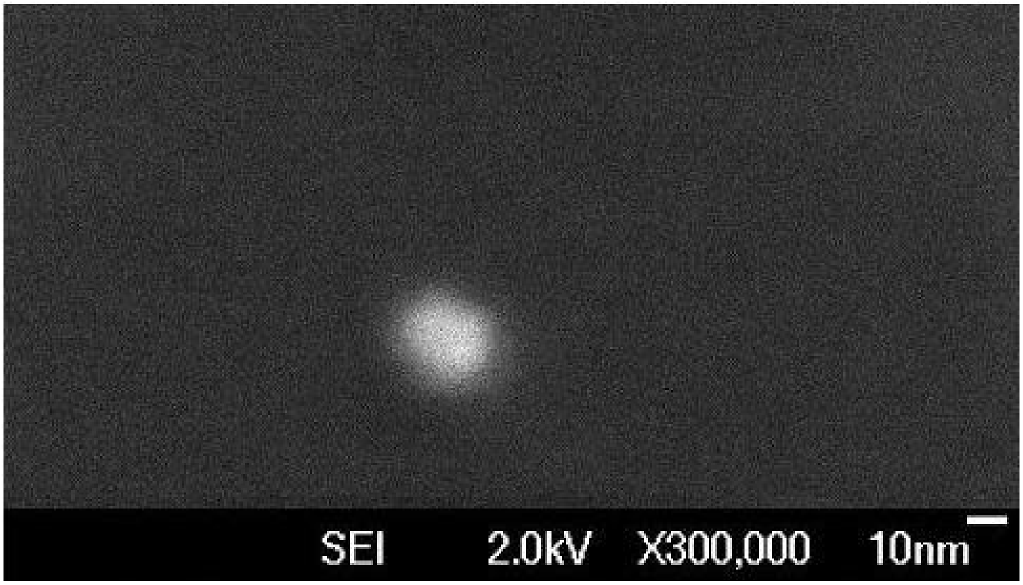
Vystavel et.al, APL, Vol.82, No.2 2003

Nb Clusters



Vystavel et.al, APL., Vol.83, No.19 2003

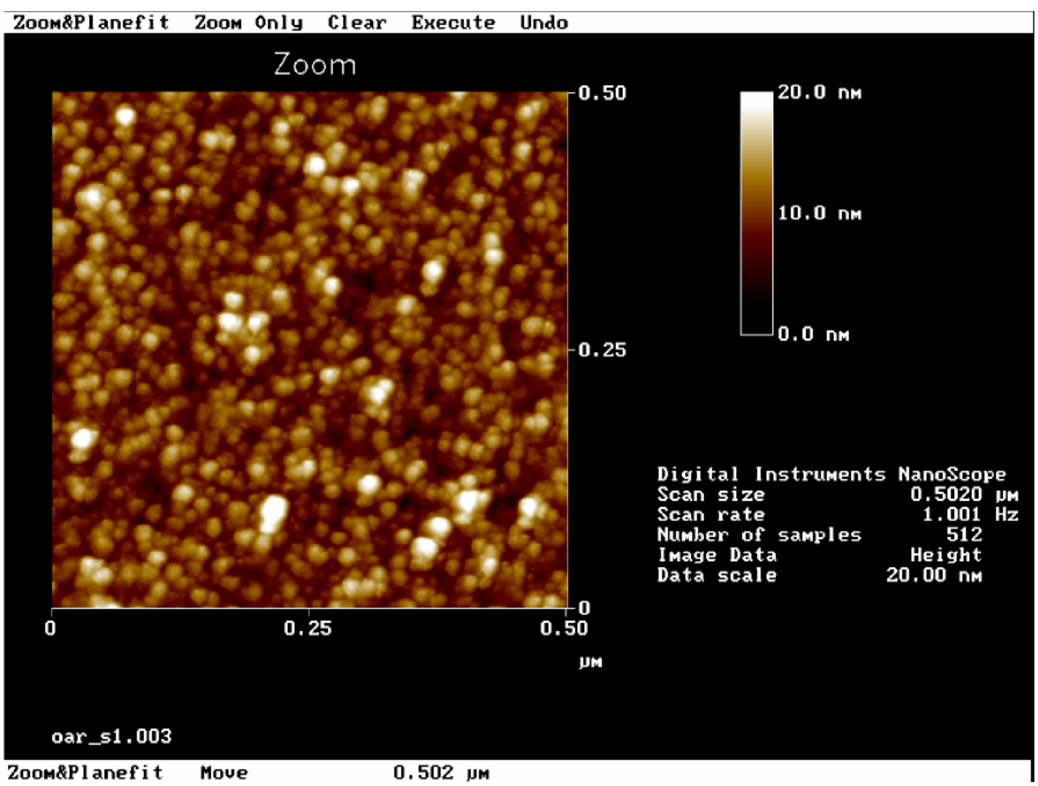
Si(SEM)



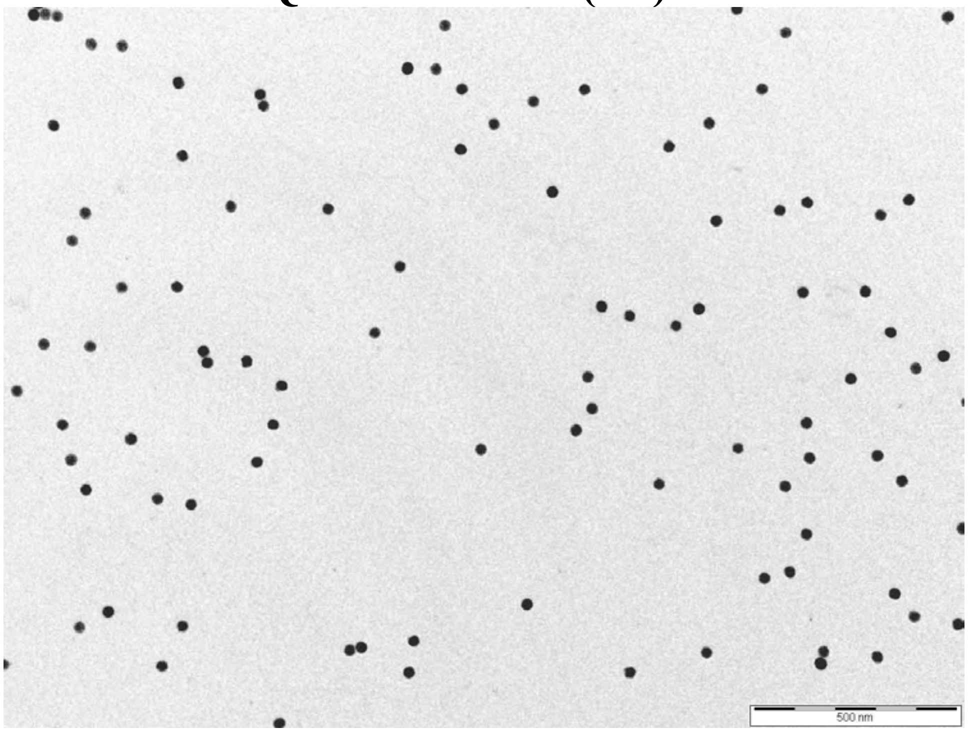
Professor Biswajit Das, UNLV

Si / Si(111)   AFM

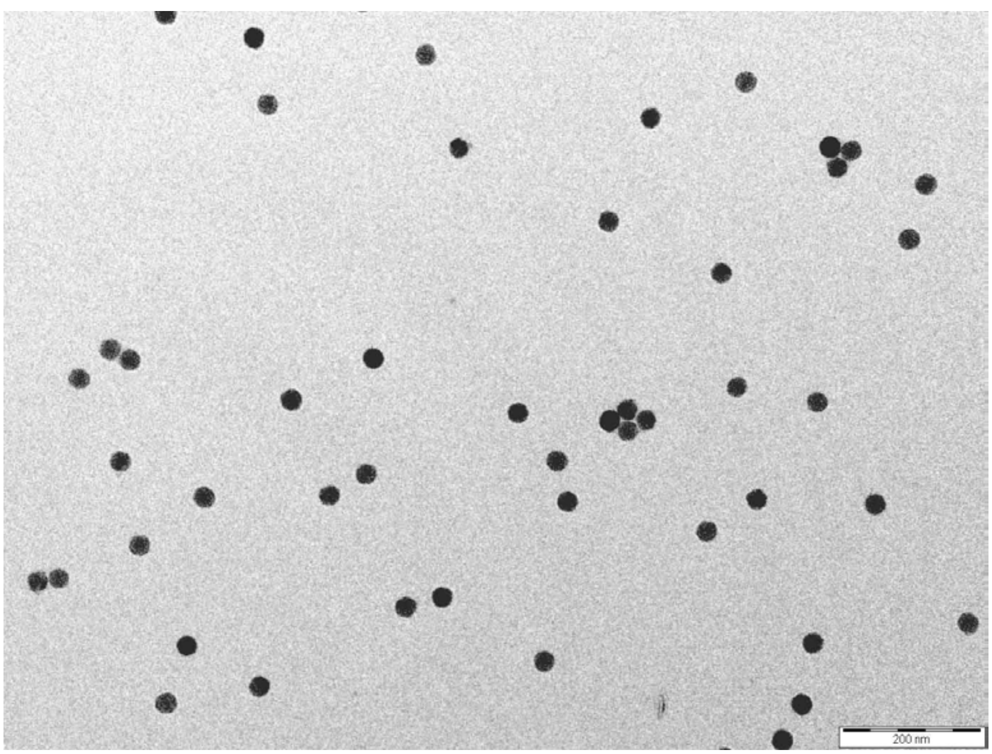
Carrier gas flow >> 10 sccm



Quartz Clusters (RF)

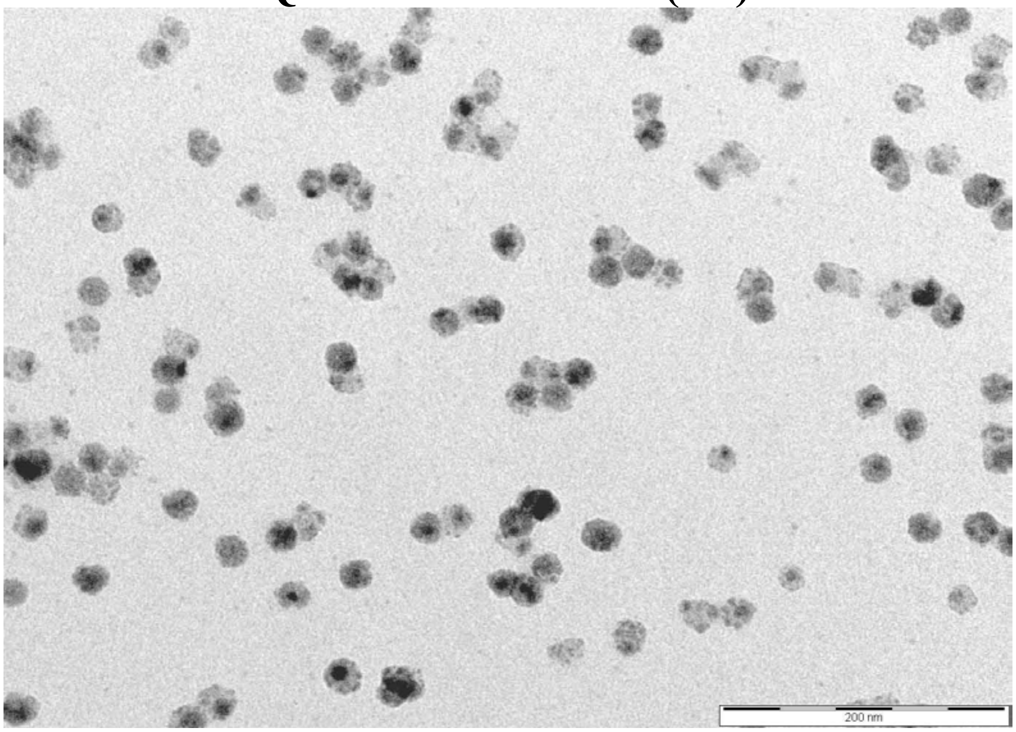


Quartz Nanoclusters (RF)



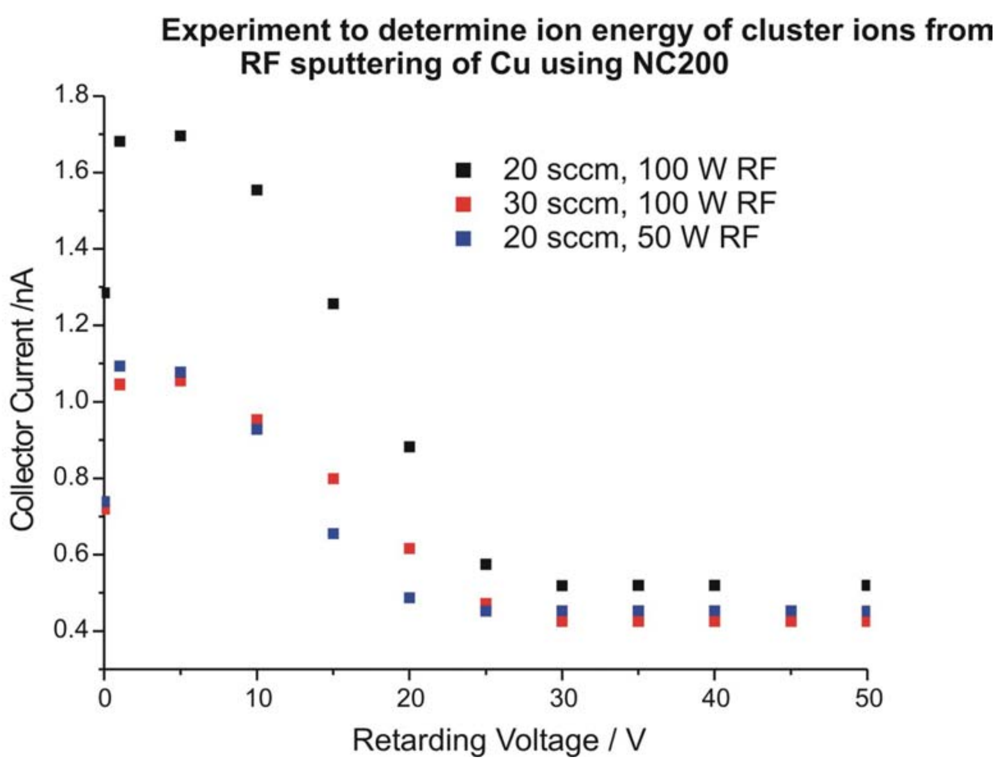
RF 200W, 55sccm Ar, 0 sccm He, 98 mm aggreg. length

Quartz Nanoclusters (RF)



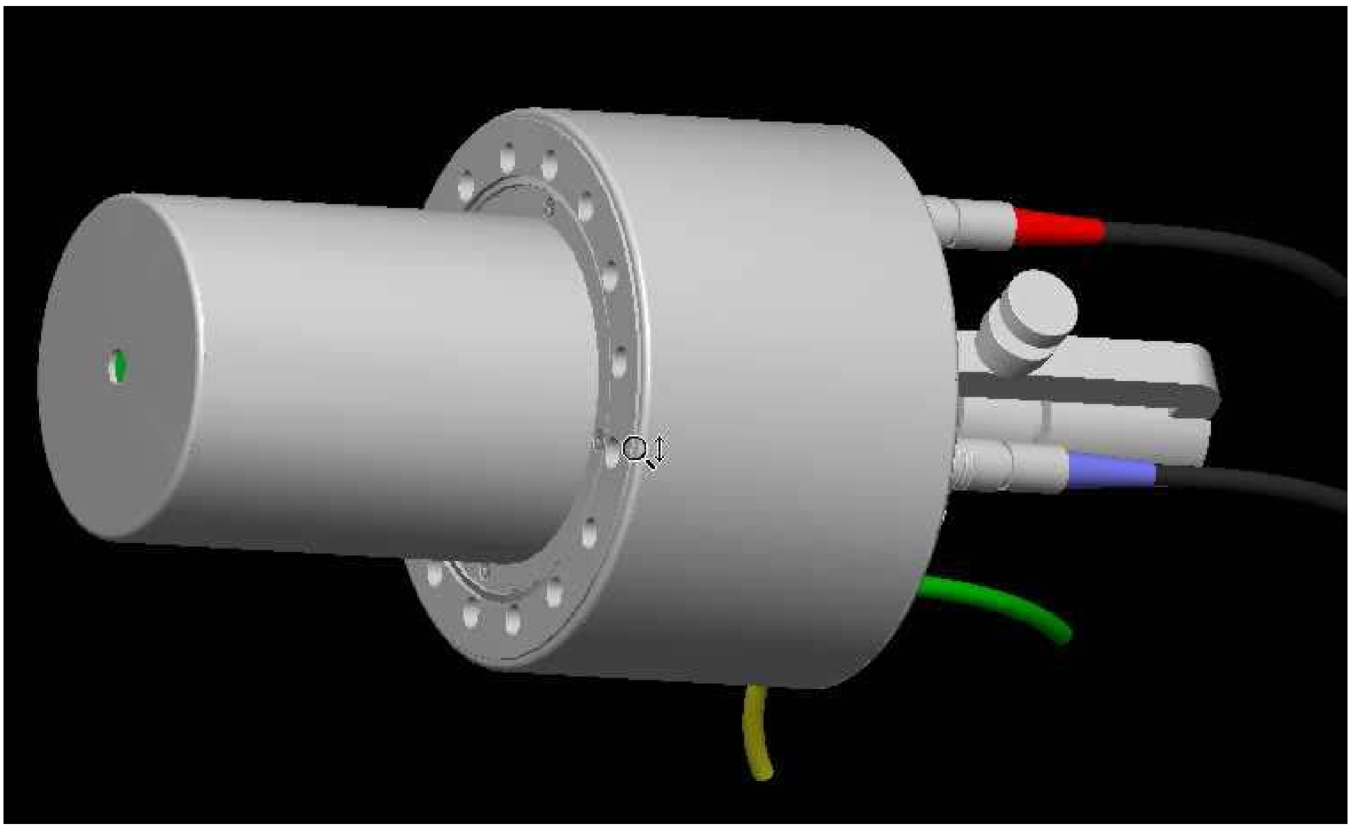
RF 300W, 55 sccm Ar, 0 He, 98 mm aggreg.length

ClusterEnergy(RF)

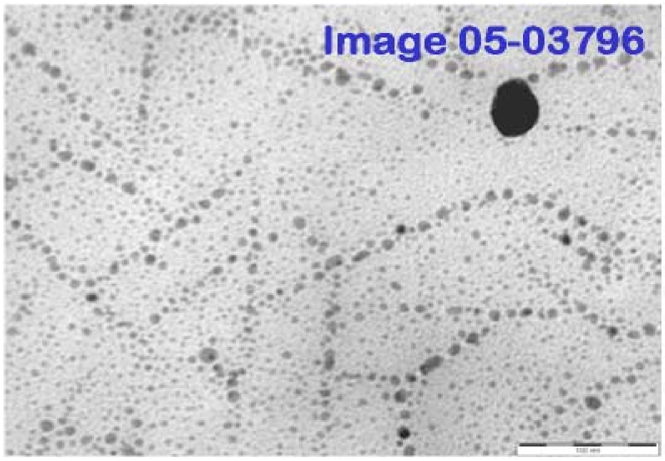


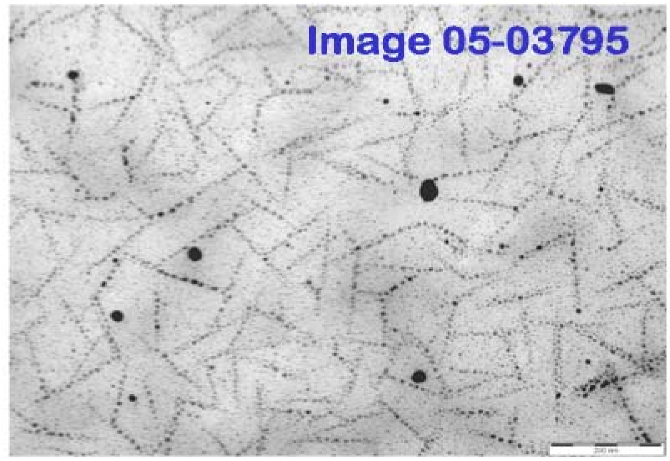
Second Generation Source

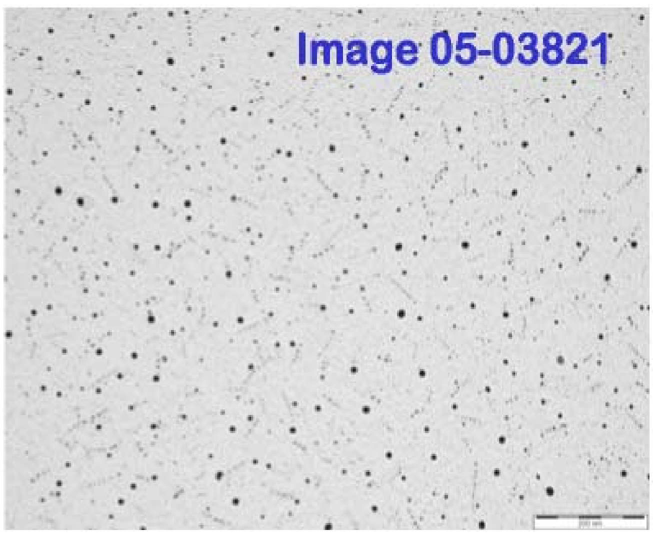
- Compact design
- Lower gas flow
- More efficient utilization of target ***(90% vs. 5%)***
- Pencil beam (***6 mm dia***.)
- High beam intensity

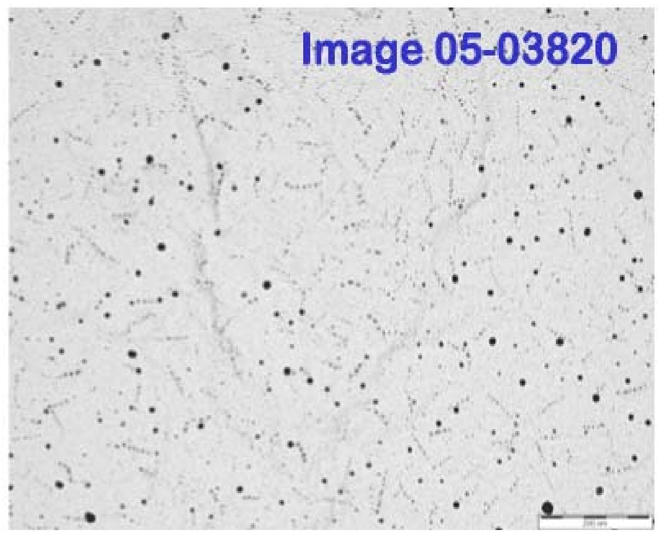


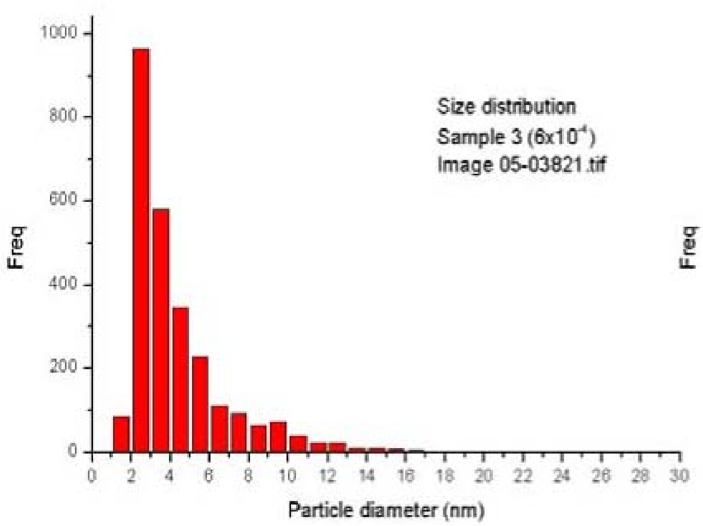
Ag Cluster (low coverage)

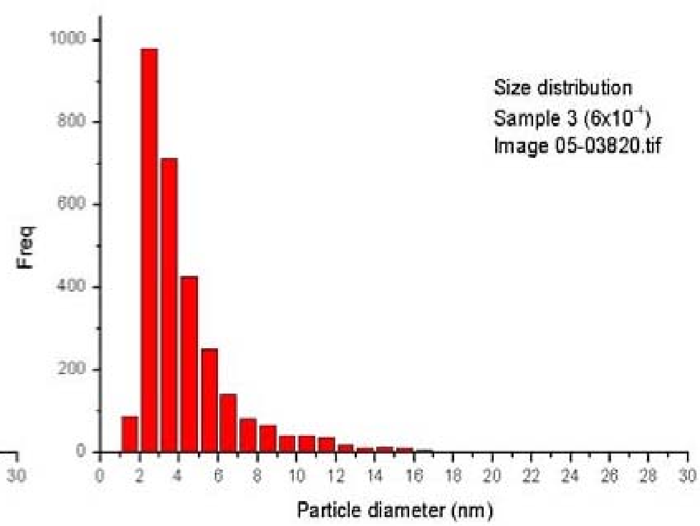




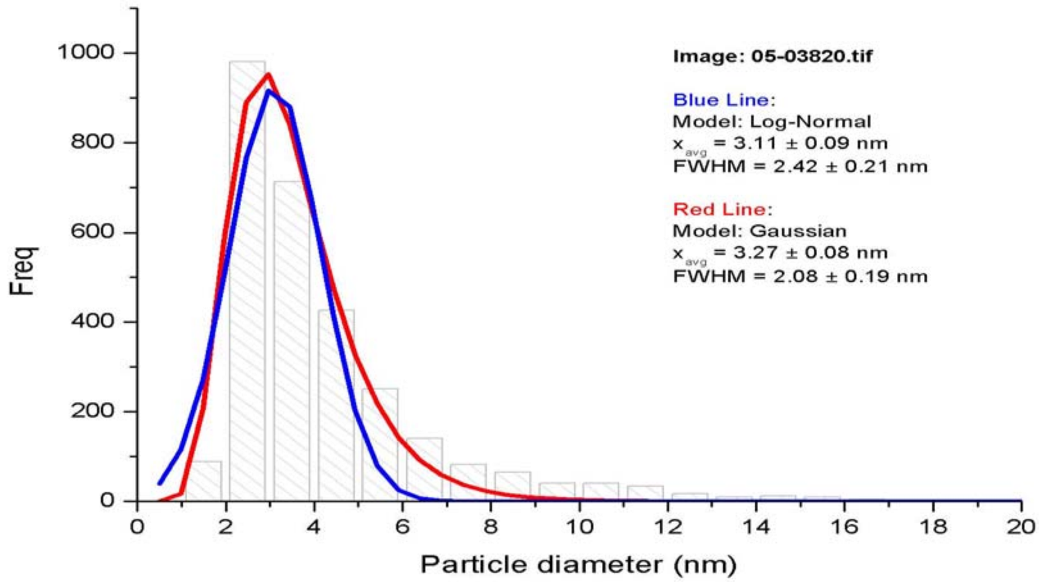




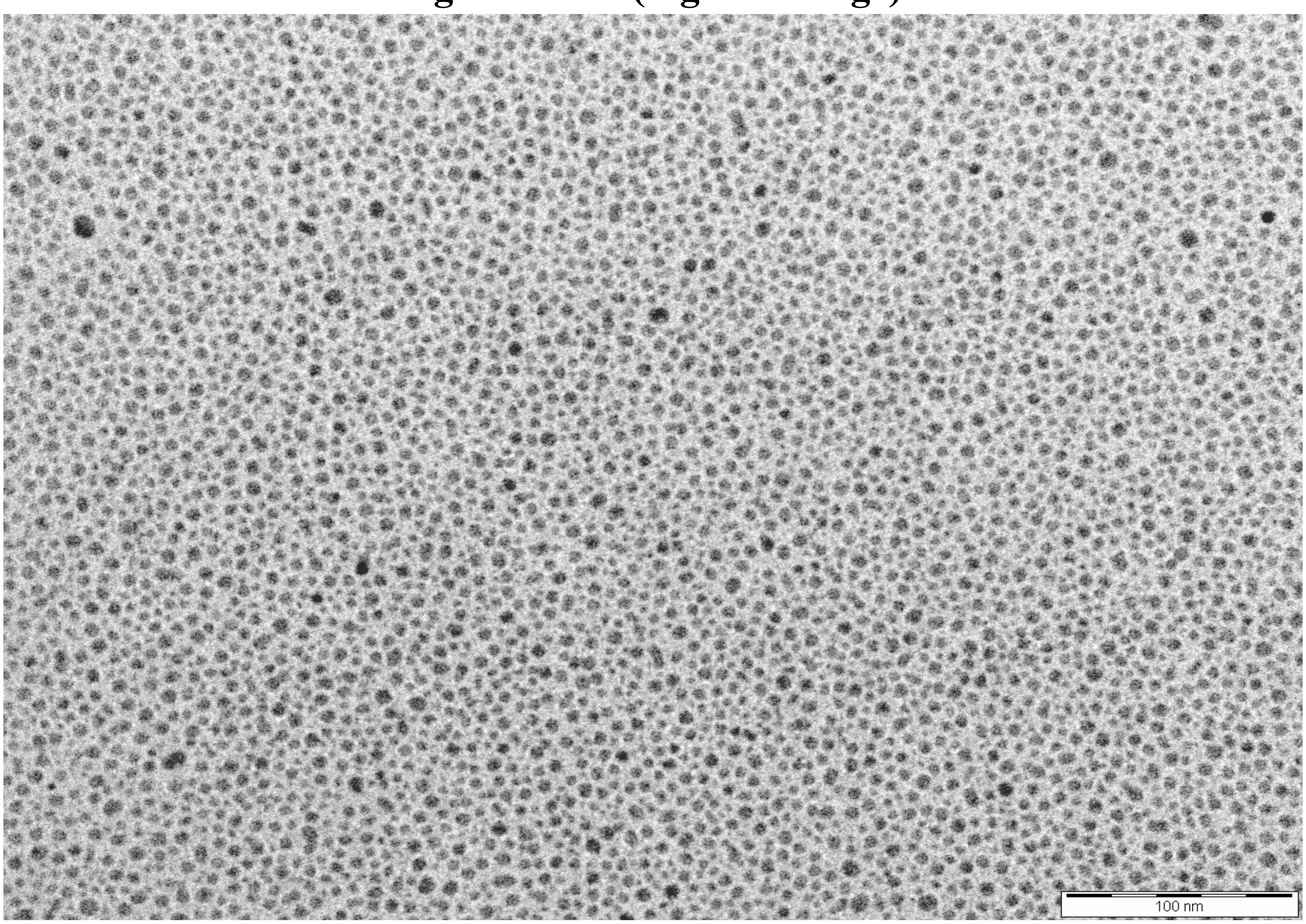




Cluster Size Distribution



Ag Clusters (high coverage)

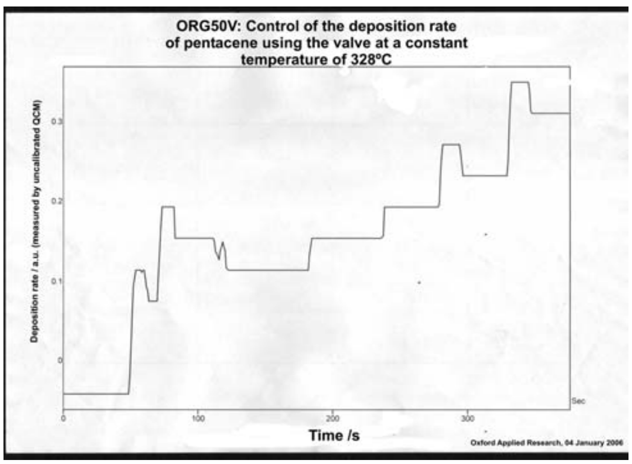


Interesting Possibilities

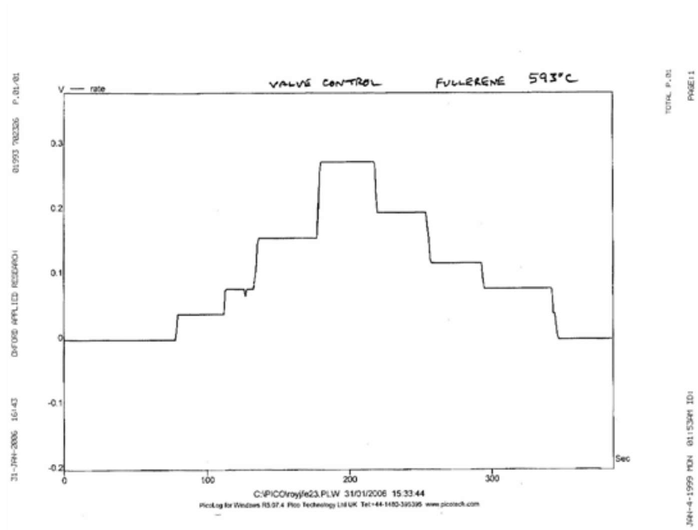
- Co-deposition of one or more nanoclusters with molecular beams of other materials

- nanoclusters / organic layers
- nanoclusters / III-V

Nanocluster + Organic MBE



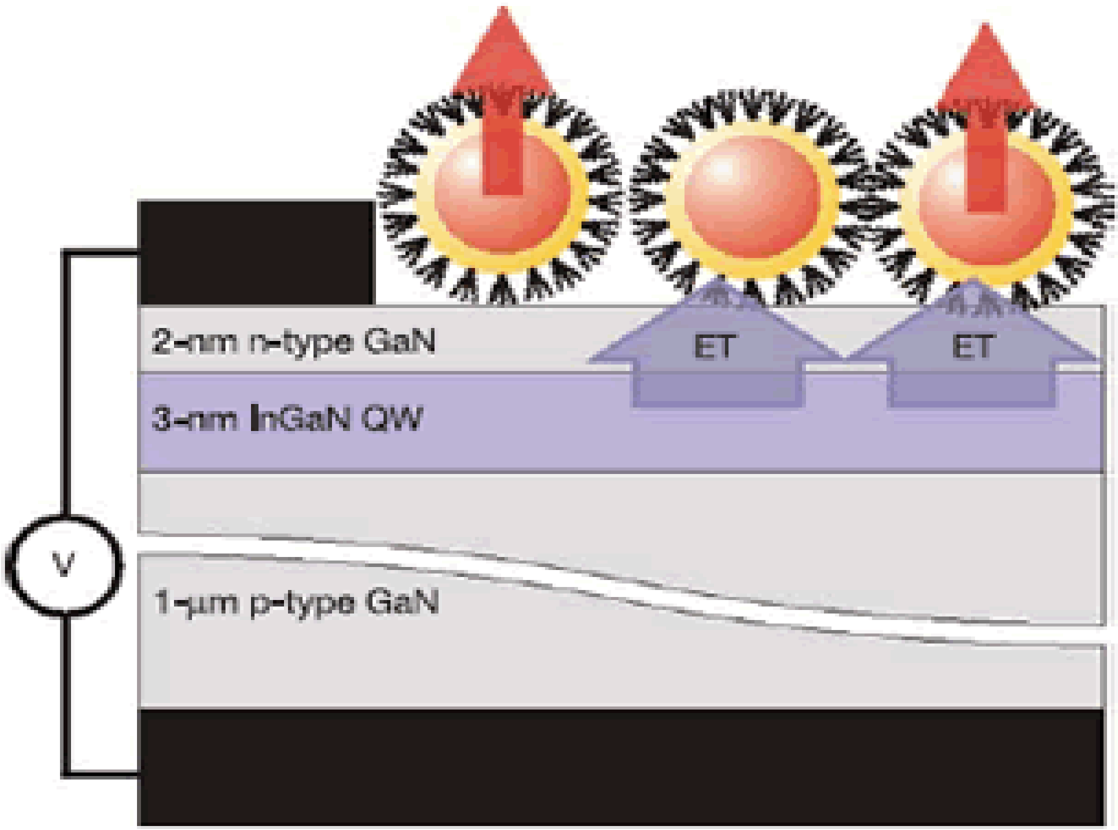
Pentacene



Fullerene

The above data was obtained using our valved organic evaporator (model ORG50V), which overcomes the thermal inertia of conventional unvalved evaporators.

Nanoclusters + Inorganic QW



Conclusions

- Design features and capabilities of OAR's first generation nanocluster source was reviewed
- Presented preliminary results obtained with OAR's second generation nanocluster source