Carbon Nanotube Electronics

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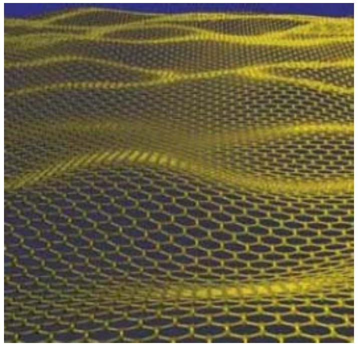
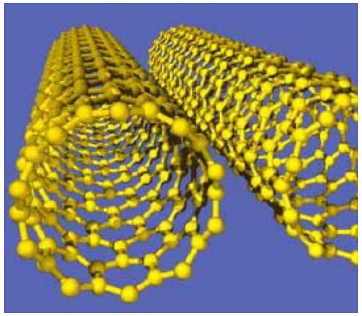
Carbon Nanotubes – Superior Electronic Properties

3D – graphite

2D – graphene



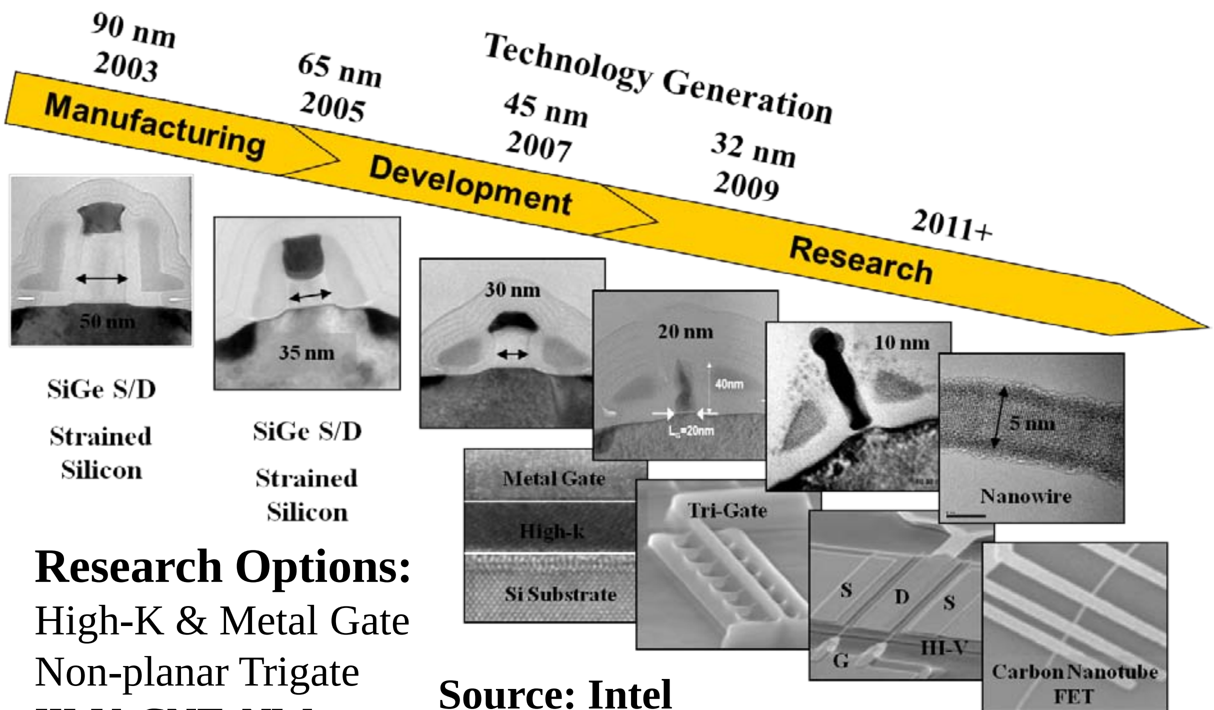
1D – Carbon nanotube



	Si	GaAs	InGaAs*	GaN	CNT	Graphene
E_G, eV	1.1	1.4	0.7	3.4	0.4 – 1	0
E_{BR}, 10^5 V/cm	5.7	6.4	4	40	-	-
μ_0, cm^2/Vs	710	4700	7000	680	>10,000	>10,000
v_{peak}, $10^7 cm/s$	1	2	2.5-3	2.5	2 - 4	2 – 4
v_{sat}, $10^7 cm/s$	1	0.8	0.7	1.5-2	2 - 4	2 - 4
κ, W/cm-K	1.3	0.5	0.05	1.2**	-	-

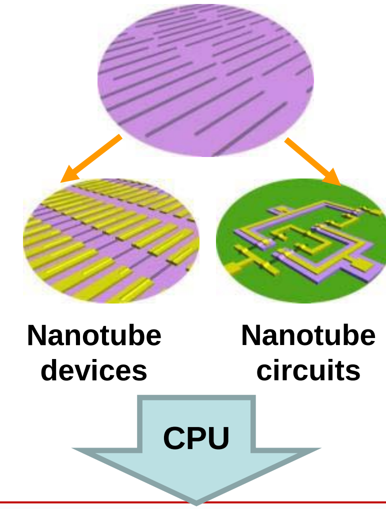
- **Very high carrier mobility (>10,000 cm^2/Vs at room temperature) for high speed transistor**
- **High carrier velocity: saturation velocity ~4×10^7 cm/s**

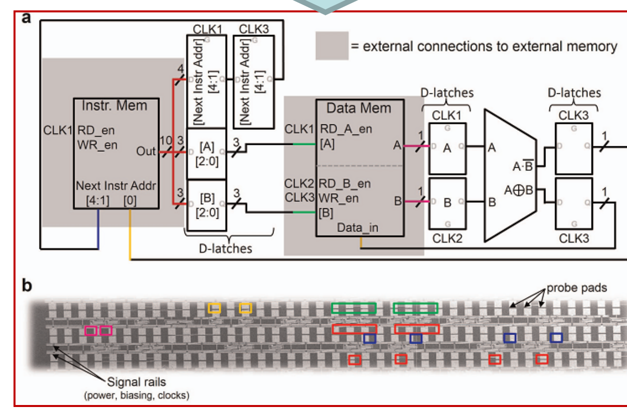
Digital Electronics



Research Options:
High-K & Metal Gate
Non-planar Trigate
III-V, CNT, NW

Source: Intel



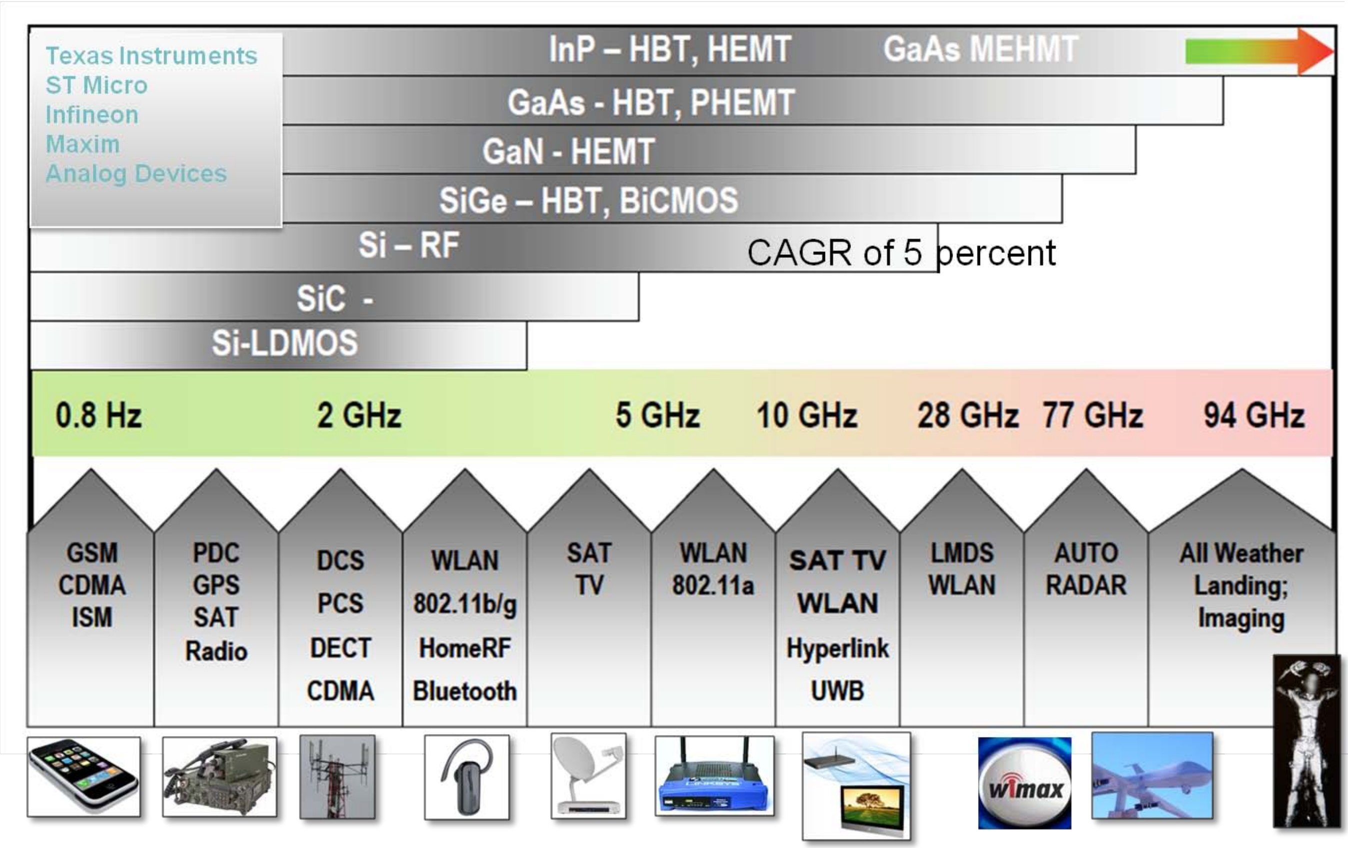


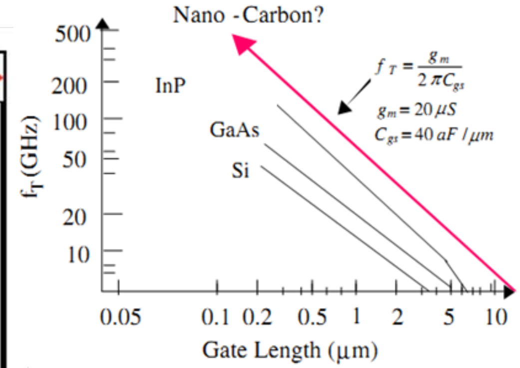
Problem:
Coexistence of metallic and semiconducting nanotubes

Goal:
Remove metallic nanotubes

My innovation:
Selective synthesis of predominant semiconducting nanotubes

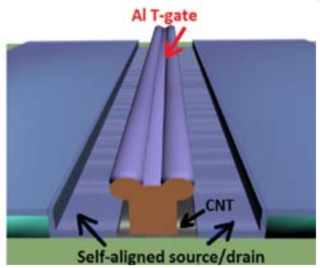
Radio frequency Electronics





Key factors in RF:

- ✓ Mobility
- ✓ Conductivity
- ✓ Linearity



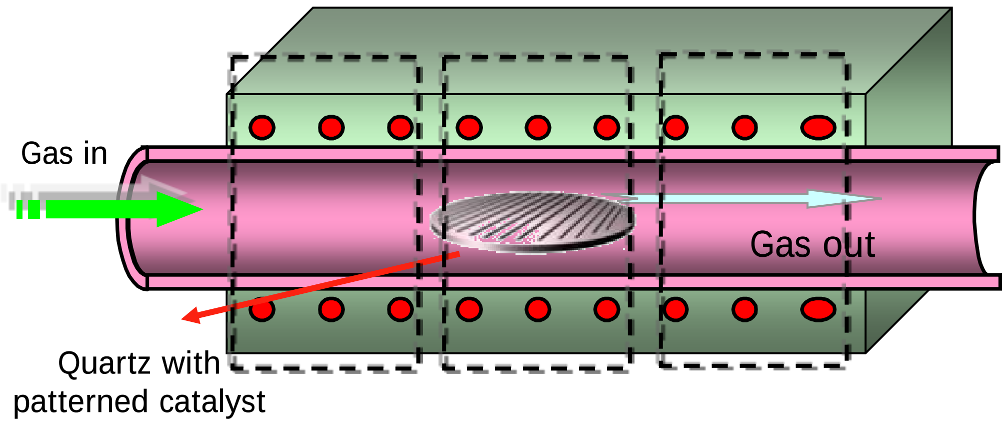
My innovation:

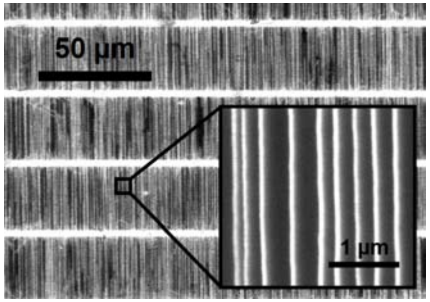
High performance carbon nanotube RF transistors and circuits

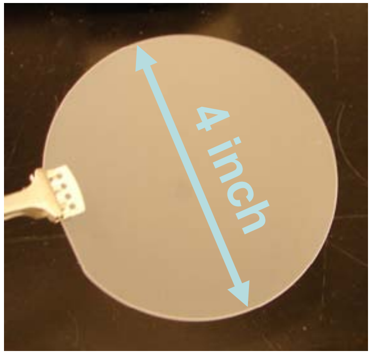
Synthesis of Predominantly Semiconducting Nanotubes

Use of isopropanol (IPA) as the carbon source

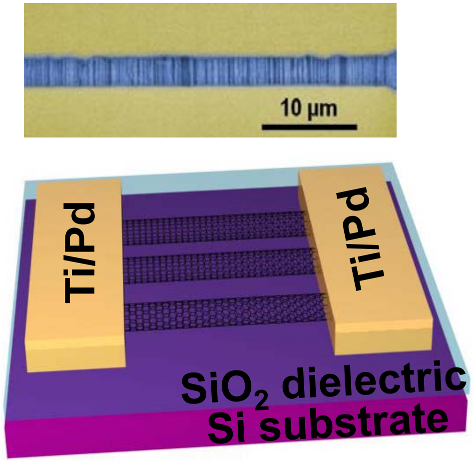
- 9 feet-long growth furnace with three-zone

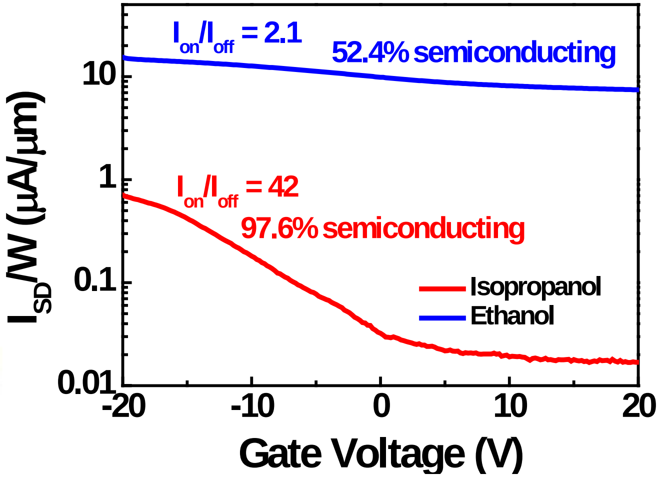






❑ High concentration of H_2O suppress of metallic CNT growth





Switch off ✓

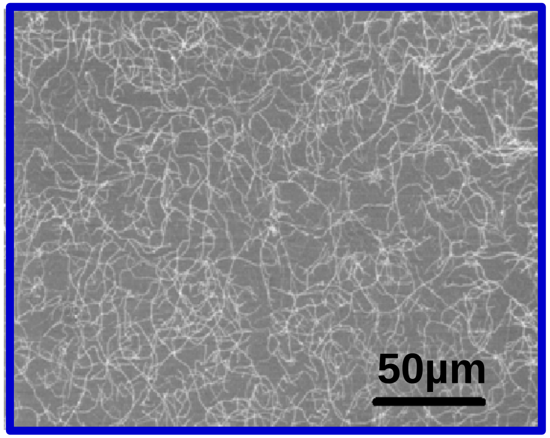
Semiconducting CNT purity:
IPA: ~97% (best device);
Ethanol: 52%

Yuchi Che, et al, ACS Nano, Vol.6,7454, 2012.

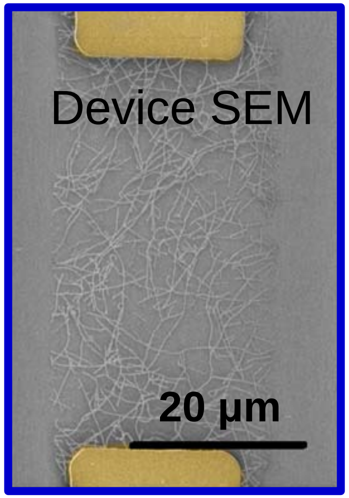
Application: Thin-film Electronics

- on/off=10^4 Mobility= 116 $cm^2/(V \cdot s)$

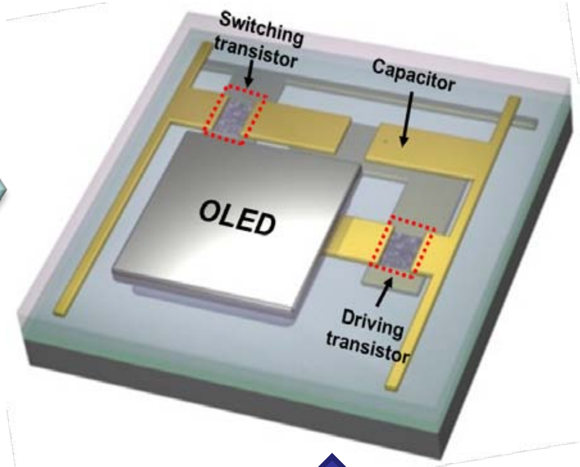
Thin film Macroelectronics (AMOLED)

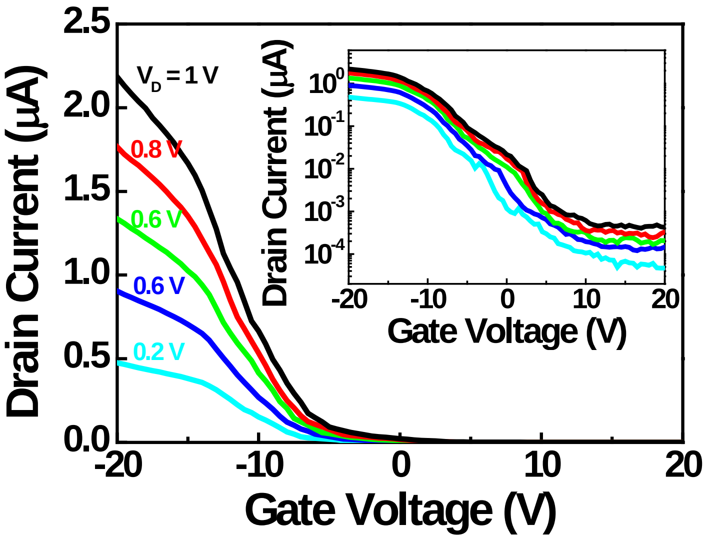


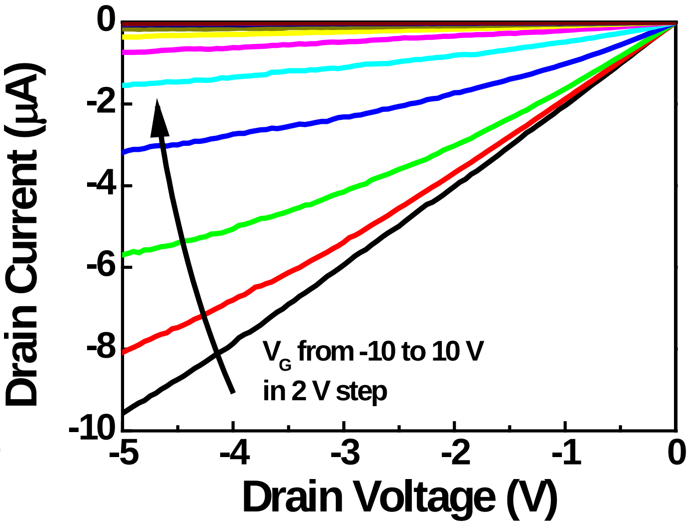
TFT



OLED





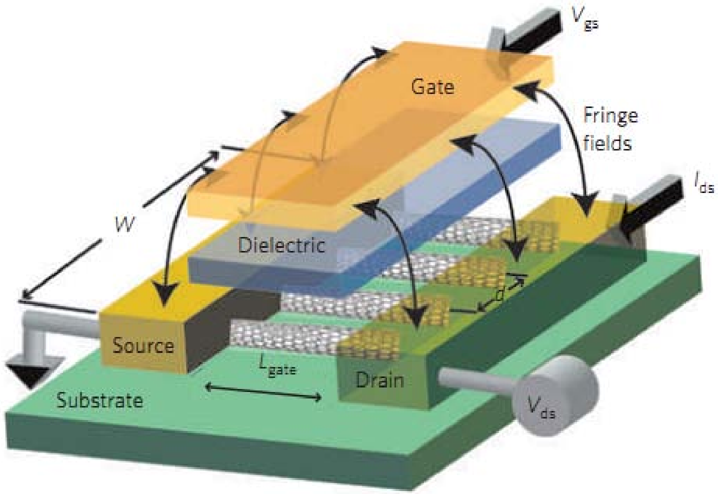


20 x 25 pixel array

Yuchi Che, et al, ACS Nano, Vol.6,7454, 2012.

Radio Frequency (RF) electronics

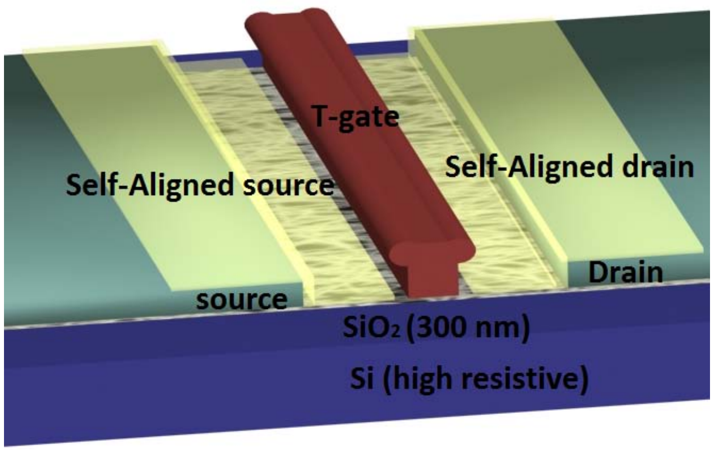
Previous design



- Misalignment
- Parasitic capacitance
- Low yield

Nature Nanotech, Vol 4, 2009

New design (T-gate)

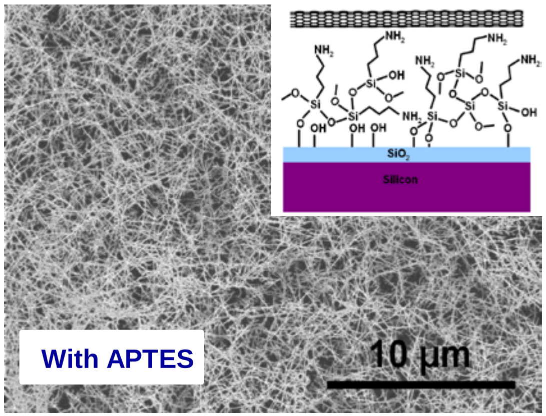


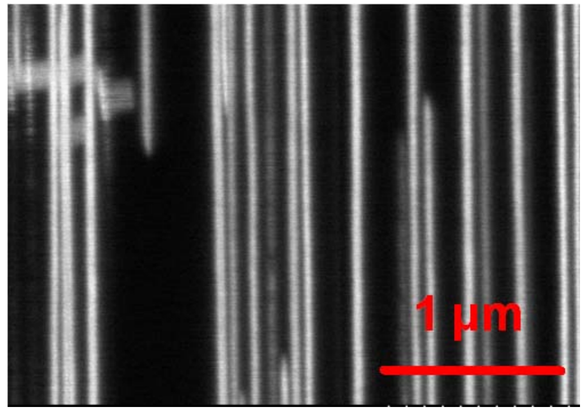
- Self-aligned technology ✓
- Reduce fringe capacitance ✓
- Reduce gate resistance ✓
- High yield ✓

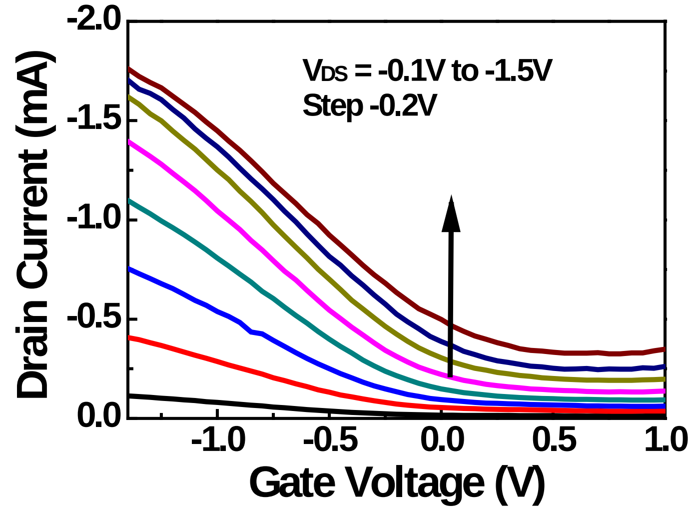
Yuchi Che, et al, ACS Nano, Vol.6,7454, 2012.

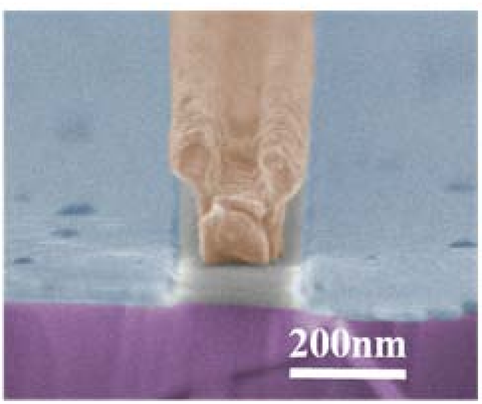
Carbon nanotube RF transistor

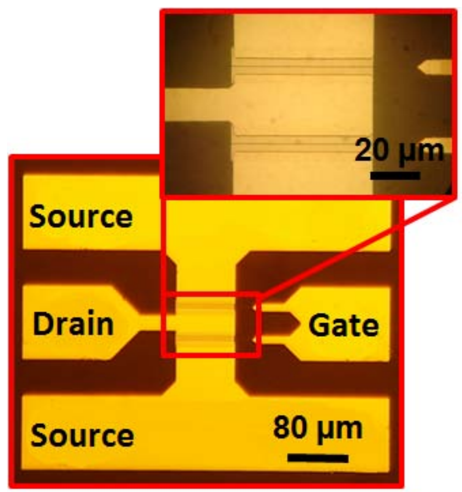
➢ **Wafer scale nanotube deposition**

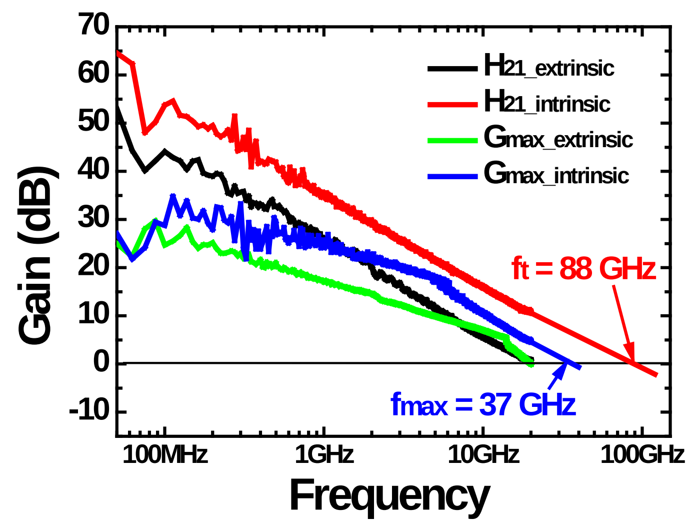










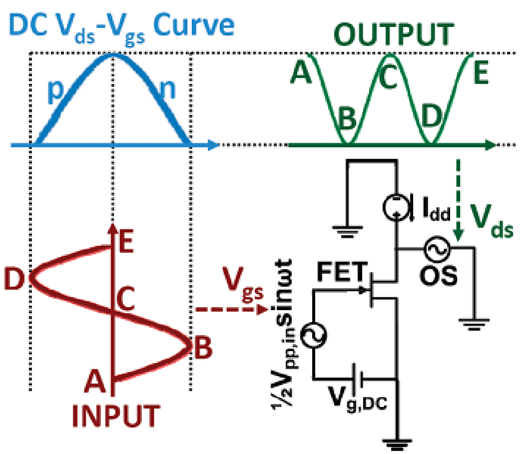


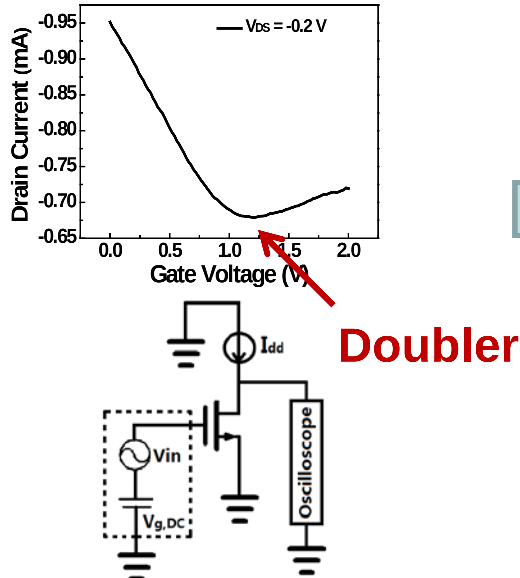
Cut-off frequency of 88 GHz and maximum Power Gain frequency of 37 GHz are achieved.

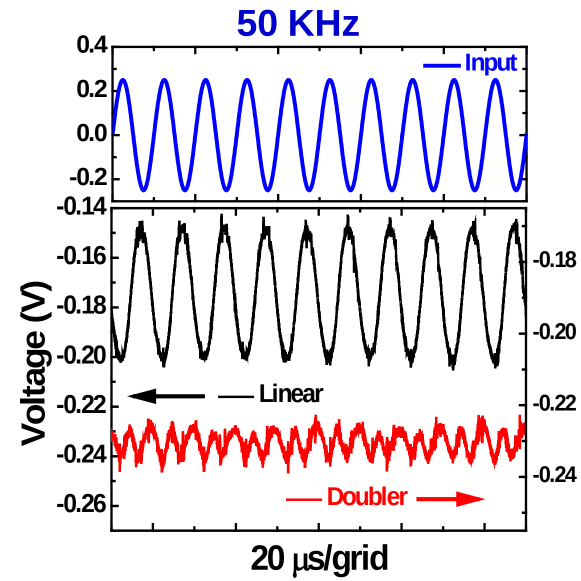
Yuchi Che, et al, ACS Nano, Vol.6,7454, 2012.

CNT-based RF Circuit

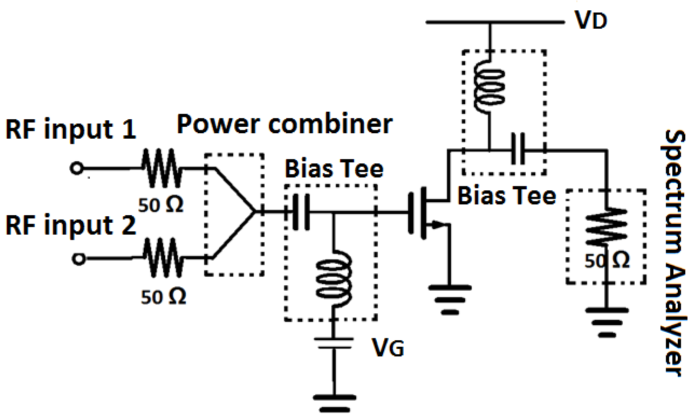
Frequency doubler: Offer a new degree of freedom in designing frequency multiplier chains

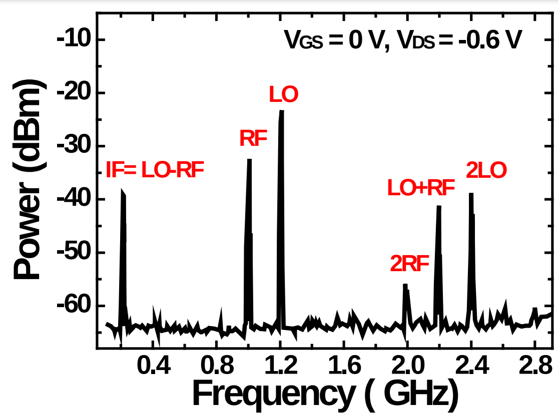






Mixer: Shift a signal from one frequency to another, keeping the properties of the initial signal.



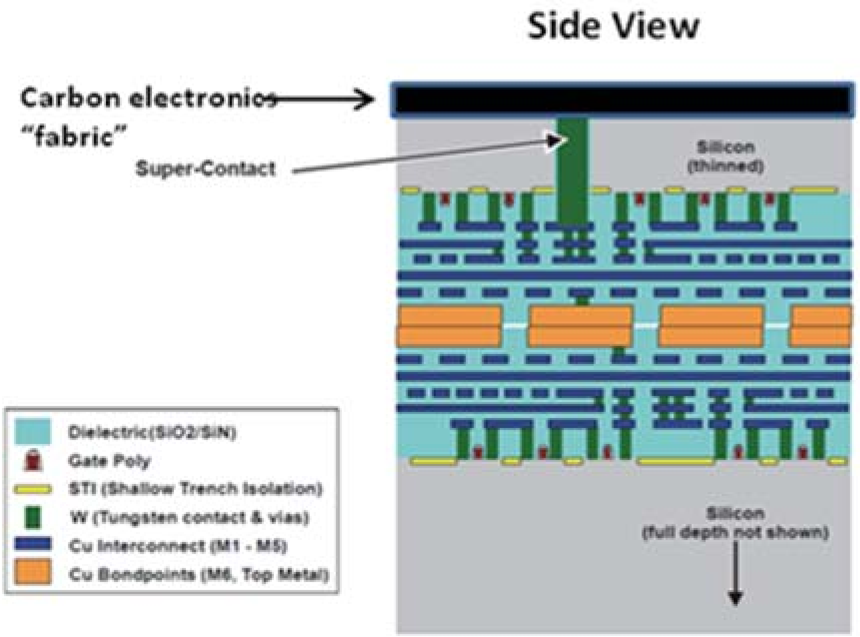


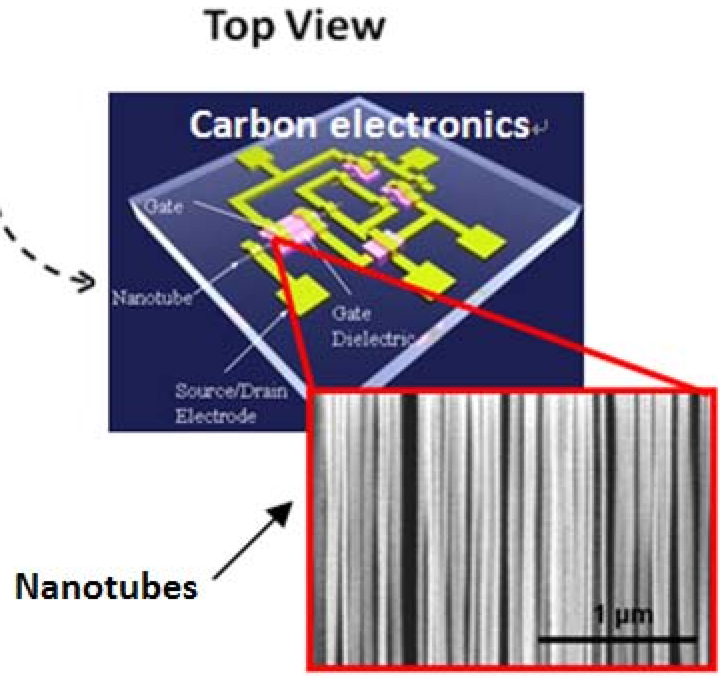
RF: 1 GHz
LO: 1.2 GHz
IF: 0.2 GHz

Conversion gain:
-24.5 dB

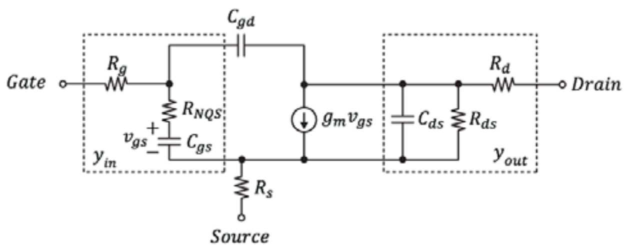
Yuchi Che, et al, ACS Nano, Vol.7, 4343, 2013.

Future plan: Hybrid circuit

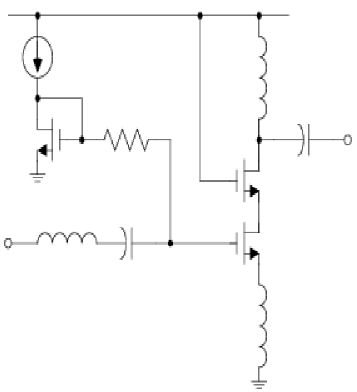




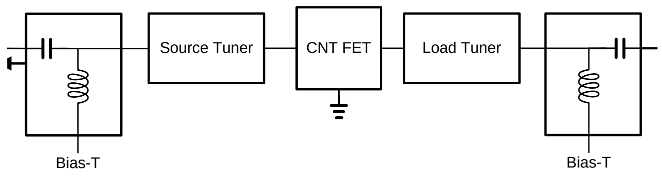
Small signal model



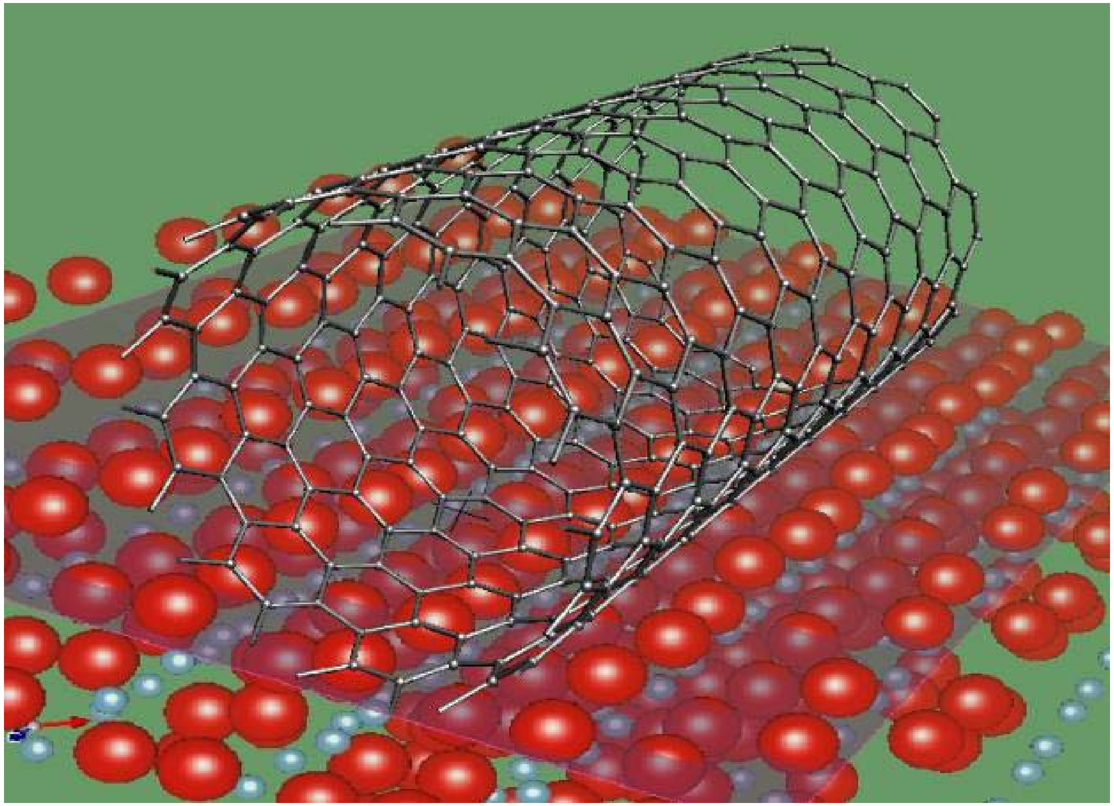
Low noise amplifier



CNTFET integrated with matching network



THANK YOU !



http://nanolab.usc.edu/