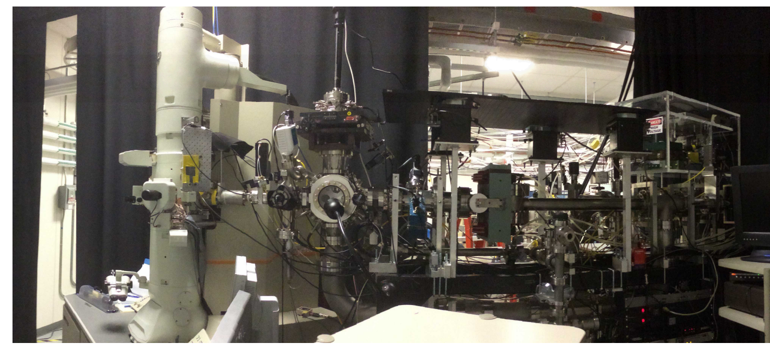
SAND2017-8999PE



Sandia and Ion Accelerators

Jon Custer

Radiation-Solid Interactions

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

ion beam lab

Why an Ion Beam Laboratory?

Sandia National Laboratories

On a Diffuse Reflection of the α-Particles.

By H. GEIGER, Ph.D., John Harling Fellow, and E. MARSDEN, Hatfield Scholar, University of Manchester.

Proc. Royal Soc. 82(557) 495-500 (1909)

LXXIX. *The Scattering of α and β Particles by Matter and the Structure of the Atom.* *By* Professor E. RUTHERFORD, *F.R.S., University of Manchester*.*

Phil. Mag 21(125) 669-688 (1911)

- Ions have been at the heart of understanding the properties of matter since the invention of the atom!
- Natural α sources were quickly deemed insufficient

Where did they get α particles?

- "Radium emanations" were the α source of choice in 1909 (well, only source)
- Radium was announced by the Curies in 1898.
- Marie Curie received the Nobel Prize in Chemistry in 1911 for discovery of radium and polonium and study of them
  - Her second after Physics in 1903
  - First to get 2 Nobel's in different fields
    - Who was the other person?
  - Name the 2-time Physics winner and the 2-time Chemistry winner
    - John Bardeen (transistor, superconductivity theory)
    - Frederick Sanger (protein and DNA sequencing)
- What if you want something besides α's?

Wikipedia

Have to invent the ion accelerator:

- Cockroft and Walton invented a high voltage supply in 1930
- Van de Graaff in 1929
- Ions besides α now where possible

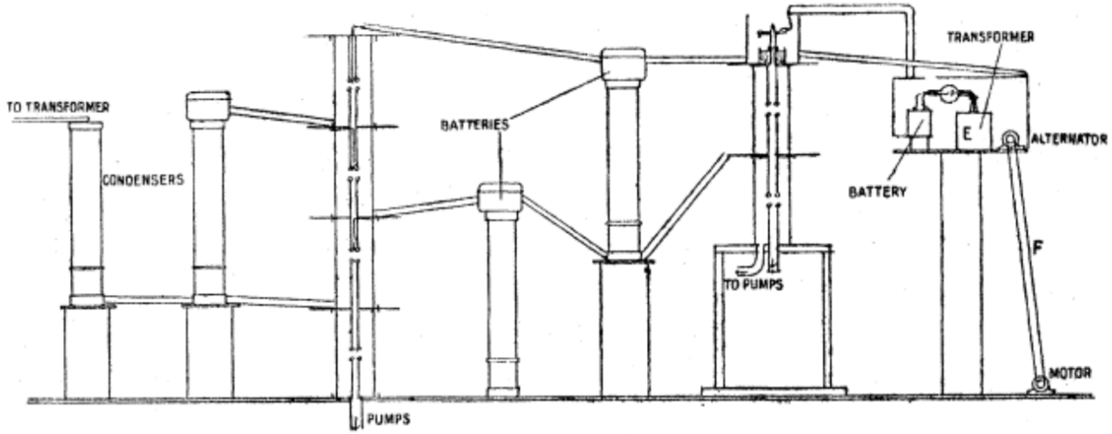
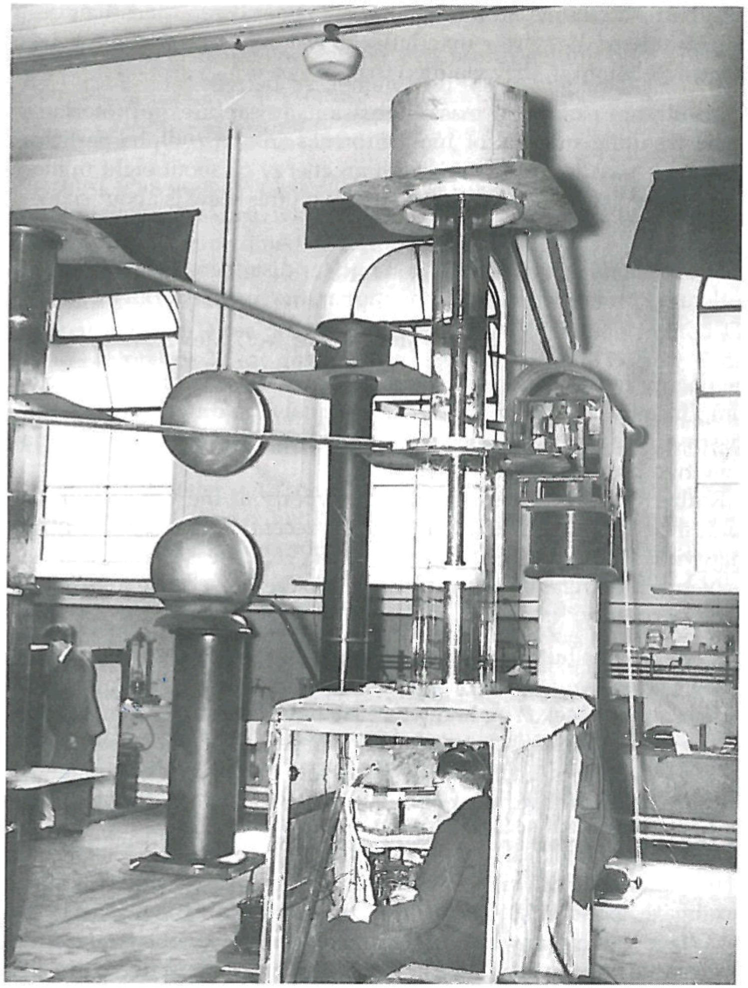


Fig. 6.



In Nuclear Transmutation to Nuclear Fission, PF Dahl, CRC Press (2002), from The Cavendish Laboratory

(1) A direct line from Rutherford

Experiments with High Velocity Positive Ions.

By J. D. Cockcroft, Fellow of St. John's College, Cambridge, and E. T. S. Walton, 1851 Overseas Student.

(Communicated by [redacted] P.R.S.—Received August 19, 1930.)

[Plate 21a.]

1. *Introduction.*

It would appear to be very important to develop an additional line of attack on problems of the atomic nucleus. The greater part of our information on the structure of the nucleus has come from experiments with α-particles and if we can supplement these with sources of positive ions accelerated by high potentials we should have an experimental weapon which would have many advantages over the α-particle. It would, in the first place, be much greater in intensity than α-particle sources, since one microampere of positive ions is equivalent, so far as numbers of particles is concerned, to 180 grams of radium equivalent. It would in addition have the advantage of being free from penetrating β and γ rays which are a complication in many experiments, whilst the velocity would be variable at will.

Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, Vol. 129, No. 811 (Nov. 3, 1930), pp. 477-489

First Intentional Nuclear Reaction

- $^{7}Li + p \rightarrow 2\,^{4}He$

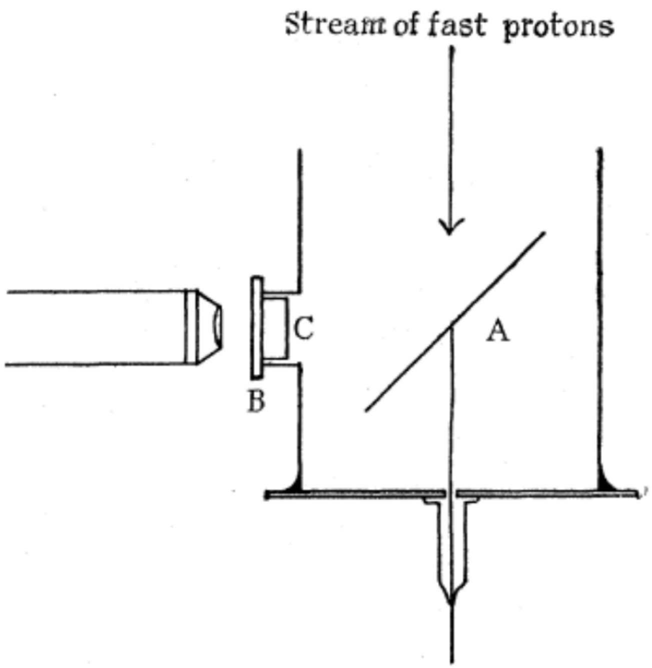


Fig. 1.

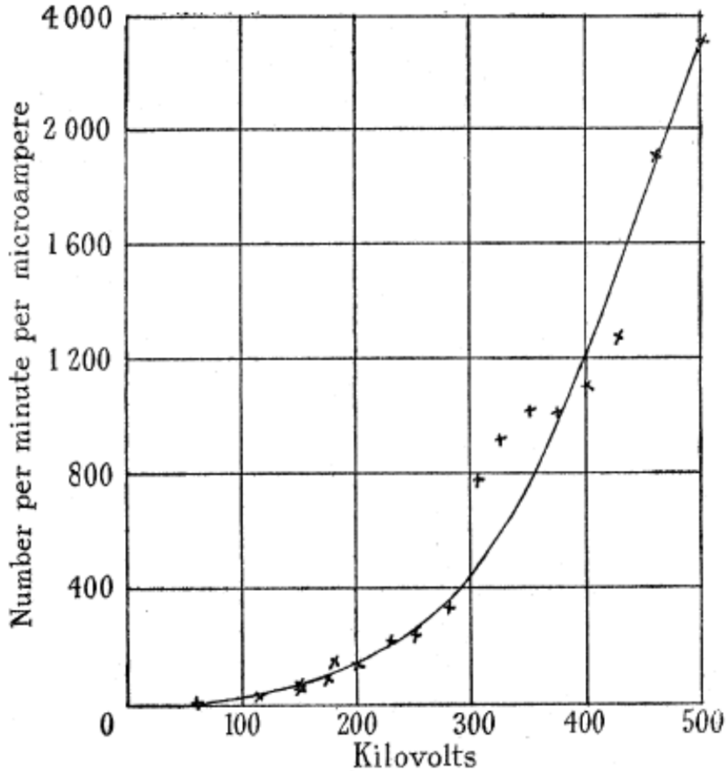


Fig. 4.

J.D. Cockcroft and E.T.S. Walton, Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, Vol. 137, No. 831 (Jul. 1, 1932), pp. 229-242

Human Induced Nuclear Reaction

4. *The Interpretation of Results.*

We have already stated that the obvious interpretation of our results is to assume that the lithium isotope of mass 7 captures a proton and that the resulting nucleus of mass 8 breaks up into two α-particles. If momentum is conserved in the process, then each of the α-particles must take up equal amounts of energy, and from the observed range of the α-particles we conclude that an energy of [redacted] would be liberated in this disintegration process. The mass of the Li_7 nucleus from Costa's determination is 7·0104 with a probable error of 0·003. The decrease of mass in the disintegration process is therefore $7{\cdot}0104 + 1{\cdot}0072 - 8{\cdot}0022 = 0{\cdot}0154 \pm 0{\cdot}003$. This is equivalent to an energy liberation of $(14{\cdot}3 \pm 2{\cdot}7) \times 10^6$ volts. We conclude, therefore, that the observed energies of the α-particles are consistent with our hypothesis. An additional test can, however, be applied. If momentum is conserved in the disintegration, the two α-particles must be ejected in practically opposite directions and, therefore, if we arrange two zinc sulphide screens opposite to a small target of lithium as shown in the arrangement of fig. 5, we should observe a large proportion of coincidences in the time of appearance of the scintillations on the two screens. The lithium used in the experiments

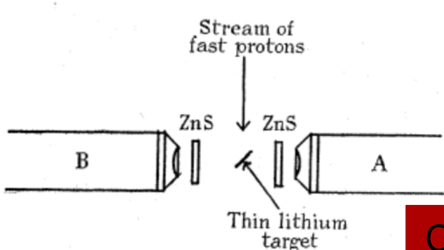


Fig. 5.

Current accepted value: 17.3468MeV

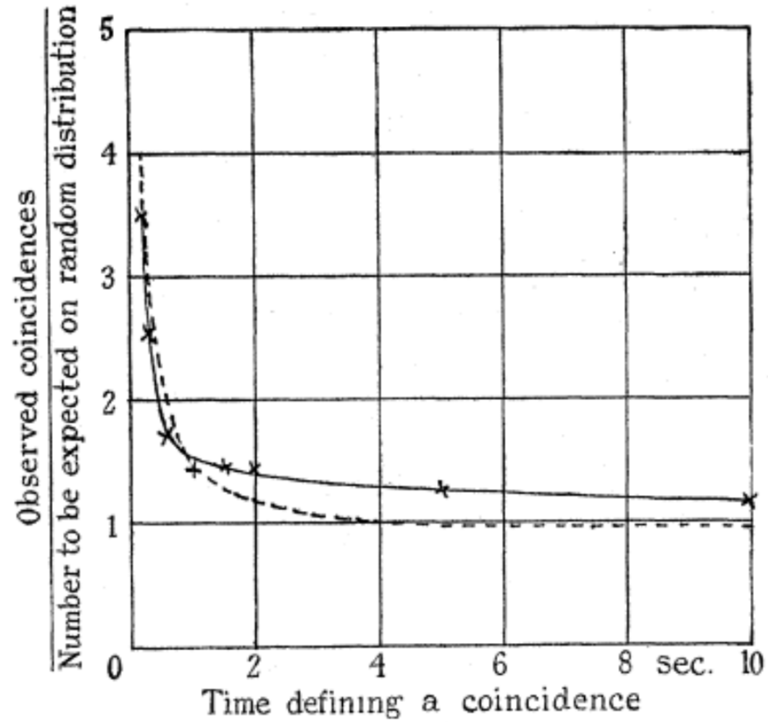


Fig. 6.

(First observed was $^{14}N(\alpha,p)^{17}O$ in 1919, only explained in 1925. P.M.S. Blackett looked through 23000 cloud chamber pictures with 415000 alpha tracks to find 8 such events)

(2) A second approach:

- "It was while at Oxford that Van de Graaff conceived of his belt-charged electrostatic, high voltage generator after reading the 1927 anniversary address on St Andrew's Day by Rutherford to the Royal Society on the need for accelerated subatomic particles"
    - From Nuclear Transmutation to Nuclear Fission, PF Dahl, CRC Press (2002)

- Van de Graaff was at Oxford as a Rhodes Scholar

Robert J. Van de Graaff (1901-1967)

- BS/MS (Mech E.) University of Alabama
- Alabama Power Company (one year)
- Studied at the Sorbonne
- PhD Oxford University 1928 (Rhodes Scholar)
- 1929-31 Princeton University
  - First generator (80kV)
- 1931-1960 MIT
- WWII directed the High Voltage Radiographic Project at MIT
- APS T. Bonner Prize in Nuclear Physics (1966)

Robert J. Van de Graaff demonstrating his 1.5 MV electrostatic generator to Karl T. Compton in 1931. (from D. Allen Bromley, Nucl. Instr. Method. 122, 1-34 (1974))

THE

PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics

VOL. 43, NO. 3 FEBRUARY 1, 1933 SECOND SERIES

The Electrostatic Production of High Voltage for Nuclear Investigations

R. J. VAN DE GRAAFF,* K. T. COMPTON AND L. C. VAN ATTA, *Massachusetts Institute of Technology*

(Received December 20, 1932)

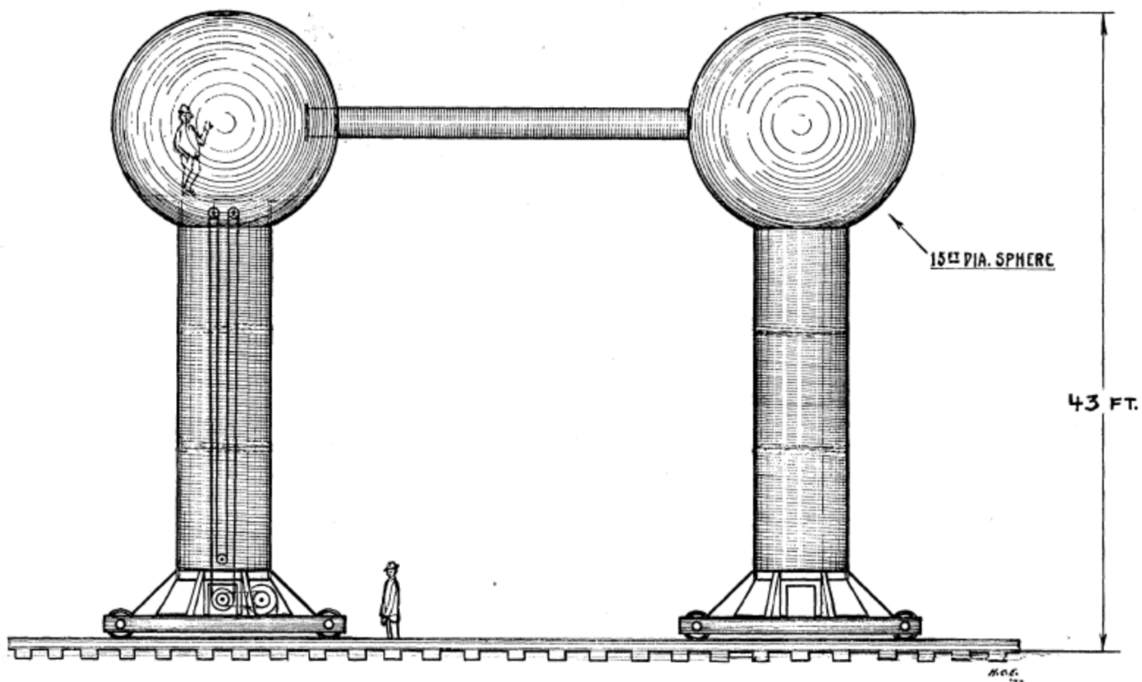


FIG. 4.

Van de Graaff thought big!

MAY 15, 1936 PHYSICAL REVIEW VOLUME 49

The Design, Operation, and Performance of the Round Hill Electrostatic Generator

L. C. VAN ATTA, D. L. NORTHRUP, C. M. VAN ATTA* AND R. J. VAN DE GRAAFF, *Massachusetts Institute of Technology*

(Received March 25, 1936)

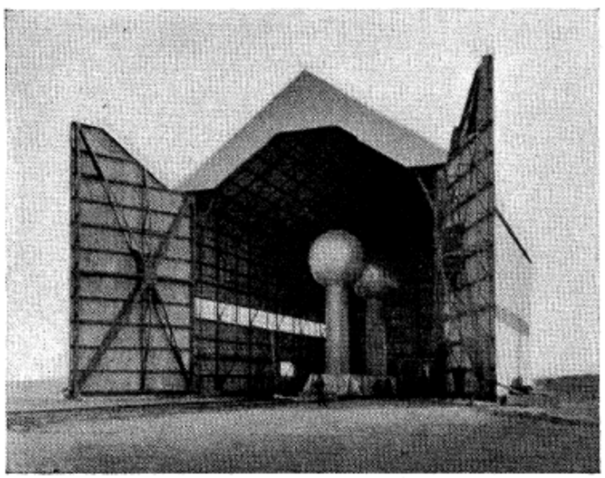
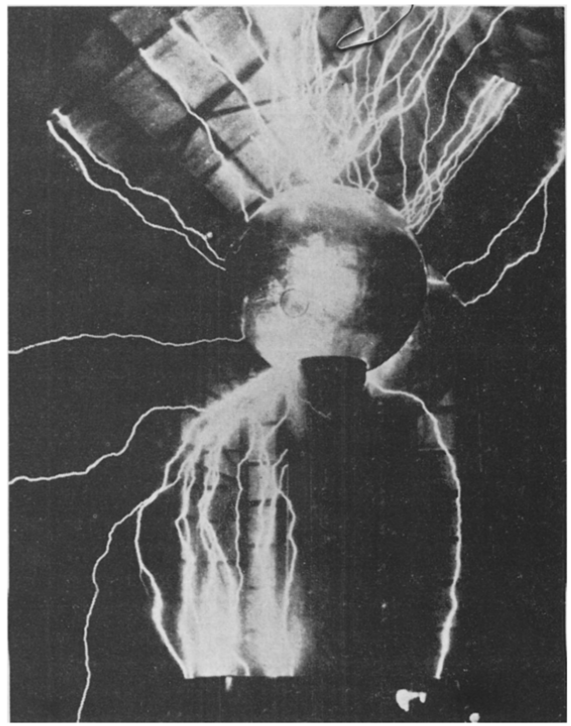
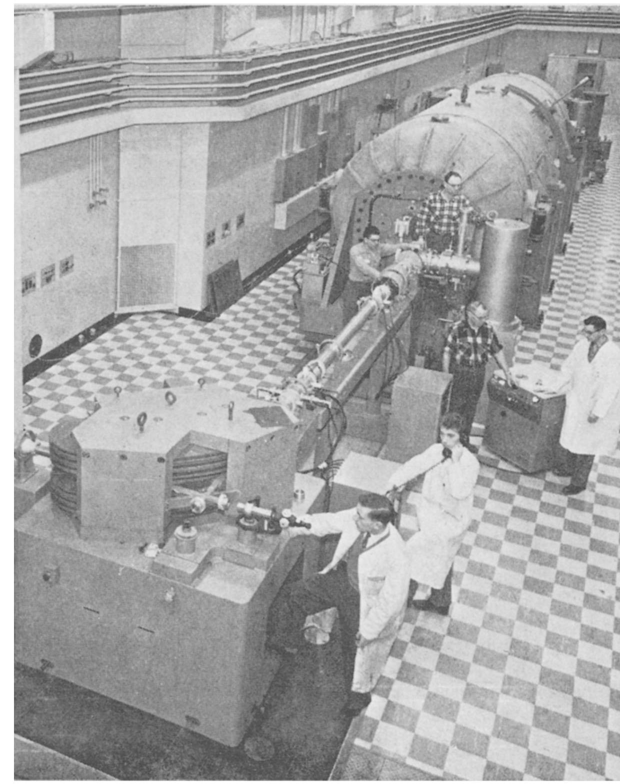


FIG. 1. Electrostatic generator and housing.



Robert J. Van de Graaff's in-air machine reached up to 5.1MV between two spheres. Construction in a large airship hanger resulted in the 'pigeon effect' shown here,



The first HVE EN Tandem at Chalk River, 1958. The High Voltage Engineering Corp. was founded by Robert Van de Graaff in 1946.

Design of a Million-Volt X-Ray Generator for Cancer Treatment and Research

By J. G. TRUMP AND R. J. VAN DE GRAAFF
Massachusetts Institute of Technology
Cambridge, Massachusetts

602

JOURNAL OF APPLIED PHYSICS

603

VOLUME 8, SEPTEMBER, 1937

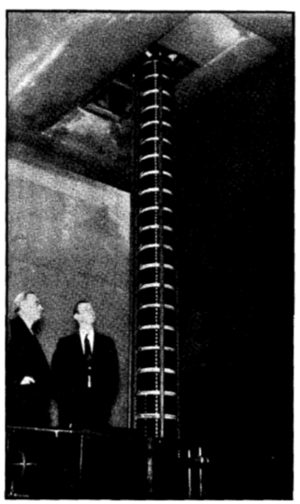


FIG. 2. Cascade type x-ray tube.

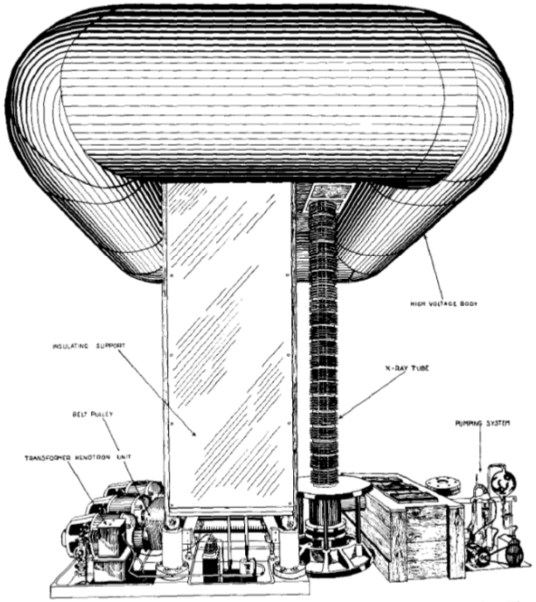
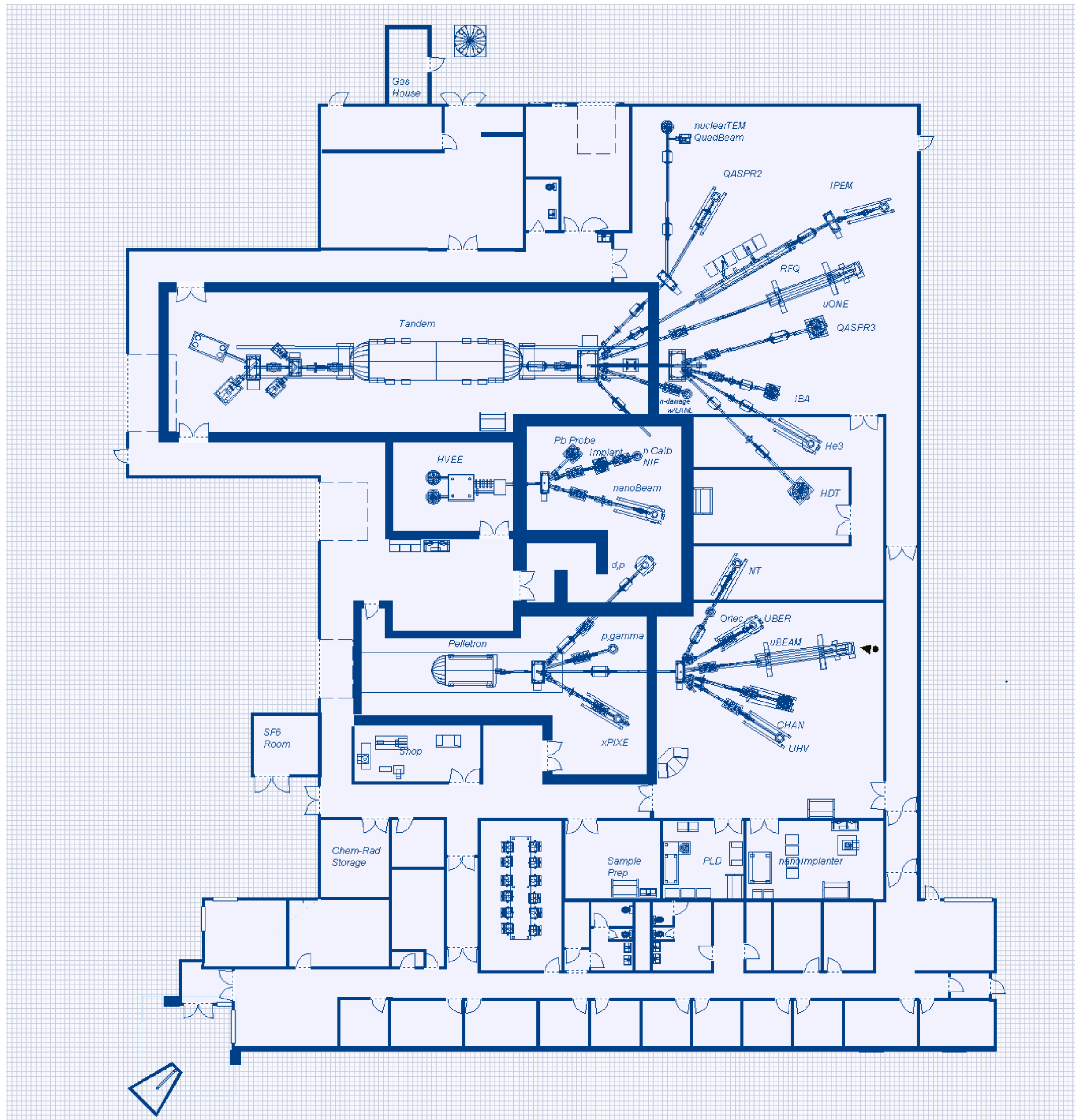


FIG. 1. General arrangement of the million-volt x-ray generator and tube. The bottom cover is shown removed.

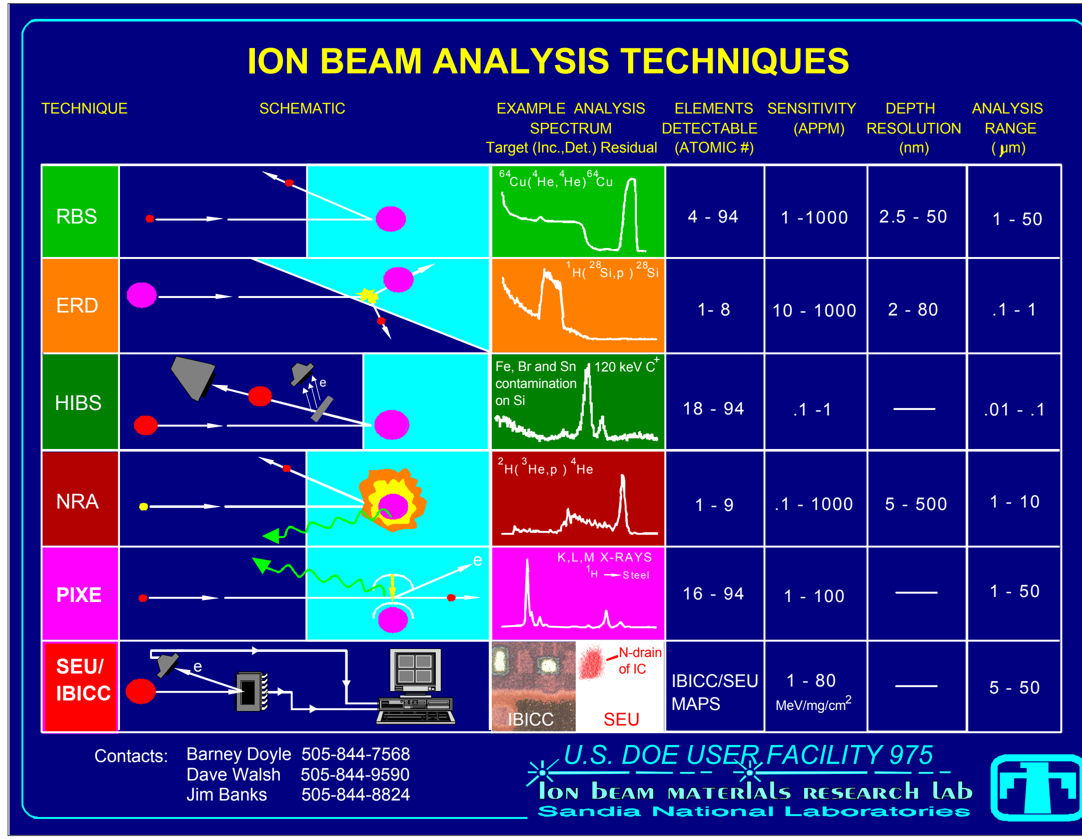
FIG. 4. Treatment room which is completely free from high voltage apparatus.

- Sandia's Ion Beam Lab:
- 4 Major Accelerators
- Unique Capabilities
- In Support of NNSA and other national security applications



Ion Beam Analysis at the IBL

- RBS – Rutherford BackScattering
- ERD - Elastic Recoil Detection
- HIBS – Heavy Ion BackScattering
- NRA - Nuclear Reaction Analysis
- PIXE - Proton Induced X-ray Emission
- SEU/IBIC – Single Event Upset and Ion Beam Induced Current Imaging



ION BEAM ANALYSIS TECHNIQUES

TECHNIQUE	SCHEMATIC	EXAMPLE ANALYSIS SPECTRUM Target (Inc.,Det.) Residual	ELEMENTS DETECTABLE (ATOMIC #)	SENSITIVITY (APPM)	DEPTH RESOLUTION (nm)	ANALYSIS RANGE (μm)
RBS		$^{64}Cu(^{4}He,^{4}He)^{64}Cu$	4 - 94	1 -1000	2.5 - 50	1 - 50
ERD		$^{1}H(^{28}Si,p)^{28}Si$	1- 8	10 - 1000	2 - 80	.1 - 1
HIBS	e	Fe, Br and Sn contamination on Si; 120 keV C^{+}	18 - 94	.1 -1	——	.01 - .1
NRA		$^{2}H(^{3}He,p)^{4}He$	1 - 9	.1 - 1000	5 - 500	1 - 10
PIXE	e	K,L,M X-RAYS ^{1}H → Steel	16 - 94	1 - 100	——	1 - 50
SEU/ IBICC	e	N-drain of IC; IBICC; SEU	IBICC/SEU MAPS	1 - 80 MeV/mg/cm^2	——	5 - 50

Contacts: Barney Doyle 505-844-7568
Dave Walsh 505-844-9590
Jim Banks 505-844-8824

Microbeam IBA experiments in the IBL

Sandia National Laboratories

- Elemental concentration distributions in 3D
- TEM samples can be analyzed
- H profiling using uERD
- Sintered Ceramics
  - H_2O well known to modify voltilization behavior of common commercial glasses
  - Where is H_2O (i.e. H) localized?
- microERD used to map H
- microRFS performed at same time to measure sample thickness variations

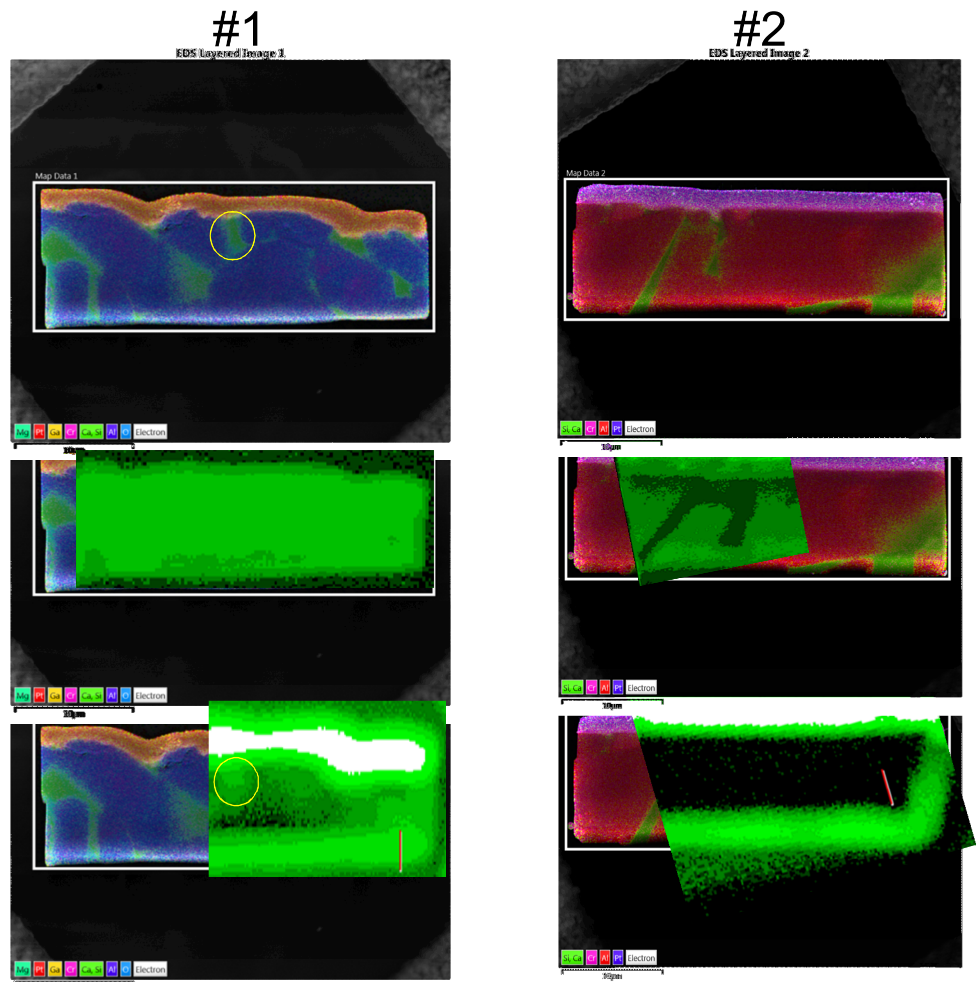
Ceramic Samples

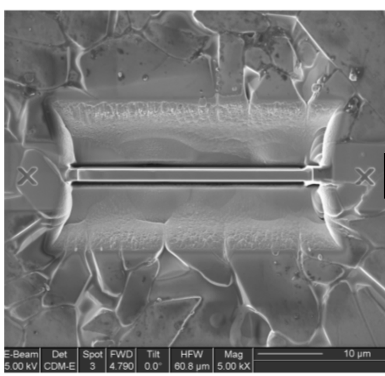
Sample prep by Gary Bryant 1819

SEM

RFS

ERD





Ion Beam Modification of Materials

2,787,564

FORMING SEMICONDUCTIVE DEVICES BY IONIC BOMBARDMENT

William Shockley, Madison, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application October 28, 1954, Serial No. 465,393

- Alloys have been known for millennia (e.g. bronze)

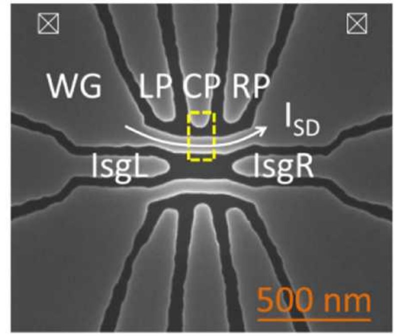
- Controlled introduction of elements fundamental to semiconductor devices – Shockley invented ion implantation for transistors only 5 years after their invention.

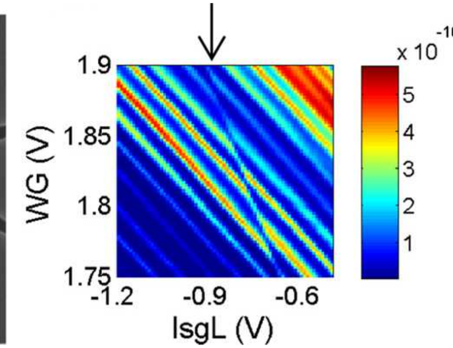
Single Ion Implant

APPLIED PHYSICS LETTERS **108**, 062101 (2016)

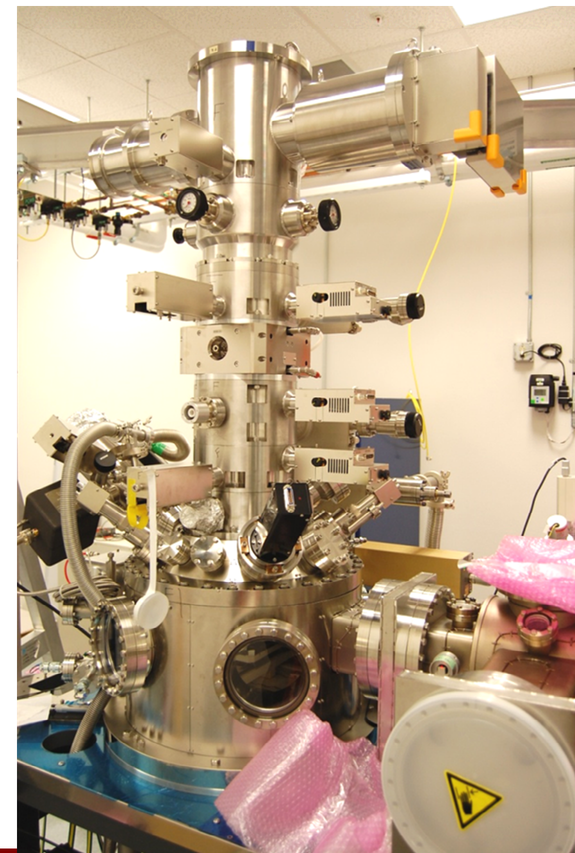
Electrostatically defined silicon quantum dots with counted antimony donor implants

M. Singh,[1,2,a)] J. L. Pacheco,[1] D. Perry,[1] E. Garratt,[1] G. Ten Eyck,[1] N. C. Bishop,[1]
J. R. Wendt,[1] R. P. Manginell,[1] J. Dominguez,[1] T. Pluym,[1] D. R. Luhman,[1,2] E. Bielejec,[1]
M. P. Lilly,[1,2] and M. S. Carroll[1]
[1]*Sandia National Laboratories, Albuquerque, New Mexico 87185, USA*
[2]*Center for Integrated Nanotechnologies, Sandia National Laboratories, Albuquerque, New Mexico 87175, USA*





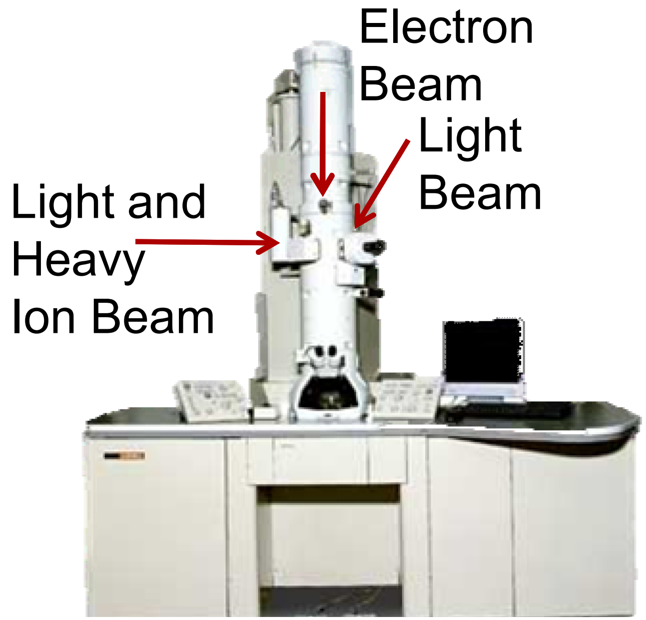
- The extreme limits of ion beam modification: One atom at a time
- One single Sb ion (a donor) put in the right place in a SET
- Quantum bit formation demonstrated

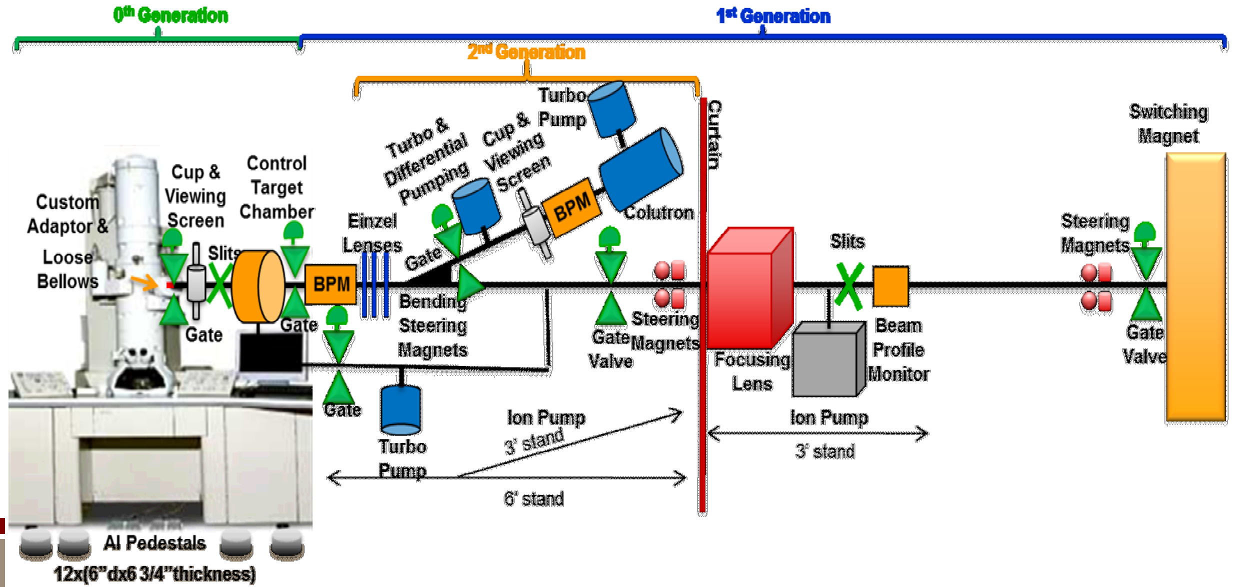


In situ Ion Irradiation TEM Facility

Capabilities:

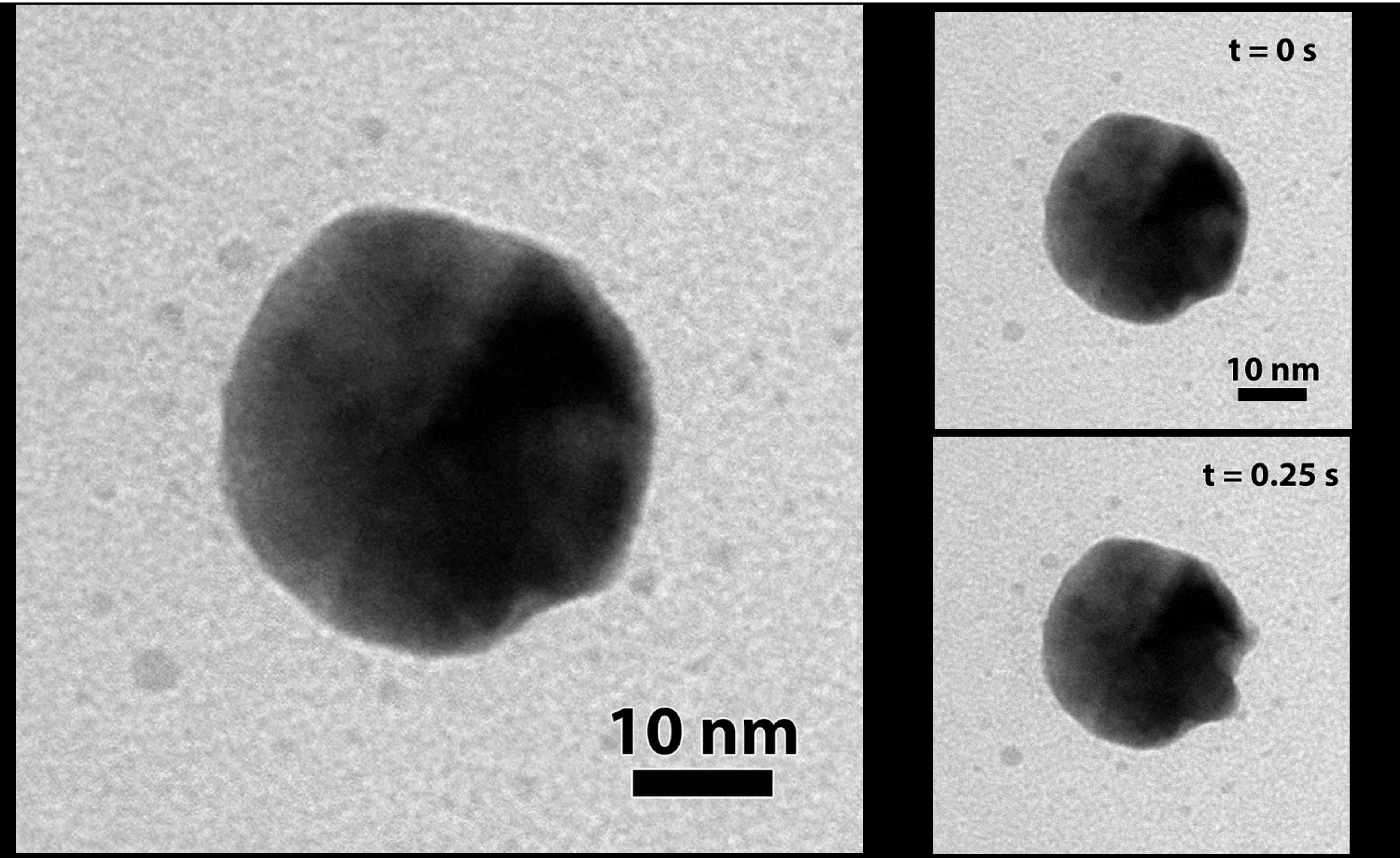
- 200 kV LaB_6 TEM
- Ion beams used:
  - Range of Sputtered Ions from Tandem
  - 10 keV D_2^+
  - 10 keV He^+
  - (Simultaneous D_2+He)
- All beams hit same location
- Nanosecond time resolution (DTEM)
- Procession scanning (EBSD in TEM)
- In situ CL, and IBIL, and PL
- *In situ* vapor phase stage
- *In situ* liquid mixing stage
- *In situ* heating
- Tomography stage (2 axis)
- *In situ* straining stage
- *In situ* cooling stage
- *In situ* electrical bias stage





46keV Au ions (range ~7nm) in Au

Khalid Hattar and D.C. Bufford



Neutron vs Ions in Semiconductors

- With care we can simulate FBR neutron response using a fast-pulsed ion beam
- Replicate time response of transistor gain
- Replicate remaining defect population
- Replicate minority carrier lifetime change
- With ions we can probe much earlier in the response
    - No coincident gammas