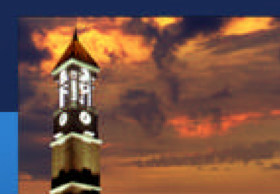
R. Fabian Pease

Nanofabrication

DISCOVERY LECTURE SERIES

2006 PURDUE UNIVERSITY



Nanofabrication

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EASTERN JOINT COMPUTER CONFERENCE

1958

Papers and Discussions Presented
at the Joint Computer Conference
Philadelphia, Pa., December 3–5, 1958

An Approach to Microminiature Printed Systems

D. A. BUCK   K. R. SHOULDERS

THE DAY is rapidly drawing near when digital computers will no longer be made by assembling thousands of individually manufactured parts into plug-in assemblies and then completing their interconnection with back-panel wiring. An alternative to this method is one in which an entire computer or a large part of a computer is made in a single process. Vacuum deposition of electrodes onto blocks of pure silicon or germanium and the subsequent diffusion of the electrode material into the block to form junctions is a most promising method. The successful development of this method would allow large numbers of transistors and all of their interconnecting wiring to be made in one operation. Vacuum deposition of magnetic materials and conductors to form coincident-current magnetic-core memory planes is a second promising method that will allow an entire memory to be made in one operation. The vacuum deposition of superconductive switching and memory circuits is a third method that will make possible the printing of an entire computer. The authors feel sure that the most significant milestone in computer component technology will be the announcement by one or more firms, in perhaps 2 years, that all of the technical problems of building a printed system have been solved, and that one of their engineers with his vacuum system can make a digital computer in an hour.

All three methods mentioned, as well as others not mentioned, involve vacuum deposition through a mask. A cleaned glass substrate or a semiconducting surface is placed in a vacuum system, and the air pumped out until the residual pressure is below 10^{-6} atmosphere. A piece of metal near to the substrate is then heated and atoms of that metal evaporate. Some condense onto the substrate, forming a thin film. Between the source of atoms and the substrate a mask is placed to in-

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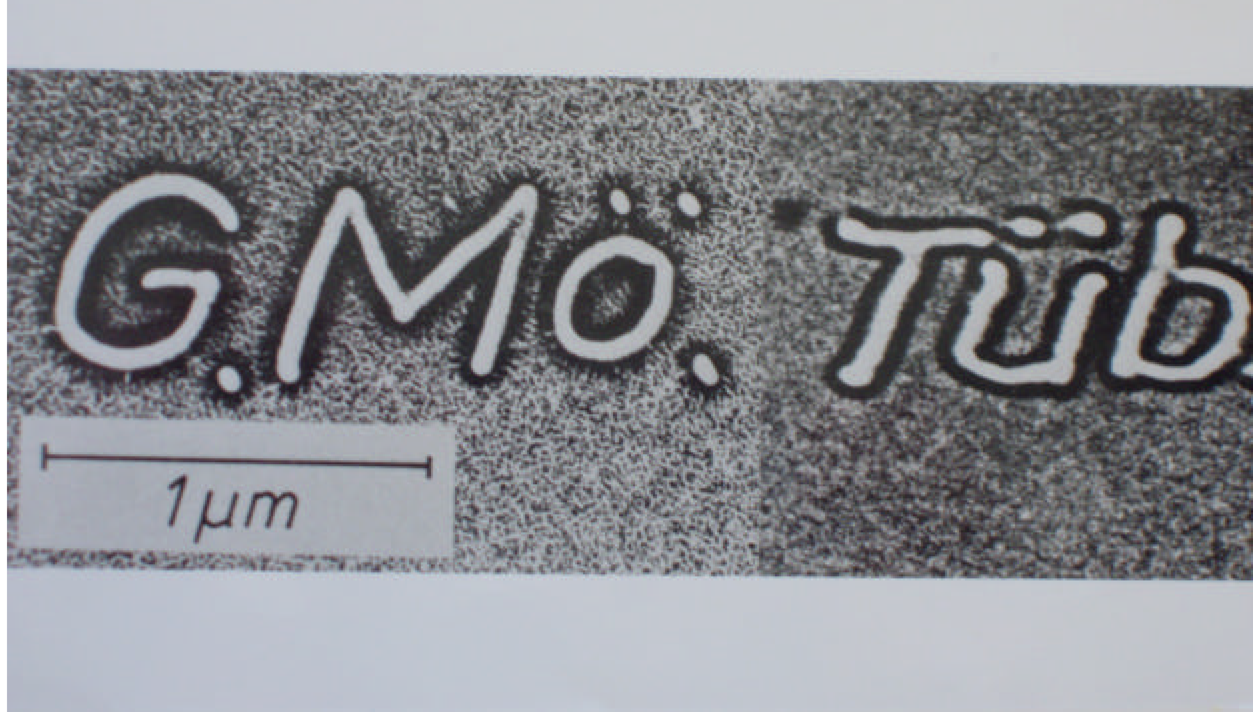
D. A. Buck (deceased) was with Massachusett[s] Institute of Technology, Cambridge, Mass.

K. R. Shoulders is with Stanford Research Insti[tute], Menlo Park, Calif.

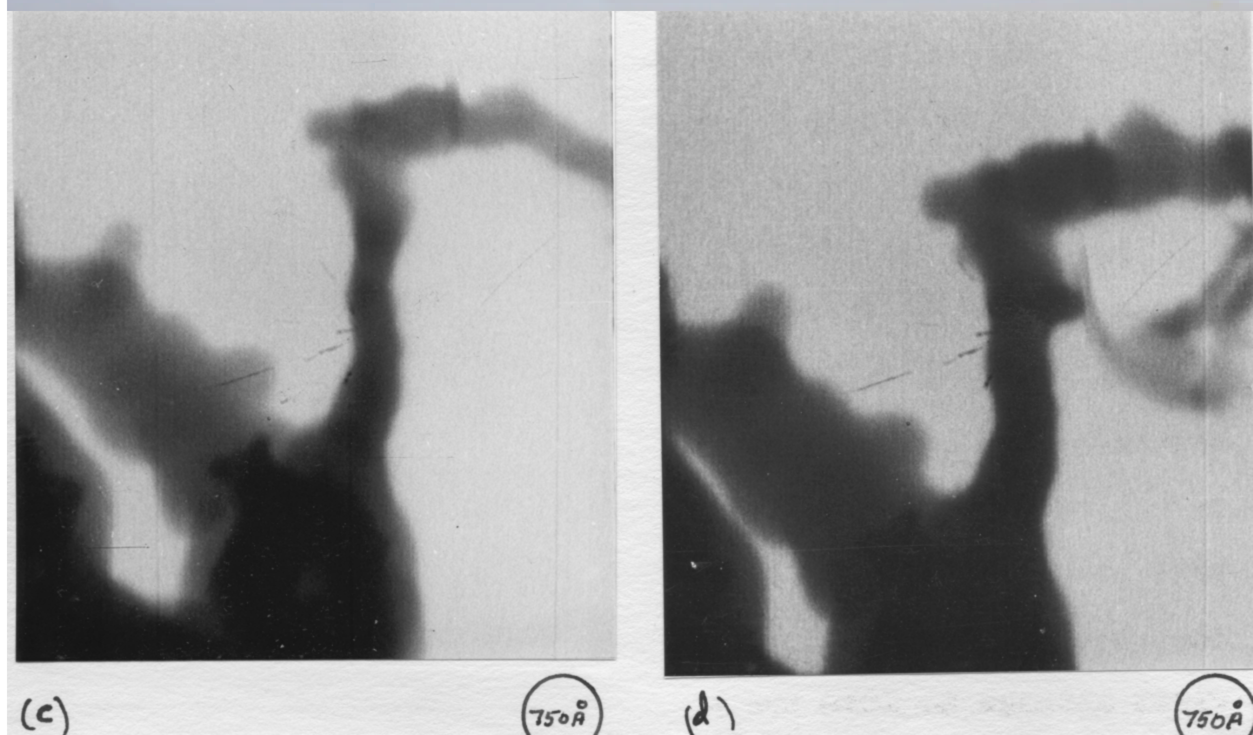
This paper is part of a panel discussion on "Th[e] Impending Revolution in Computer Technology."

The work reported here was supported in part b[y] the U. S. Navy (Bureau of Ships) and in part by th[e] U. S. Army (Signal Corps), the U. S. Air Forc[e] (Office of Scientific Research and Developmen[t] Command), and the U. S. Navy (Office of Nava[l] Research).

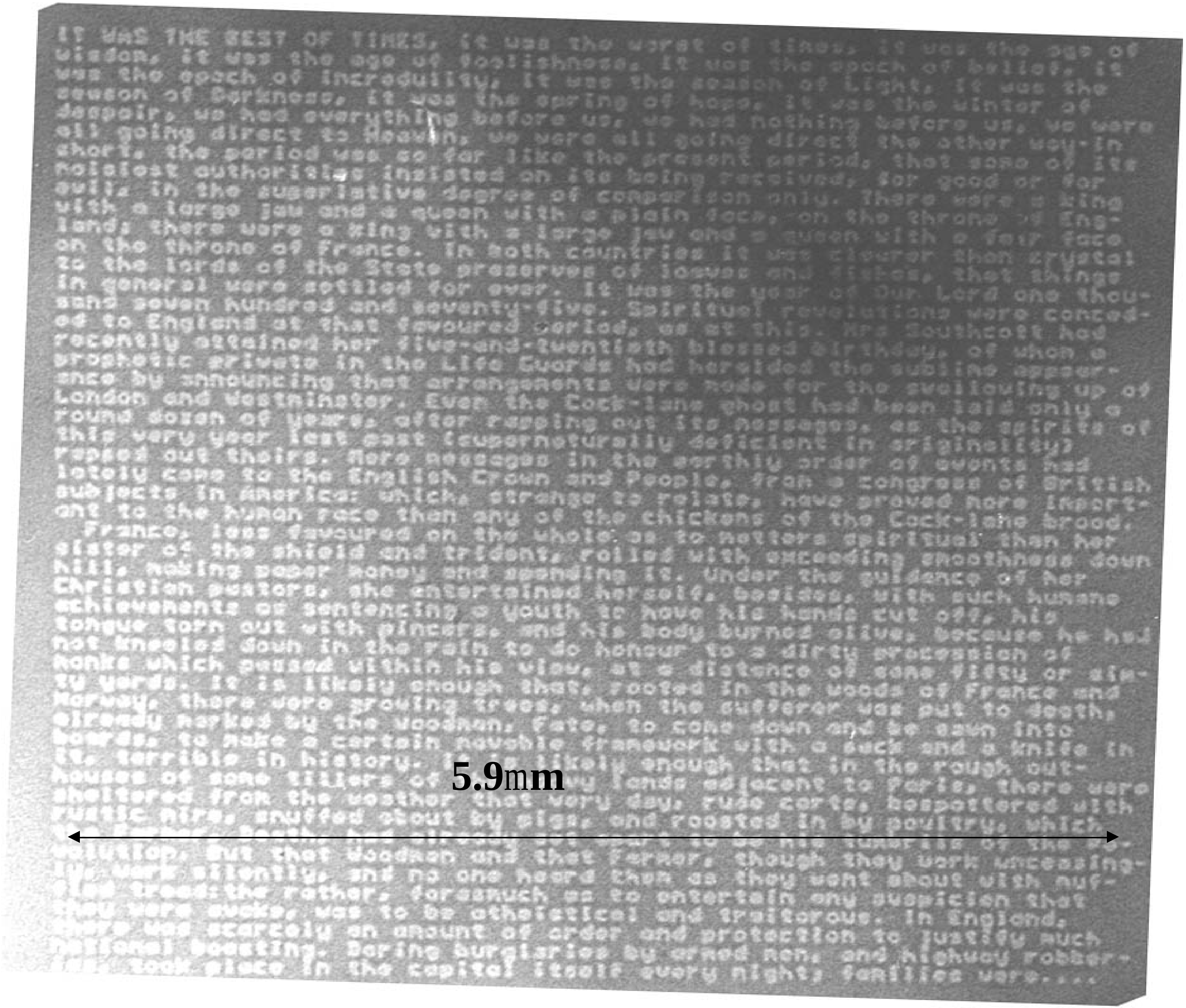
Moellenstedt and Speidel, 1960
One of the first examples of
'Nanowriting' using a modified
transmission electron microscope to
deform a collodion film and then
shadowing with evaporated metal
(G. Mollenstedt and R. Speidel,
Physikalische Blatter, February
1960).



Pease, 1963 SEM 5 (Tx-mode),
'Free-standing contamination
Structures'



Tom Newman, Ann Marshall, Stanford, 1985



CALIFORNIA INSTITUTE OF TECHNOLOGY

CHARLES C. LAURITSEN LABORATORY OF HIGH ENERGY PHYSICS

November 19, 1985

Dr. Thomas H. Newman
452 McCullough Building
Stanford University
Stanford, CA 94305

Dear Dr. Newman:

Congratulations to you and your colleagues. You have certainly satisfied my idea of what I wanted to give a prize for. Others have apparently made as small or smaller marks, but no one tried to print an entire page. And on a 512 x 512 dot printer! Each dot is only about 60 atoms on a side. I can't quite manage to imagine the square 1/160 mm on a side onto which all that is printed. It would be 20 times too small on a side to see with the naked eye. Only ten wave lengths of light. The entire Encyclopaedia Brittanica, perhaps 50,000 to 100,000 pages of your size would be on less than 2 mm on a side - the head of a small plain pin.

Your description of the square silicon nitride windows was a bit incomplete. How big are the windows? Is each window a page, or (less probably?) a letter? Can application to computers be far behind?

As promised long ago, I am enclosing a check for $1,000 for your accomplishment.

Sincerely,

Richard P. Feynman

Richard P. Feynman

RPF;ht
encl.

RICHARD P. FEYNMAN
GWENETH FEYNMAN
797-1262
2475 BOULDER RD.
ALTADENA, CA 91001

16-66/1220

760

DATE Nov. 17, 1985

PAY TO THE ORDER OF Thomas H. Newman $1000.00

One thousand and no/100 DOLLARS

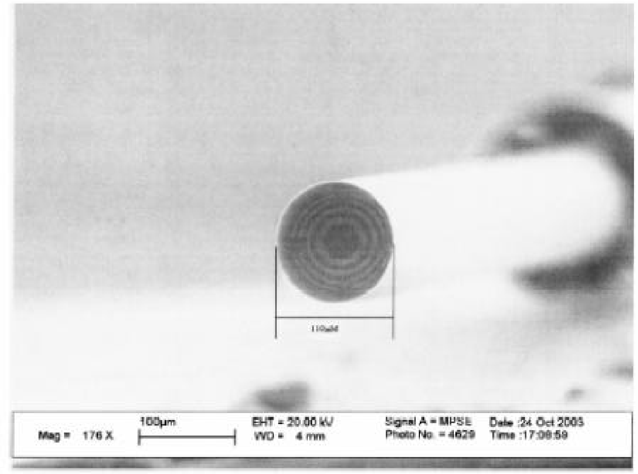
BANK OF AMERICA
ALTADENA BRANCH 0591
2345 NORTH LAKE AVENUE
P.O. BOX 577
ALTADENA, CA 91001

Richard P. Feynman

⑆122000661⑆0760⑈05912⑈01393⑈

Examples of More Flexible Tools

- High resolution EBL systems with tilt stages
  - Lithography performed at the end of an optical fiber in an SEM by P. S. Kelkar *et al.* J. Vac. Sci. Technol. A **22**, 743 (2004)

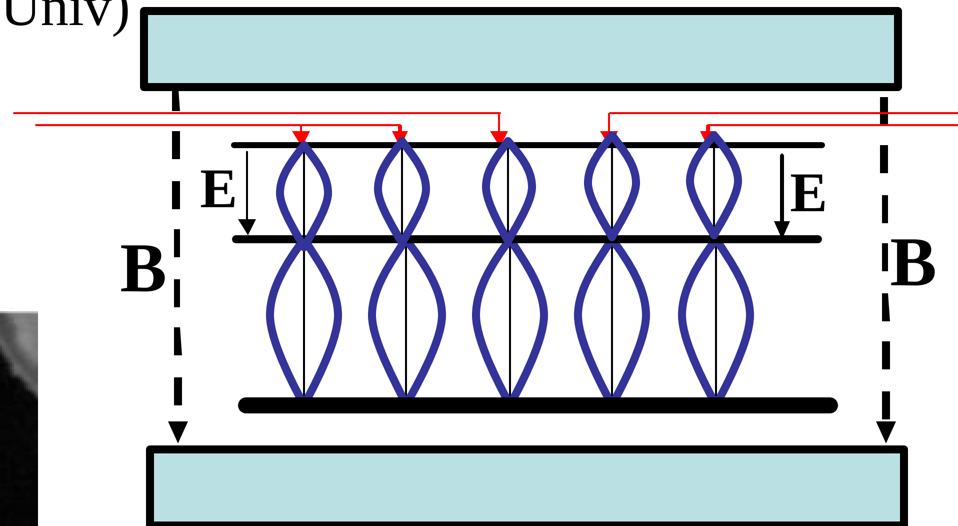


- High resolution dedicated EBL systems with variable pressure chambers
  - Benefits already being explored for photomask CD metrology. For example, D.C. Joy Proc. SPIE Int. Soc. Opt. Eng. **5375**, 10 (2004)
  - Simplify patterning of bulk insulators, SFIL templates, etc.

CNF Cornell NanoScale Science and Technology Facility

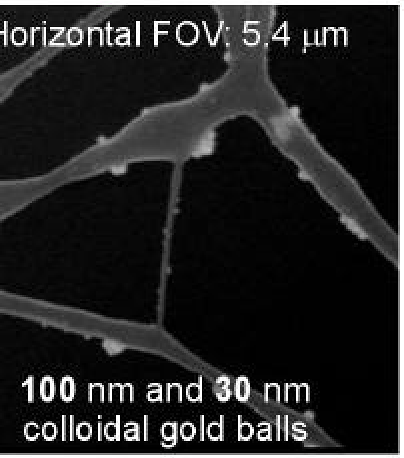
For 1cm^2/s EBL at 22nm we need distributed-axis electron optics

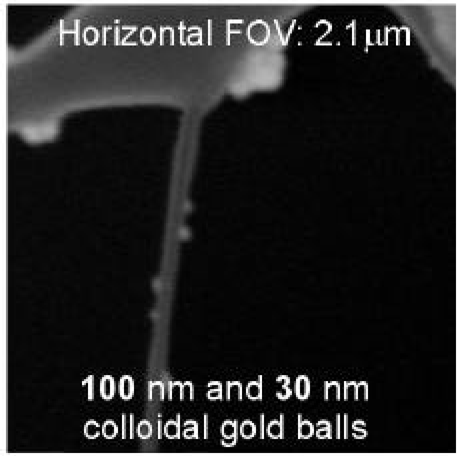
DIFA (Groves, Leica and Pickard, Stanford Univ)



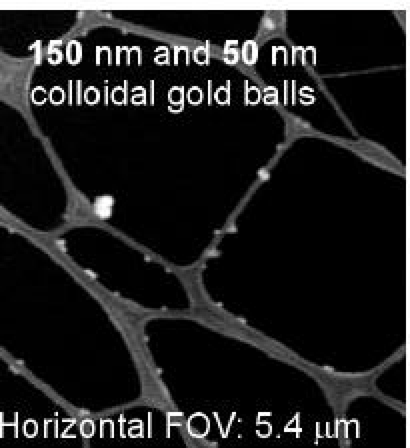
High Resolution (below 50 nm) Imaging
(10 kV, 2 orbits)

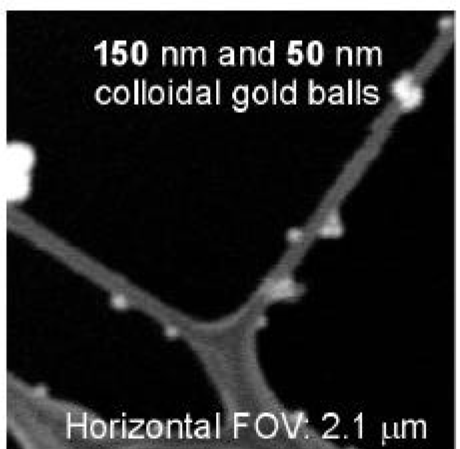
0 nm and **30** nm colloidal gold balls:

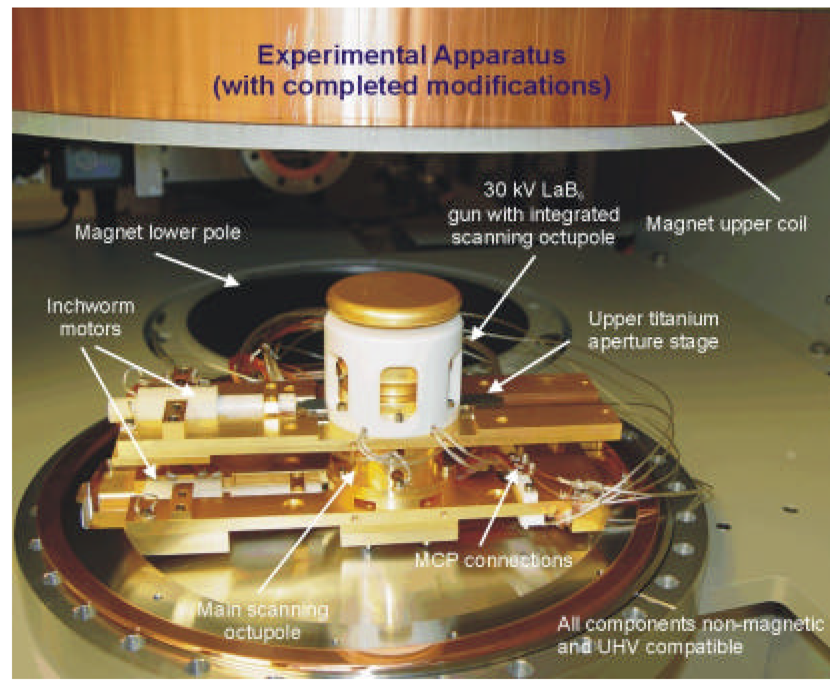




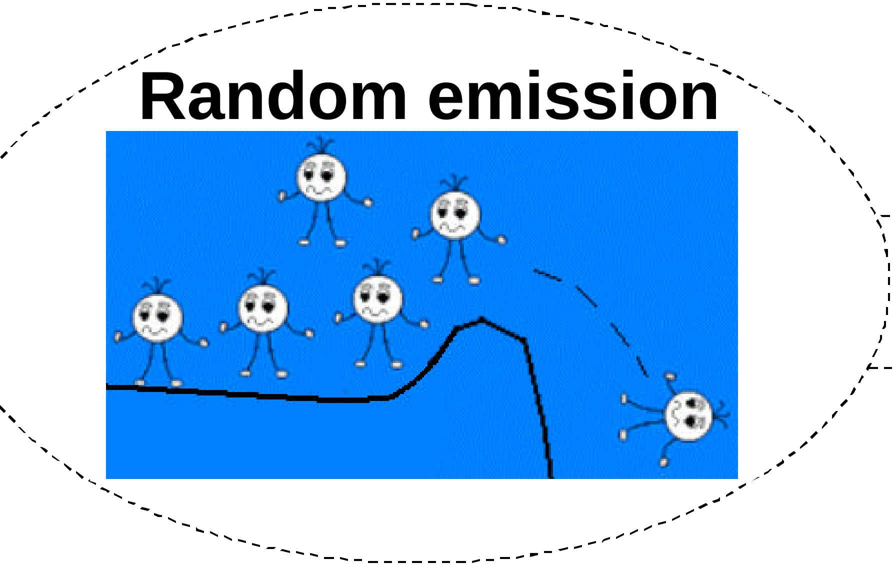
0 nm and **50** nm colloidal gold balls:

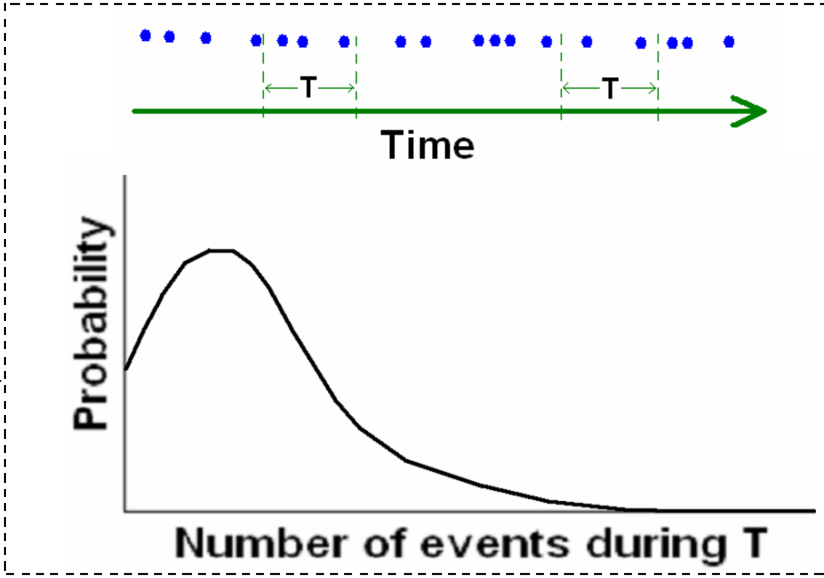


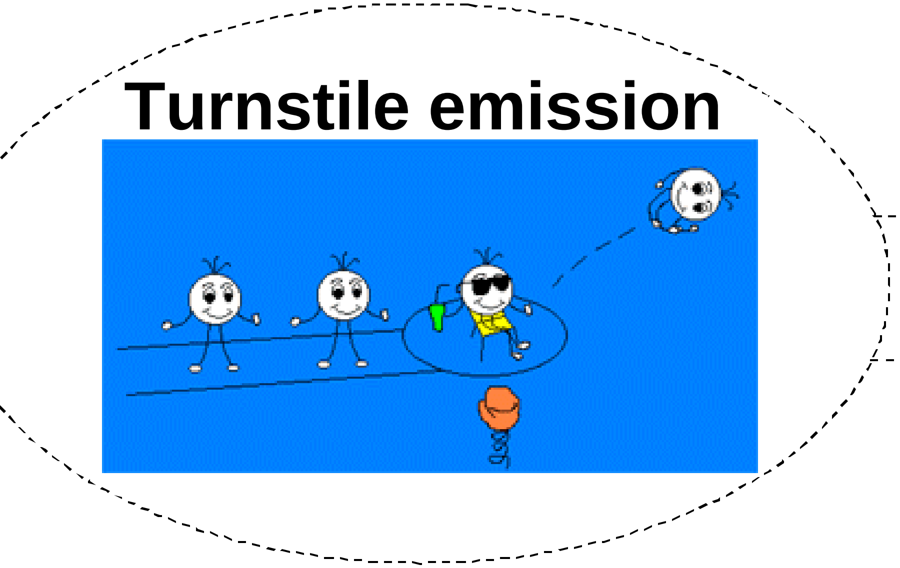


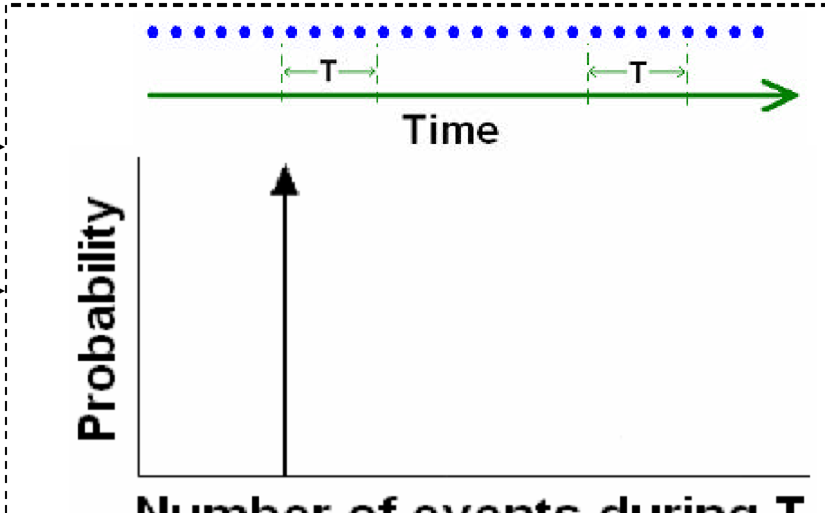


Shot noise


Random emission

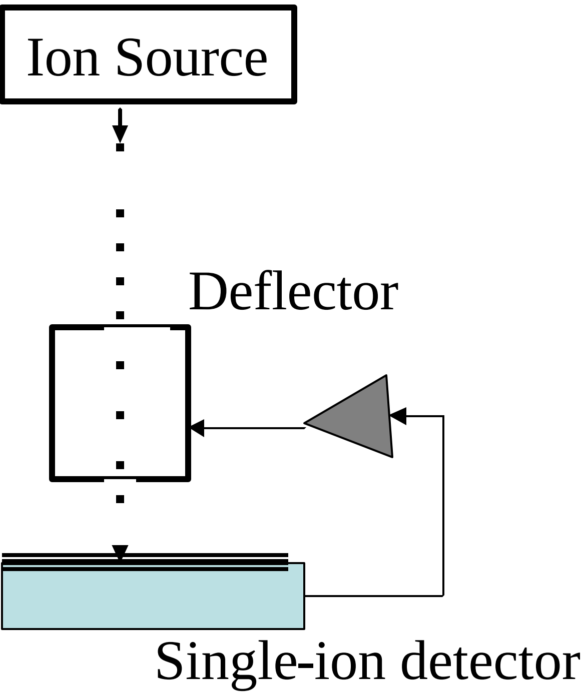

T
T
Time
Probability
Number of events during T

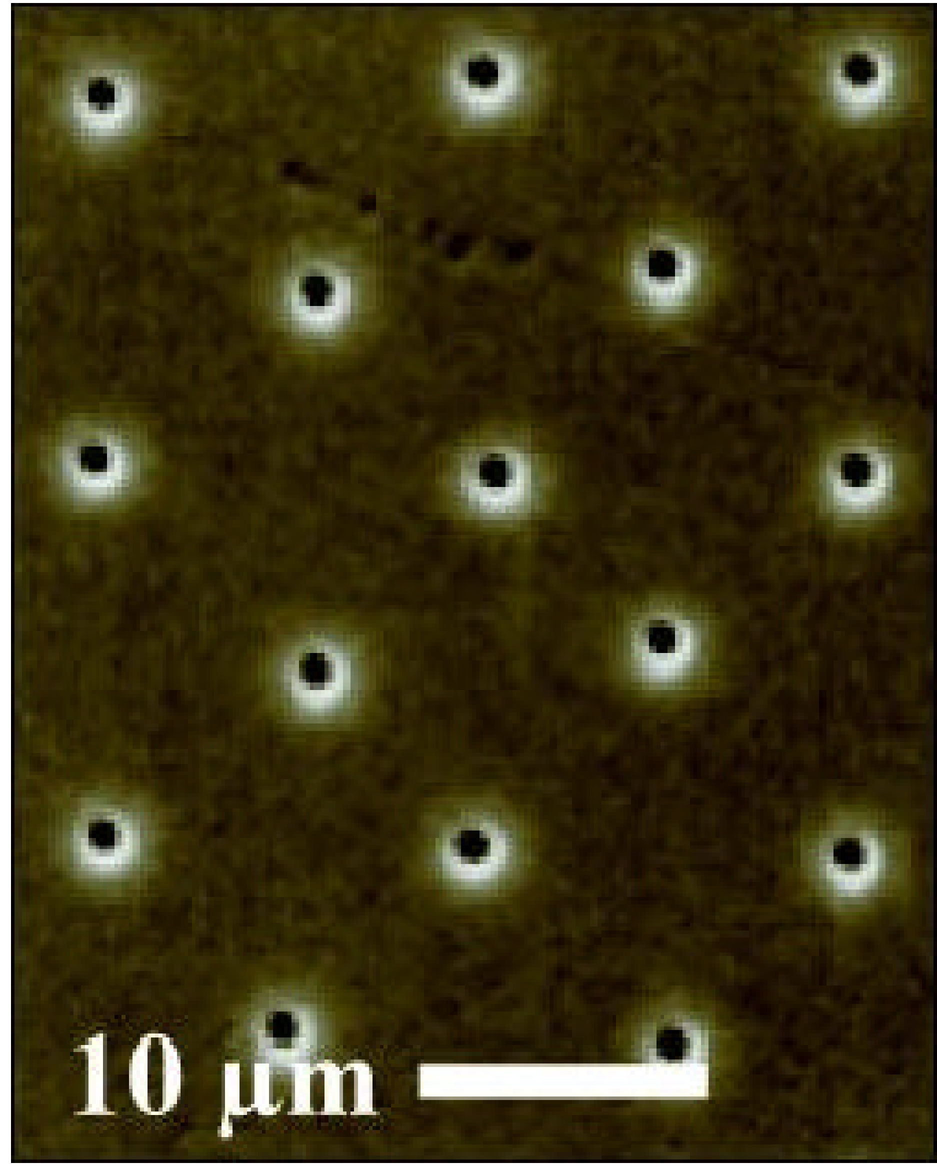

Turnstile emission


T
T
Time
Probability

Opportunity: Do something about the shot noise: realize the single-quantum feature

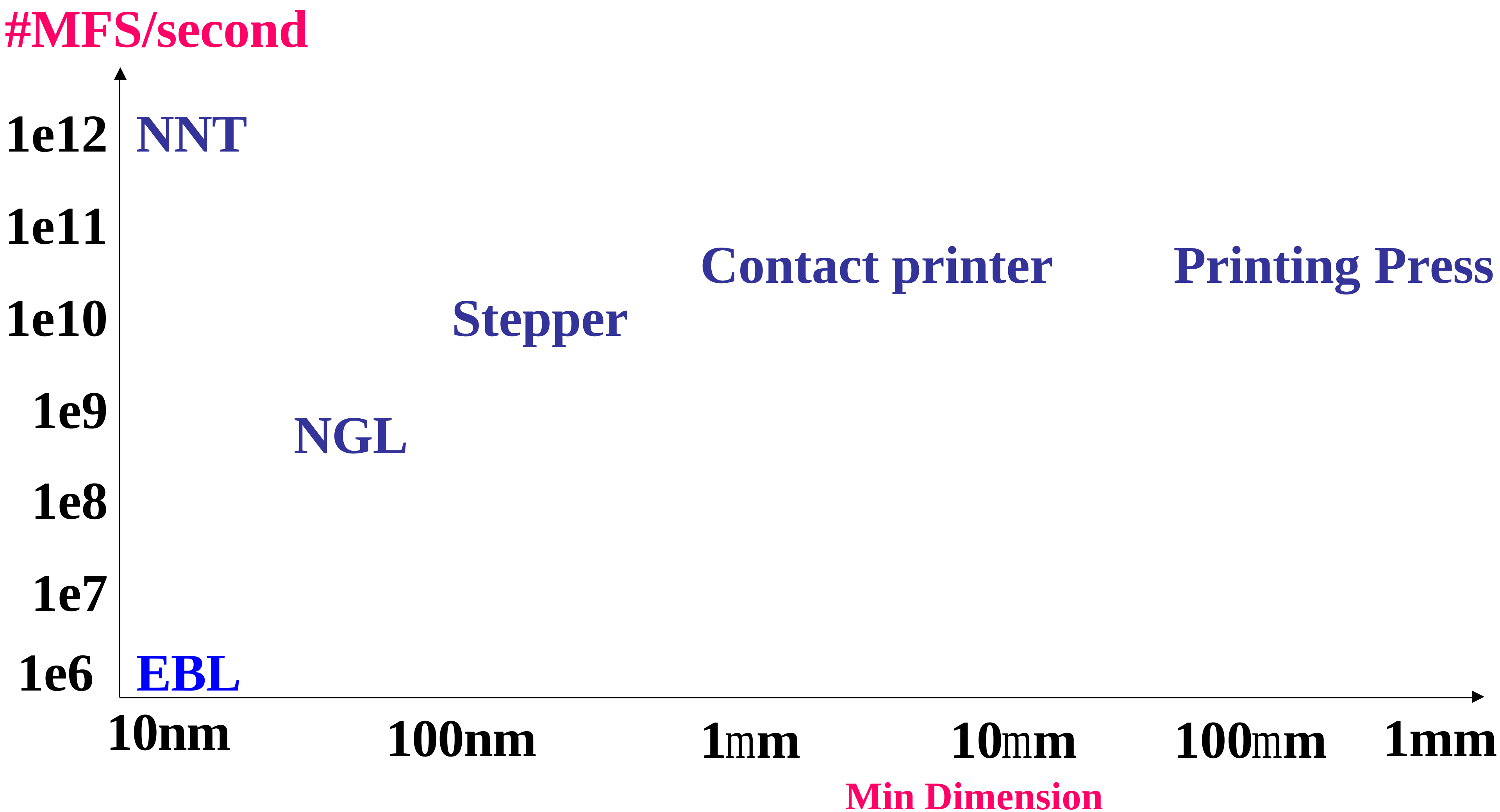
FIB exposure:
moved 'beam position' after monitoring 1 ion landing.





Europhysics News (2004) Vol. 35 No. 5
Ion tracks – a new route to nanotechnology
Alois Weidinger, Hahn Meitner Institute Berlin, Berlin, Germany


10 nm
First International Conference on
NNT
Nanoimprint and Nanoprint Technology
San Francisco, C
Dec 11-13, 2002

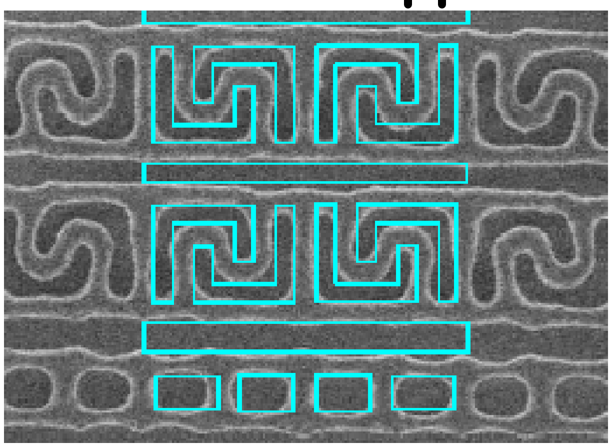

#MFS/second
1e12
1e11
1e10
1e9
1e8
1e7
1e6
NNT
Contact printer
Printing Press
Stepper
NGL
EBL
10nm
100nm
1mm
10mm
100mm
1mm
Min Dimension

Intel / Princeton

Intel

1.13 µm² cell by 193 nm lithography & phase masks (2002)

110 nm Half-Pitch



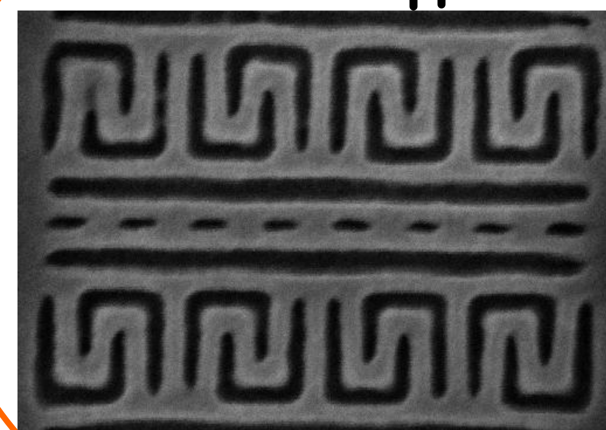
ftp://download.intel.com/research/silicon/BorodovskyPhotomaskJapan0402pres.pdf

Reduction:
-- 6X in linear
-- 30X in area

Princeton

0.04 µm² cell by nanoimprint lithography

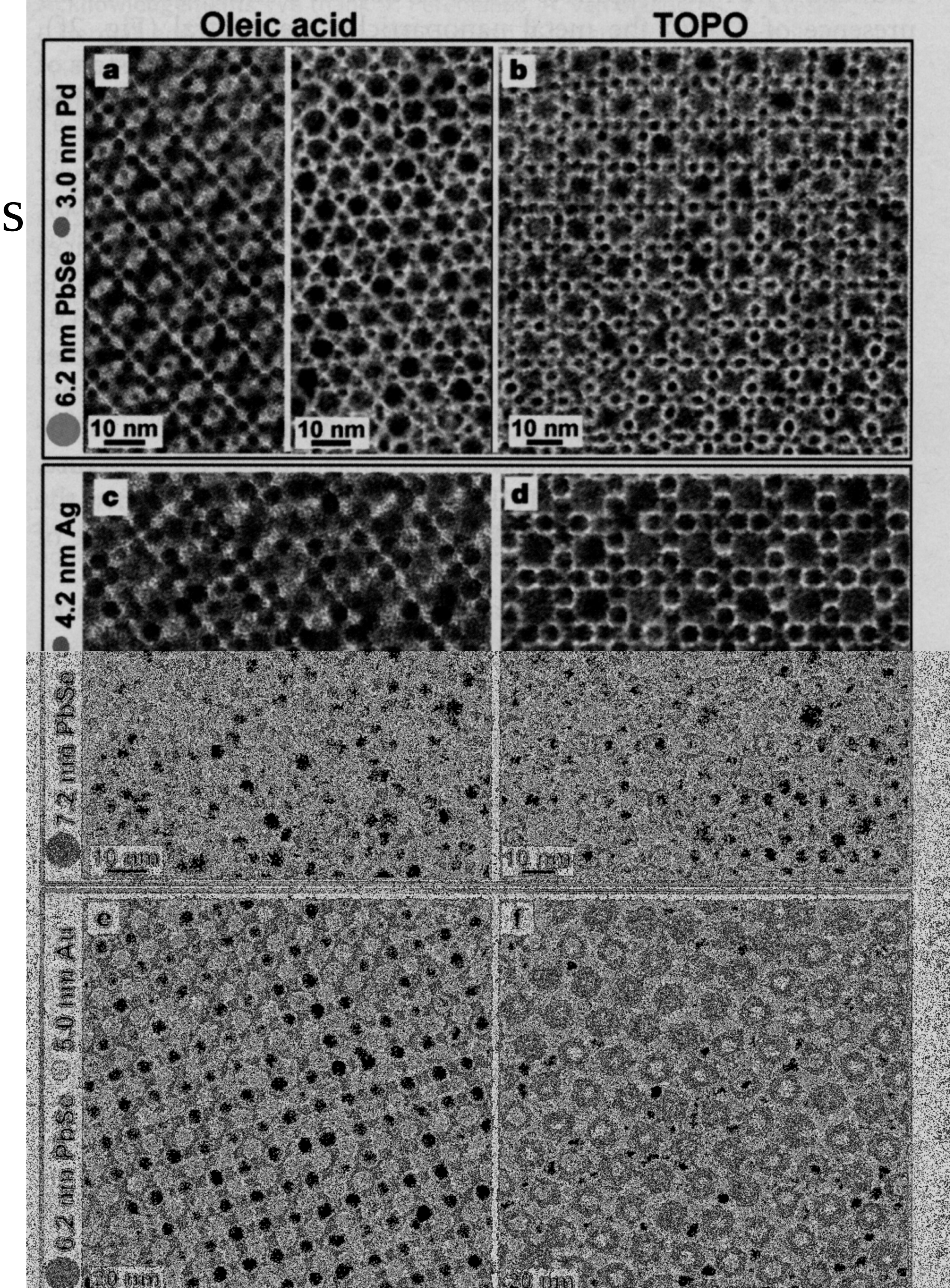
20 nm Half-Pitch



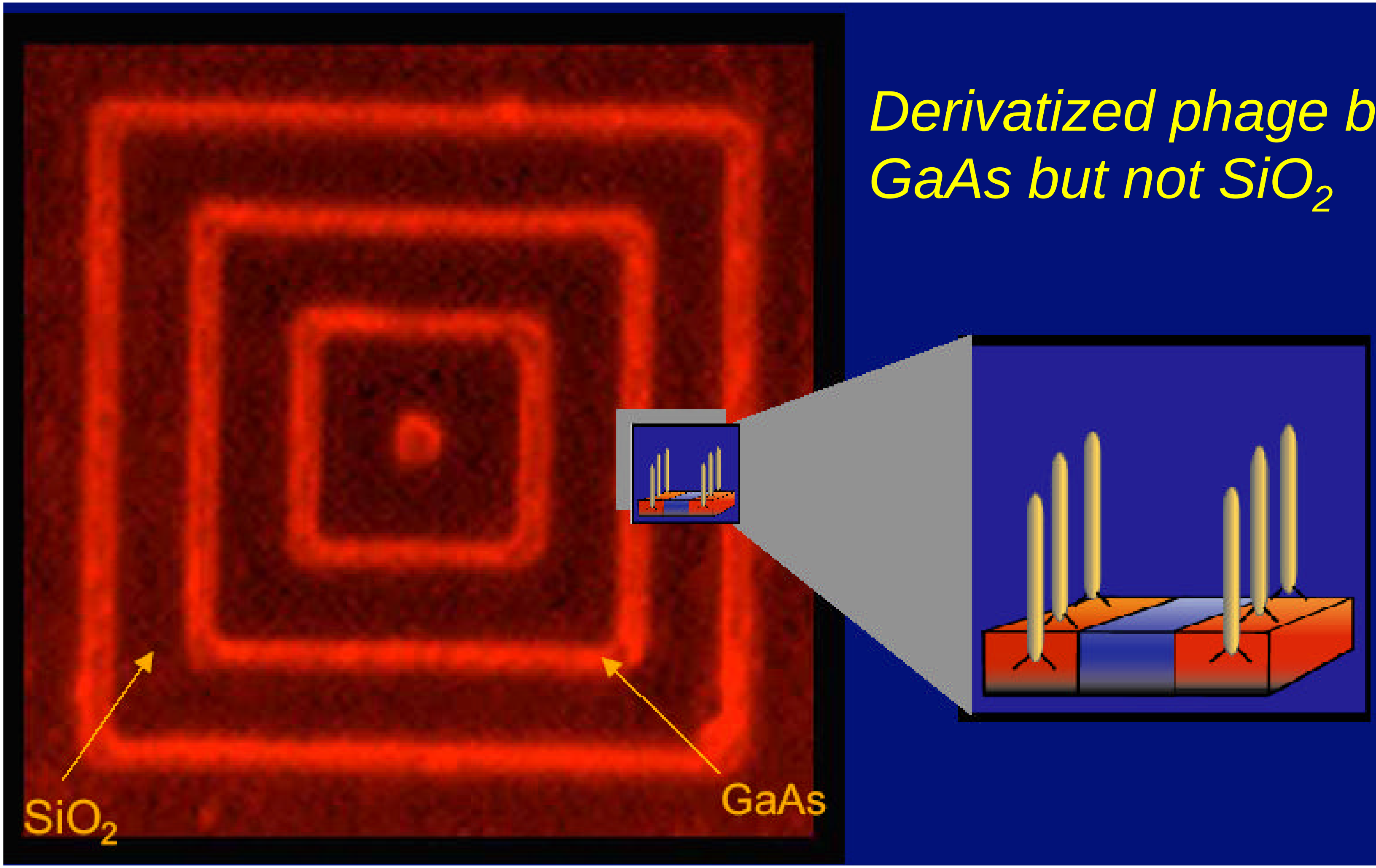
Austin and Chou to be published
Nanonex NX-2000 NIL machines
Nanonex NXR-2010 resist

Shevchenko et al.
Nature,**439**, 5Jan2006, p.55

Binary Nanoscale Superlattices

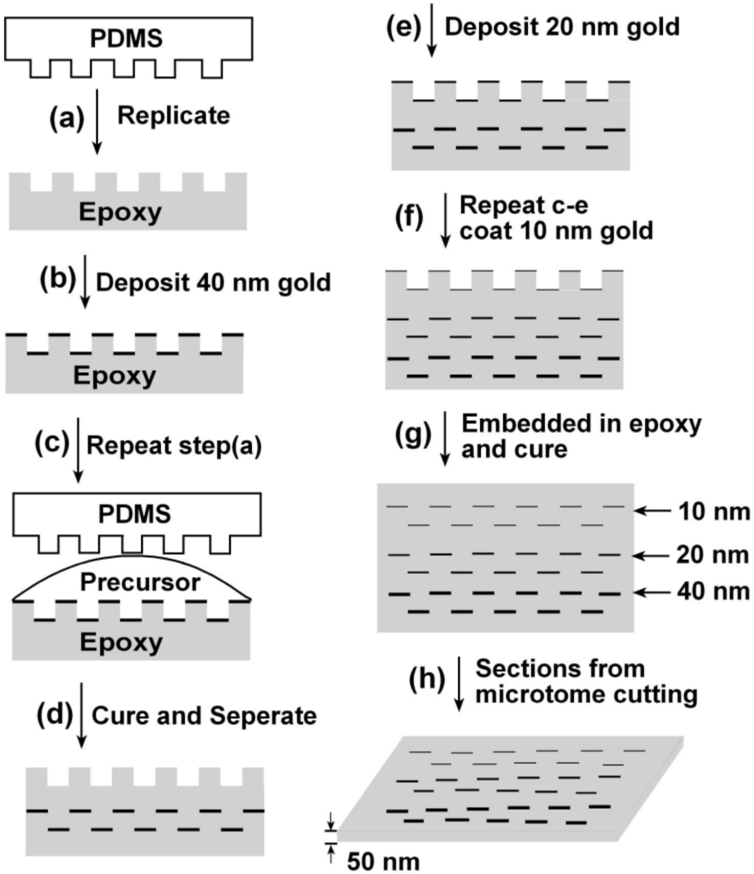


Binding Agents Are Highly Specific

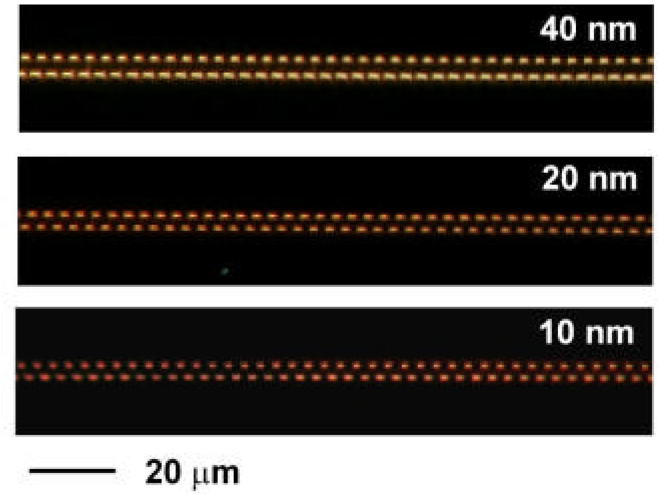


Derivatized phage bind to GaAs but not SiO_2

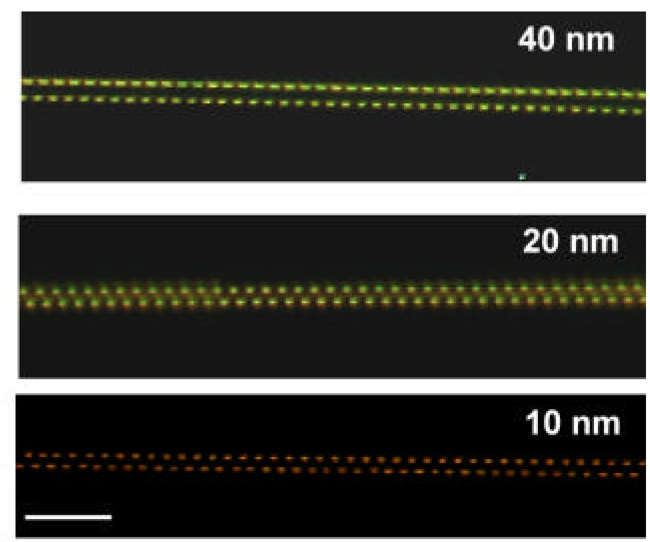
Sectioning as a route to nanostructures…



100 nm section



50 nm section



Unpublished results

Conclusions

- Very low volume nanofabrication is well established,
- Manufacturing at the nanoscale presents major challenges: pattern generation, economic throughput, placement, assured freedom from defects,
- There are many opportunities for improvement. New ideas are continually emerging. They need a disciplined approach.