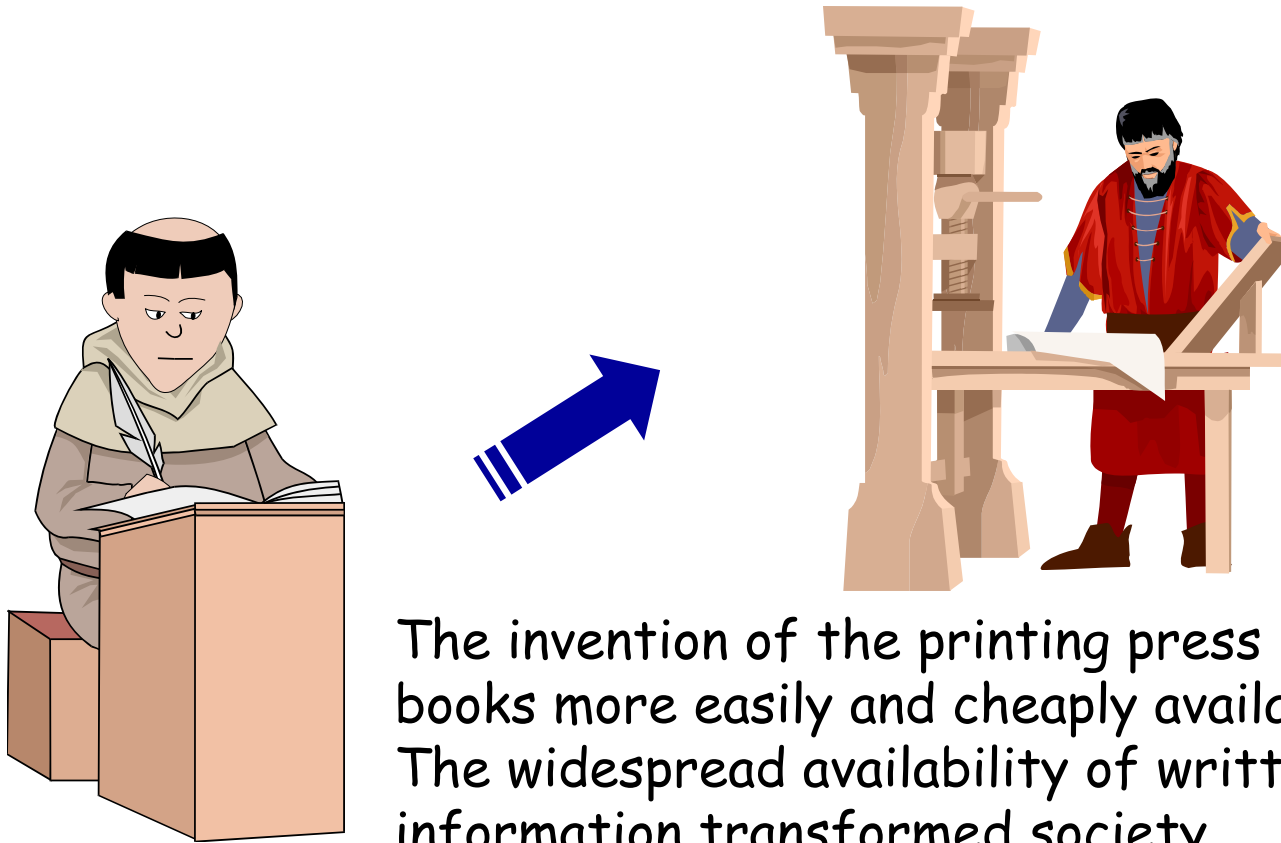


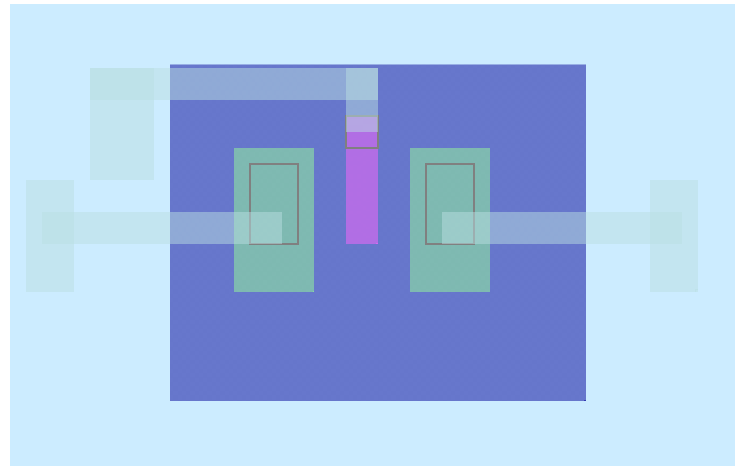
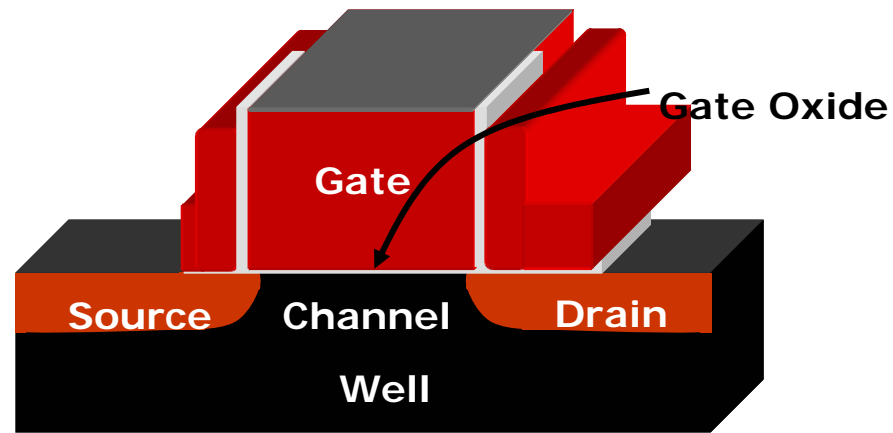
A 'Paradigm Shift': Gutenberg's Printing Press Reappears



The invention of the printing press made books more easily and cheaply available
The widespread availability of written information transformed society.

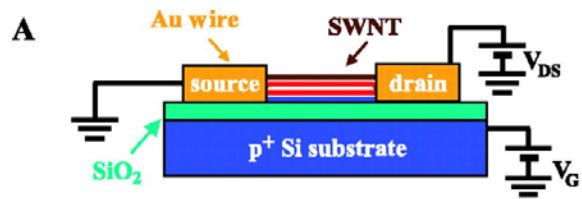
How do you 'write' a transistor?

Building a 3D Structure, layer by layer



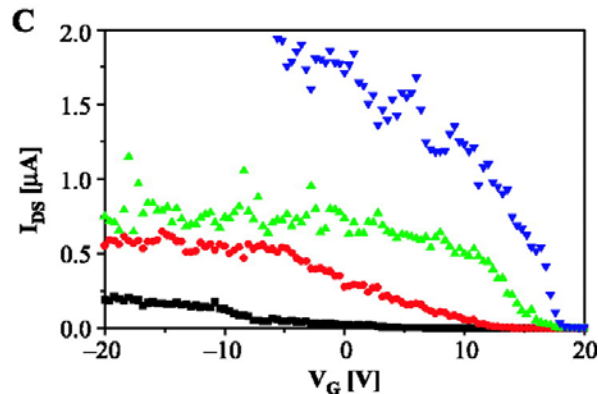
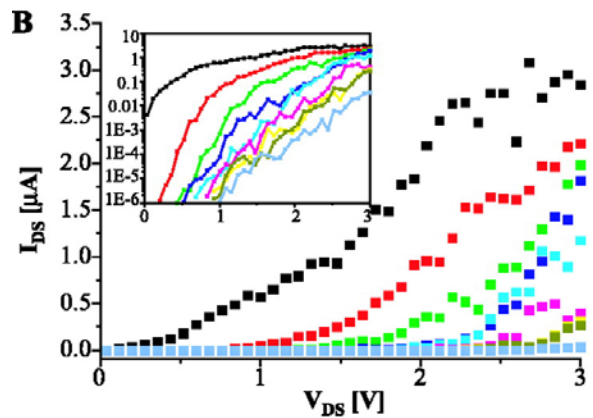
Well
Source and drain
Gate
Windows
Metal interconnects

Time for another 'paradigm shift'?



DNA-Templated Carbon Nanotube Field-Effect Transistor

Kinneret Keren,¹ Rotem S. Berman,¹ Evgeny Buchstab,²
Uri Sivan,^{1,2} Erez Braun^{1,2*}



- not a 2D, printing-press technique
- use pre-formed nano-components
- program the structures to help the assembly

K. Keren et al., *Science* 302, 1380 -1382 (2003)

Published by AAAS

Understanding the Process

(i) RecA Polymerization



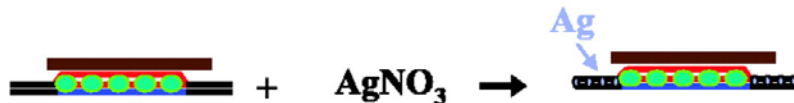
(ii) Homologous recombination



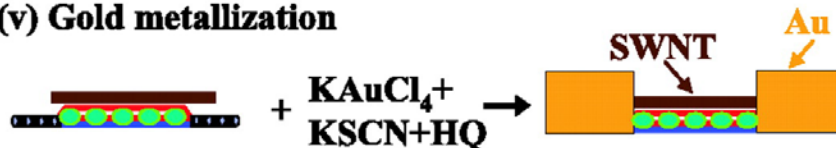
(iii) Localization of a SWNT using antibodies



(iv) RecA protects against silver reduction



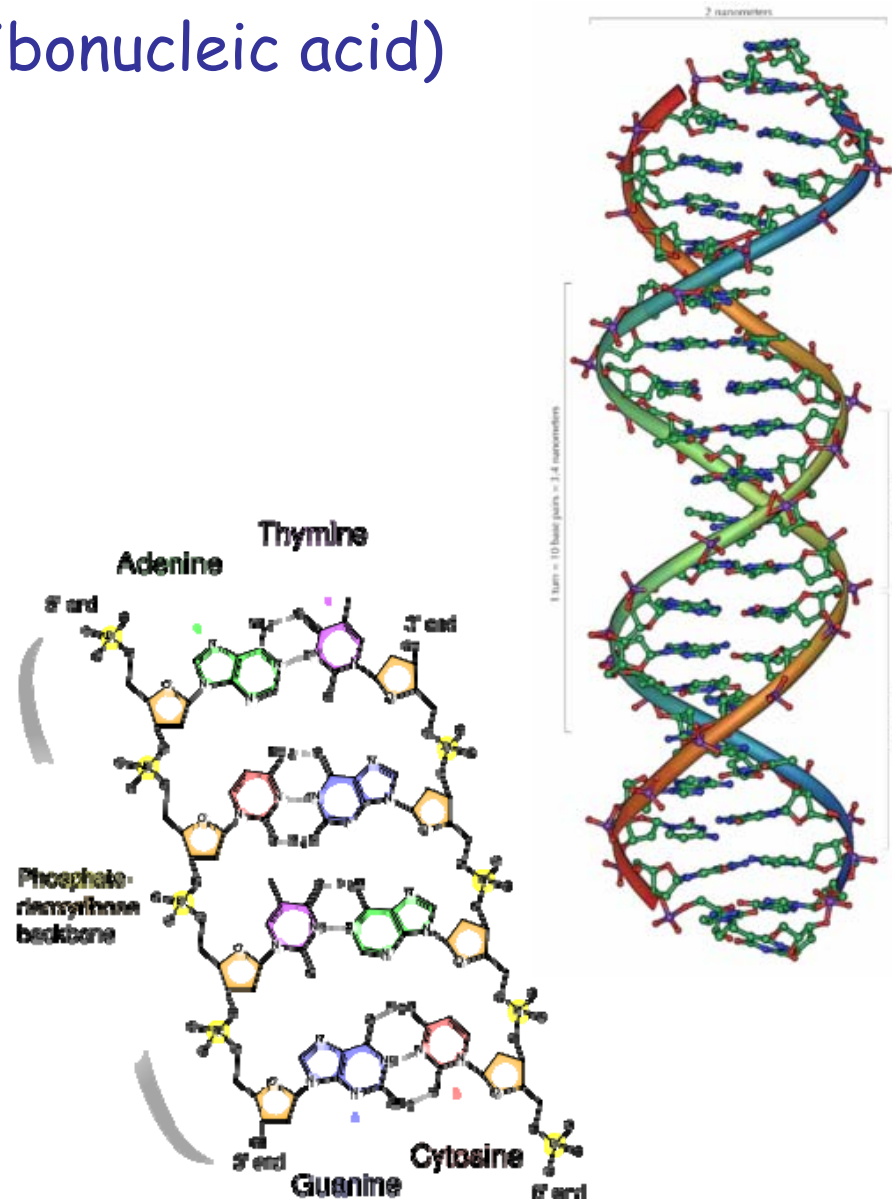
(v) Gold metallization



K. Keren et al., Science 302, 1380 -1382 (2003)

Structure of DNA (deoxyribonucleic acid)

- Chemically, DNA is a long polymer of simple units called nucleotides, with a backbone made of sugars and phosphate groups joined by ester bonds. Attached to each sugar is one of four types of molecules called bases.
- Each type of base on one strand forms a bond with just one type of base on the other strand. This is called complementary base pairing.
 - Adenine-Thymine
 - Cytosine-Guanine



Understanding the Process

(i) RecA Polymerization



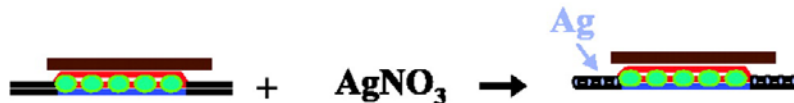
(ii) Homologous recombination



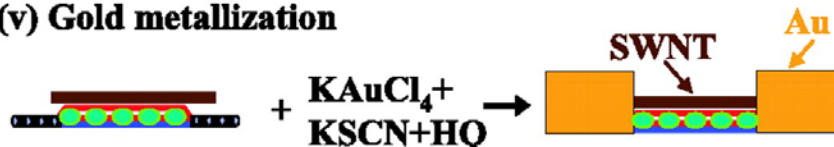
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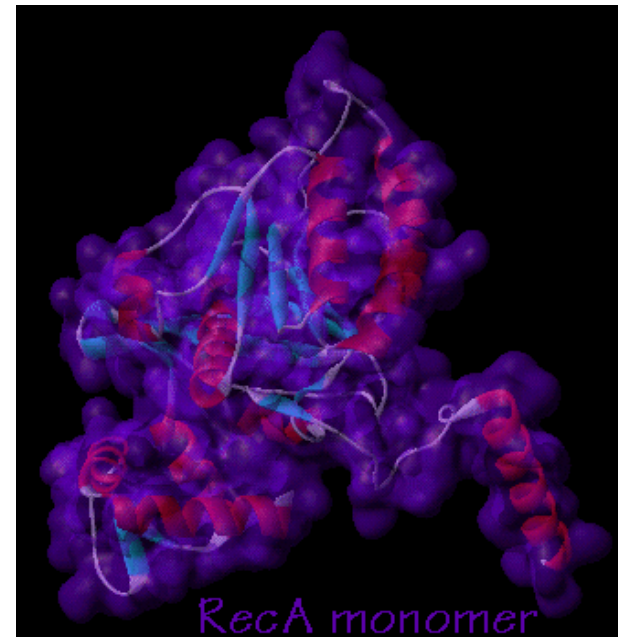
(v) Gold metallization



K. Keren et al., Science 302, 1380 -1382 (2003)

RecA Protein

- **RecA** protein essential for the repair and maintenance of DNA.
- RecA protein binds strongly and in long clusters to single stranded DNA (ssDNA) to form a nucleoprotein filament
- The RecA protein catalyzes the pairing of ssDNA with complementary regions of double stranded DNA (dsDNA).



RecA Monomer

http://www.callutheran.edu/Academic_Programs/Departments/BioDev/omm/reca/recamast.htm

Next step?

<http://en.wikipedia.org/wiki/RecA>

Understanding the Process

(i) RecA Polymerization



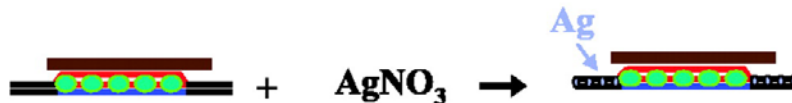
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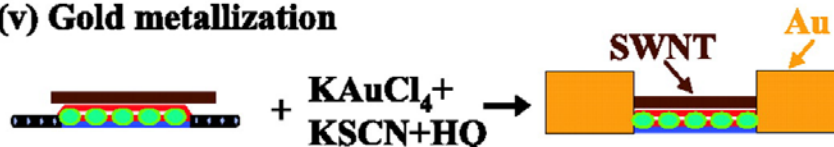
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K. Keren et al., Science 302, 1380 -1382 (2003)

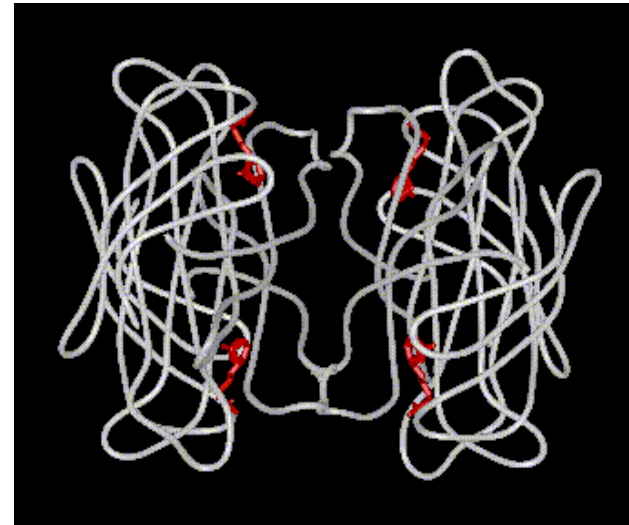
- SSDNA: engineered for precision placement on ds DNA
- RecA: catalyzes alignment
- Streptavidin-coated SWNT

Streptavidin-Biotin

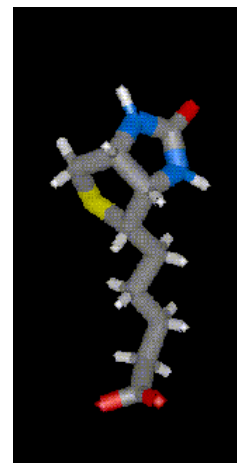
- One of the largest free energies of association of yet observed for noncovalent binding of a protein and small ligand in aqueous solution ($K_{\text{assoc}} = 10^{14}$).
- The complexes are also extremely stable over a wide range of temperature and pH.

**So, streptavidin-biotin is the glue
That will fix the SWNT in the right place**

<http://web.csb.ias.edu/amber8/tutorial/streptavidin/index.html>



Streptavidin bound to biotin



biotin

Understanding the Process

(i) RecA Polymerization



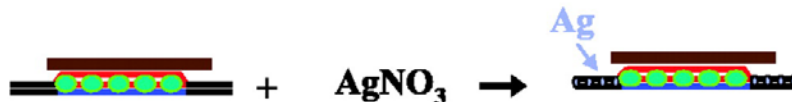
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(iv) RecA protects against silver reduction



(v) Gold metallization



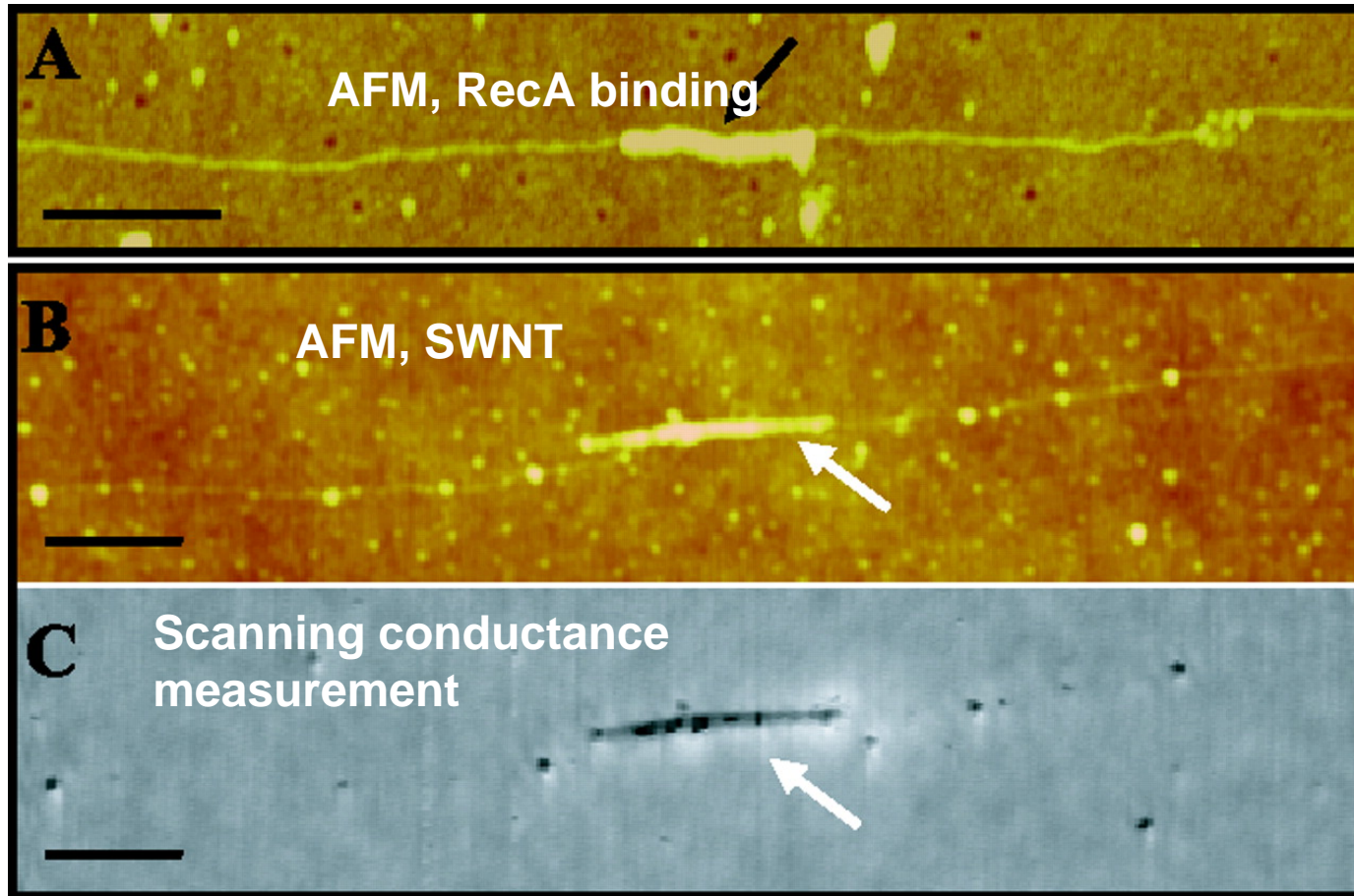
- SSDNA: engineered for precision placement on ds DNA
- RecA: catalyzes alignment
- Streptavidin-coated SWNT
- RecA antibody/biotin-antibody

Recap:

- SWNT is our pre-formed channel
- DNA affinities allow us to place the channel where we want
- RecA catalyzes the placement
- Streptavidin-biotin allows us to glue the SWNT to the ssDNA anchor

K. Keren et al., Science 302, 1380 -1382 (2003)

Fig. 2. Localization of a SWNT at a specific address on the scaffold dsDNA molecule using RecA



K. Keren et al., Science 302, 1380 -1382 (2003)

**Atomic Force Microscope and Scanning Conductance
Microscope**

Published by AAAS



Understanding the Process

(i) RecA Polymerization



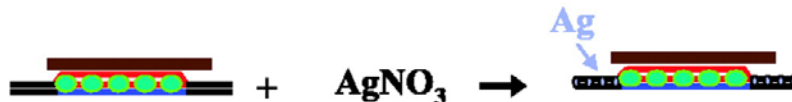
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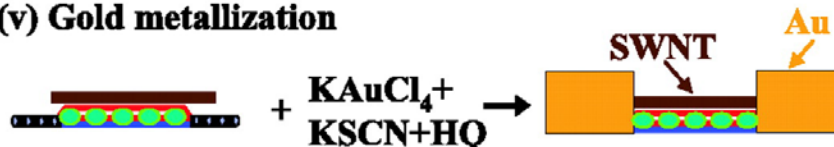
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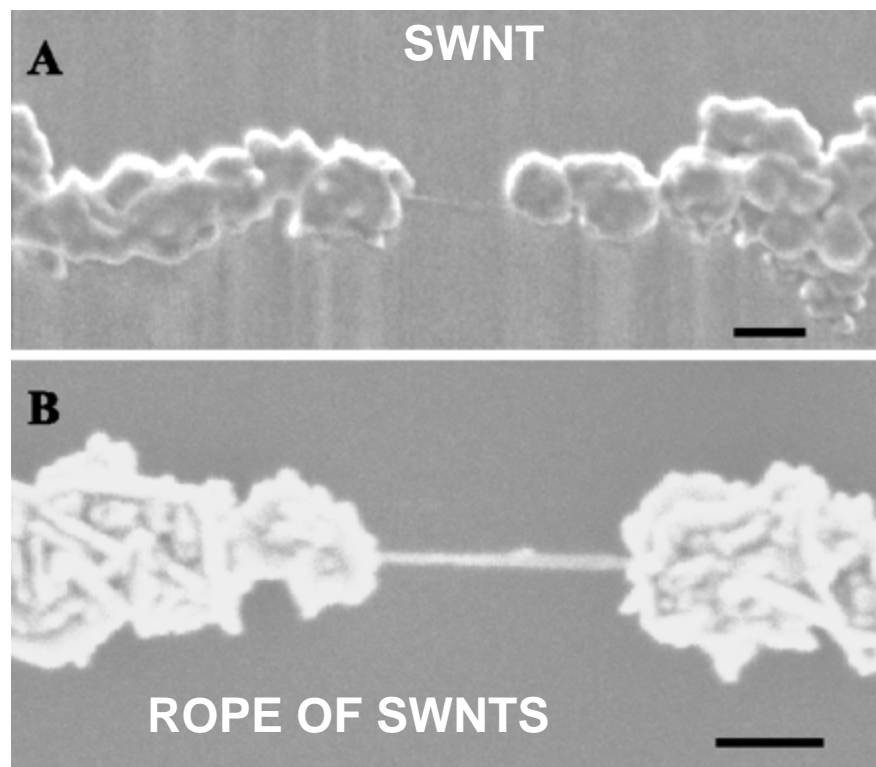
- SSDNA: engineered for precision placement on ds DNA
- RecA: catalyzes alignment
- Streptavidin-coated SWNT
- RecA antibody/biotin-antibody
- Pre-treatment of DNA with glutaraldehyde: make DNA active
- reducing agent for AgNO₃
- RecA serves as a mask: no Ag
- Au electroless deposition on Ag

In other words:

- The remaining DNA will be selectively treated (masked) to nucleate Ag
- The Ag regions will allow formation of Au contacts

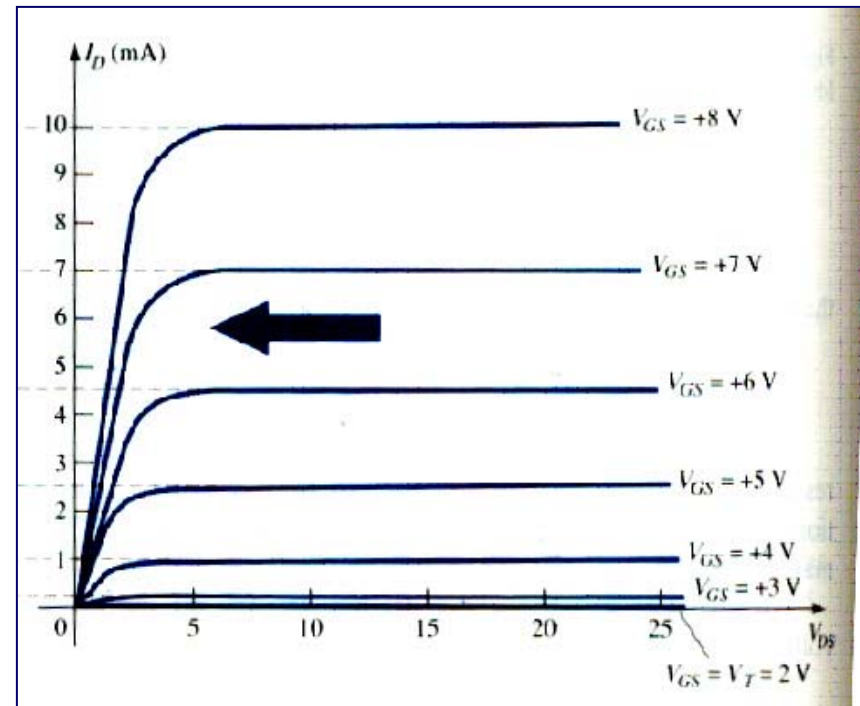
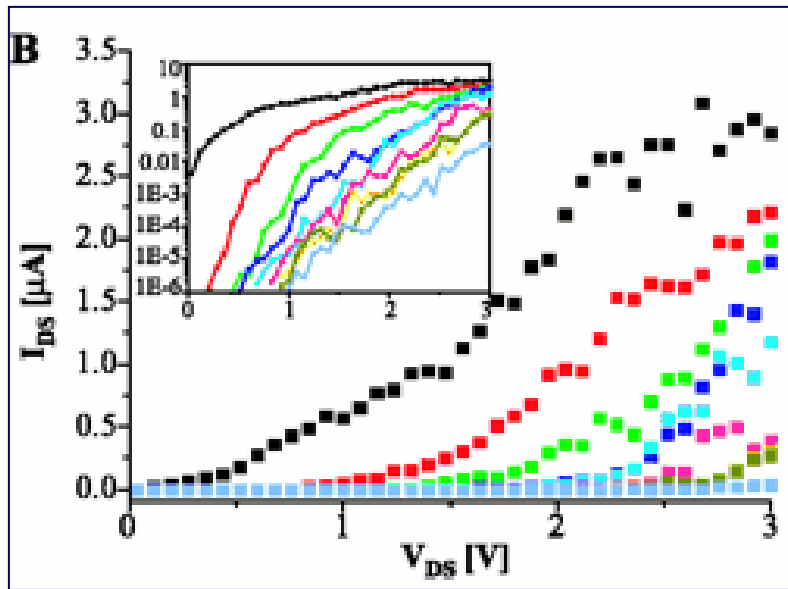
K. Keren et al., Science 302, 1380 -1382 (2003)

CHANNEL AND METAL CONTACTS



Bar = 100 nm

Comparing I-V curves



- Look at the values of maximum current and voltages: what can they tell you?
- What is the transconductance?
- Why are the value of current at low voltage so different?