Carbon Nanotubes and Semiconductor Nanowires as Electron Field Emitters

Jun Jiao

Physics Department

Portland State University

Portland, OR 97207

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Introduction

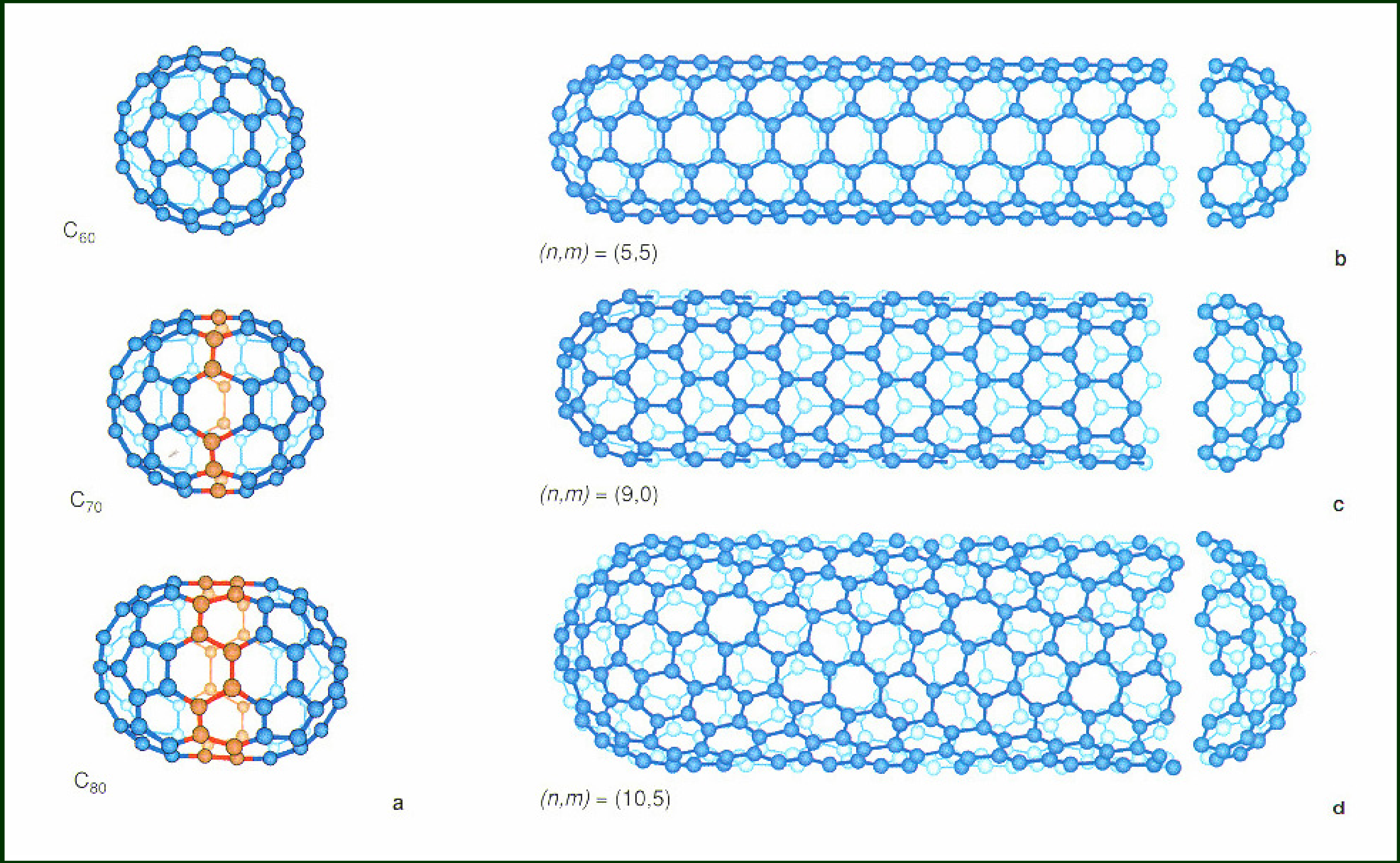
- Nanotubes and nanowires, one-dimensional nanostructures, have shown great potential for nanoscaled electronic and optoelectronic devices.

- Because of the difficulties of fabricating these nanoscale materials with controlled structural configurations, the realization of their technological promises is still a distant goal.

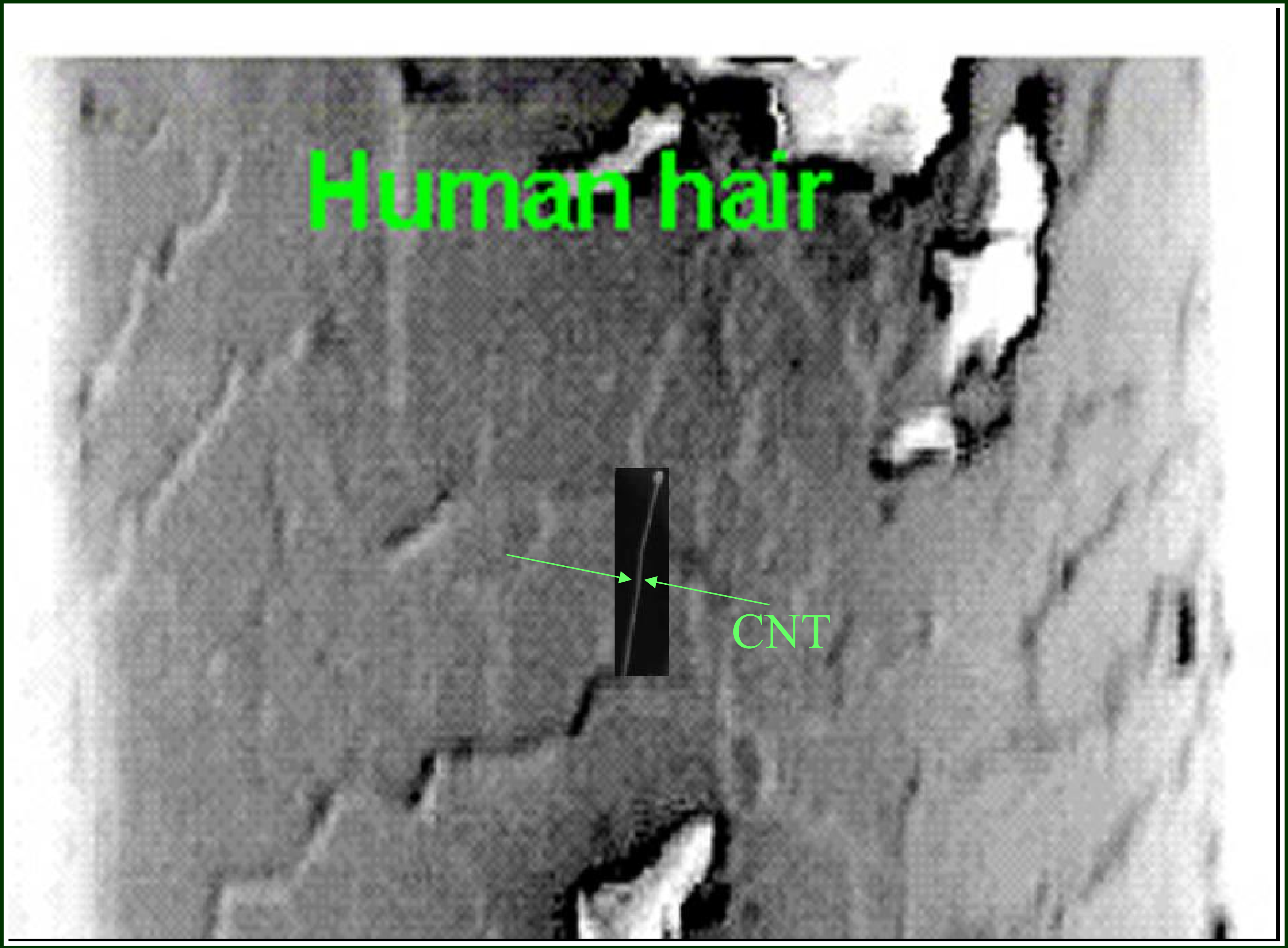
- The research presented here is aimed at tailoring nanotubes and nanowires to designed specifications by systematically investigating the effects of preparation parameters, and to develop reliable nanofabrication techniques.

- The research effort also includes the study of electron field emission properties of these nanostrucures, as we strive to develop a new generation of electron field emitters.

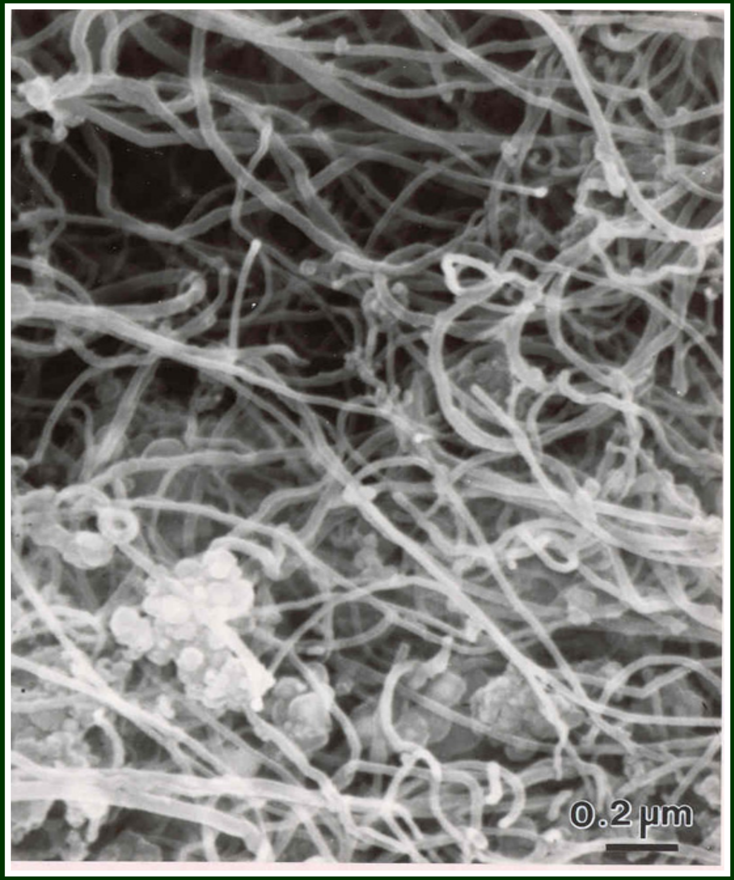
Chirality of Carbon Nanotubes vs Electronic Properties



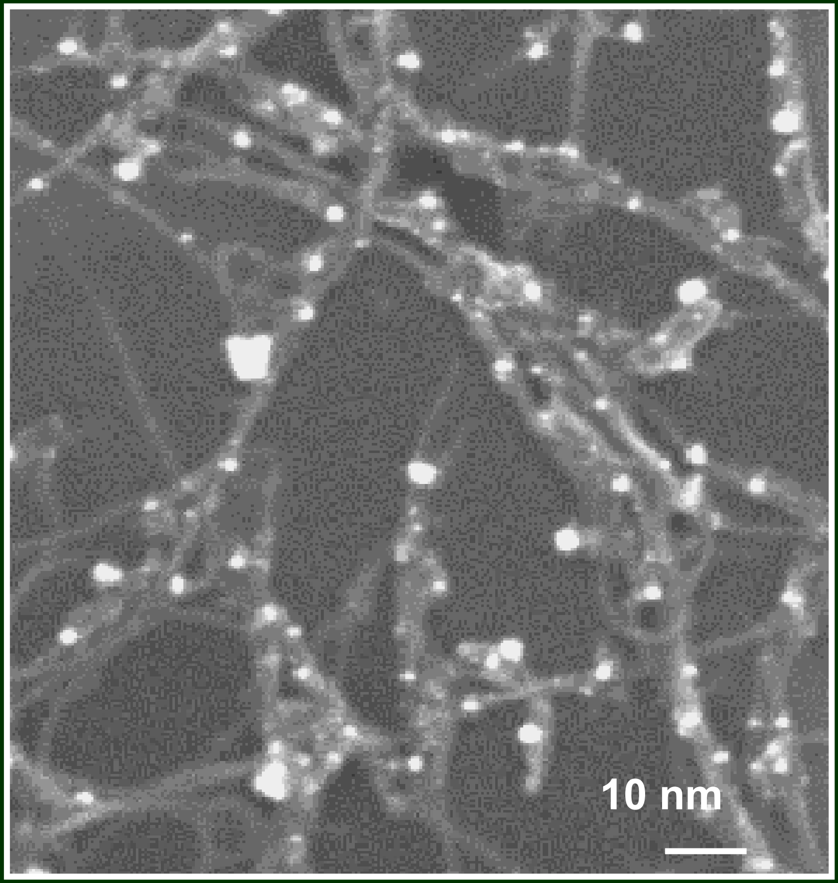
A Human Hair vs a Carbon Nanotube



FESEM Overview of the Morphologies of Carbon Nanotubes

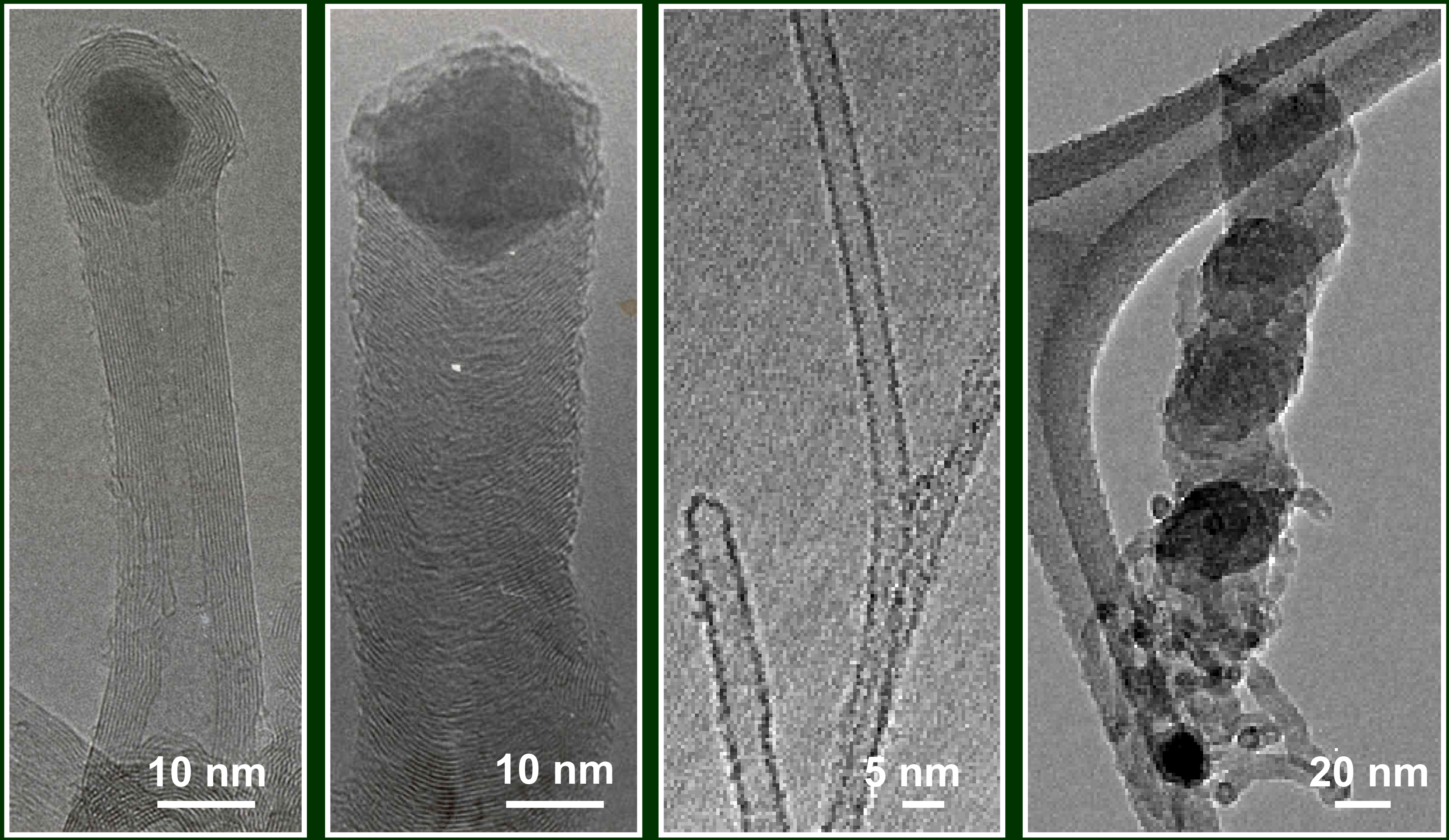


Multi-walled nanotubes

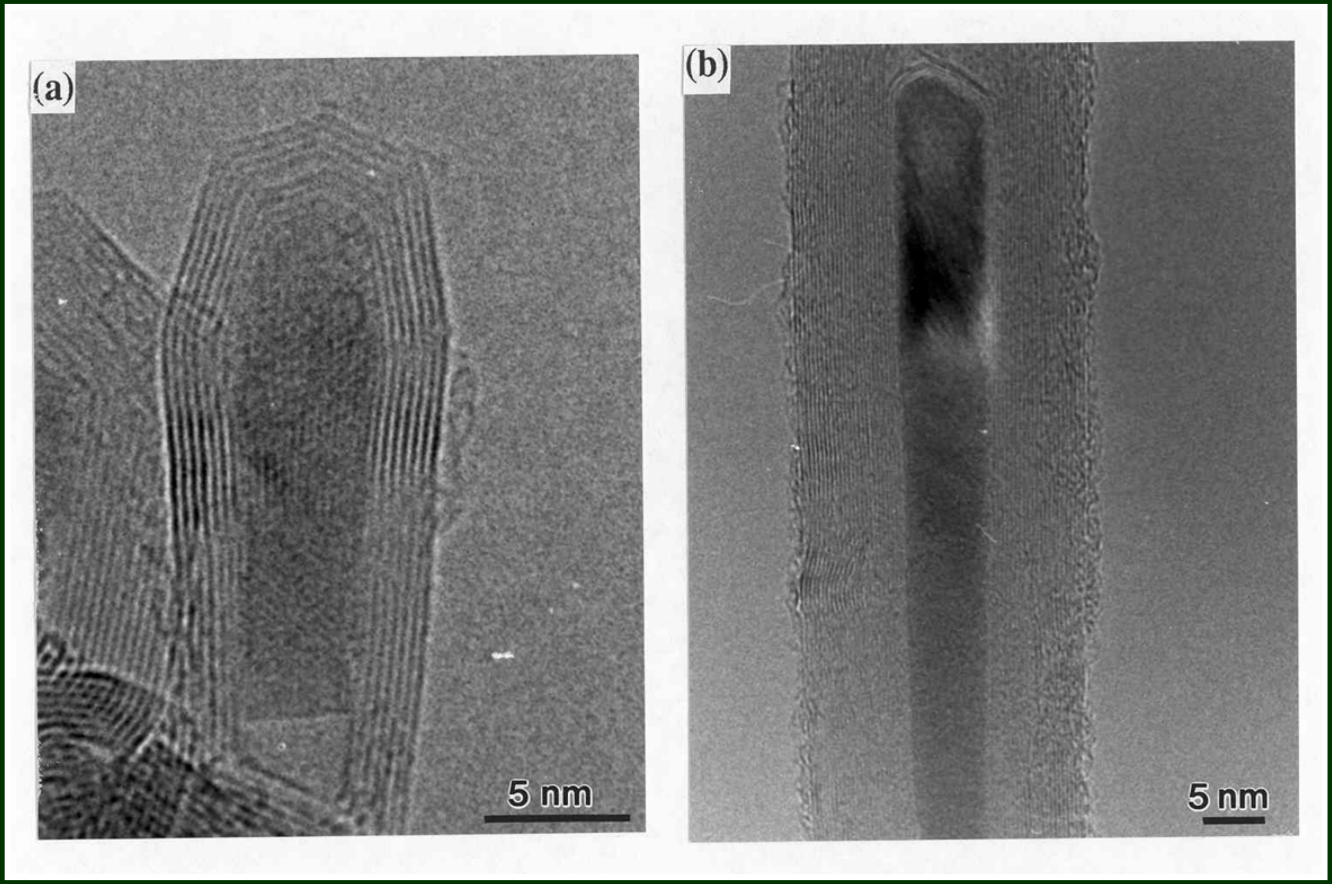


Single-walled nanotubes

Carbon Nanotubes of Different Internal Structures



Filling Nanotubes with Foreign Materials



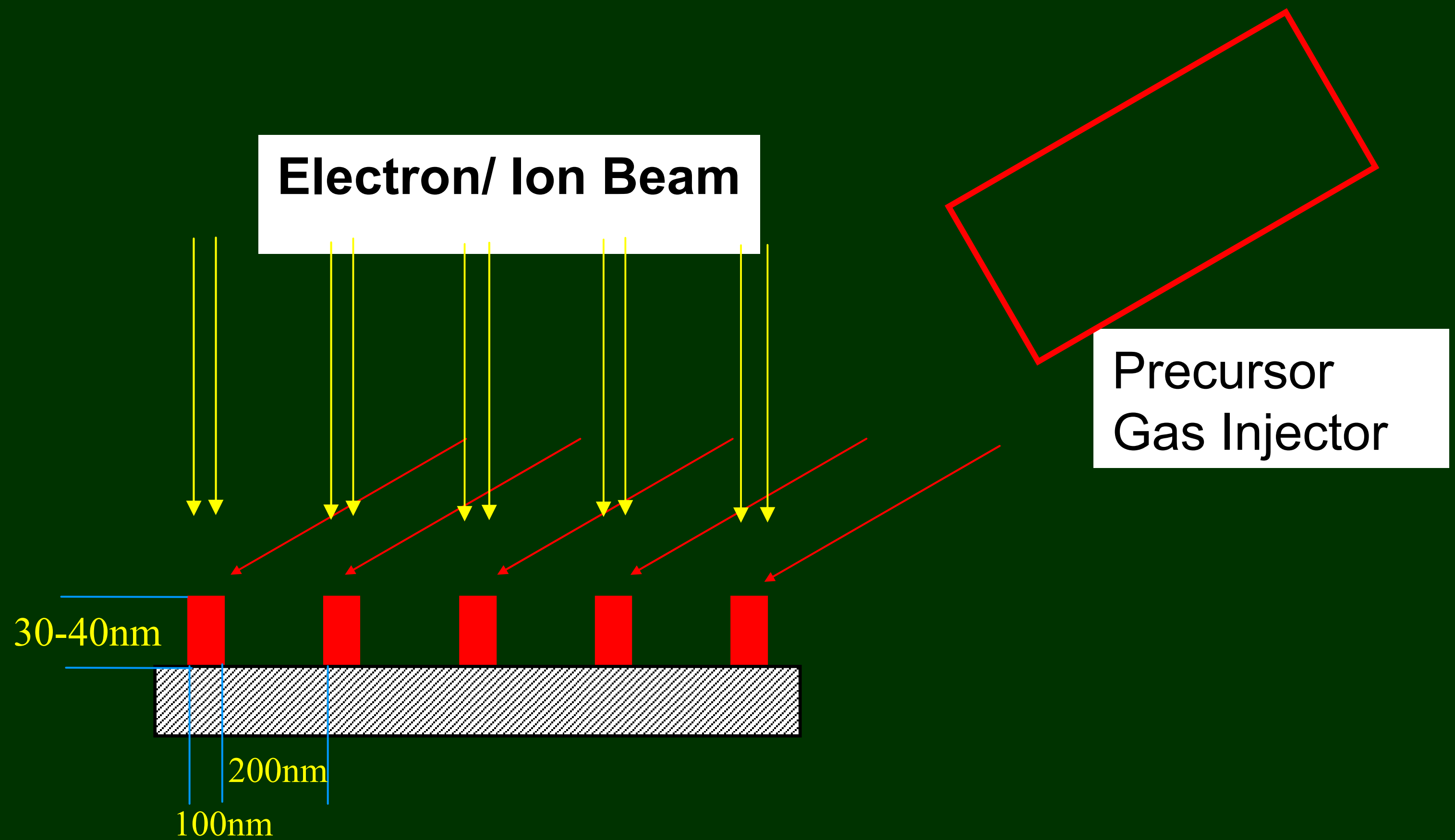
What are the Challenges in Making Field Emitters from Carbon Nanotubes and Nanowires?

- The lack of techniques for producing carbon nanotubes (CNTs) and nanowires with controlled properties has been widely acknowledged as the primary hurdle for the development of nanotube-nanowire-based electronic technologies.

- The fabrication of nanotube and nanowire emitters is hampered by the lack of methods to directly position these nanostructures on the designed substrates.

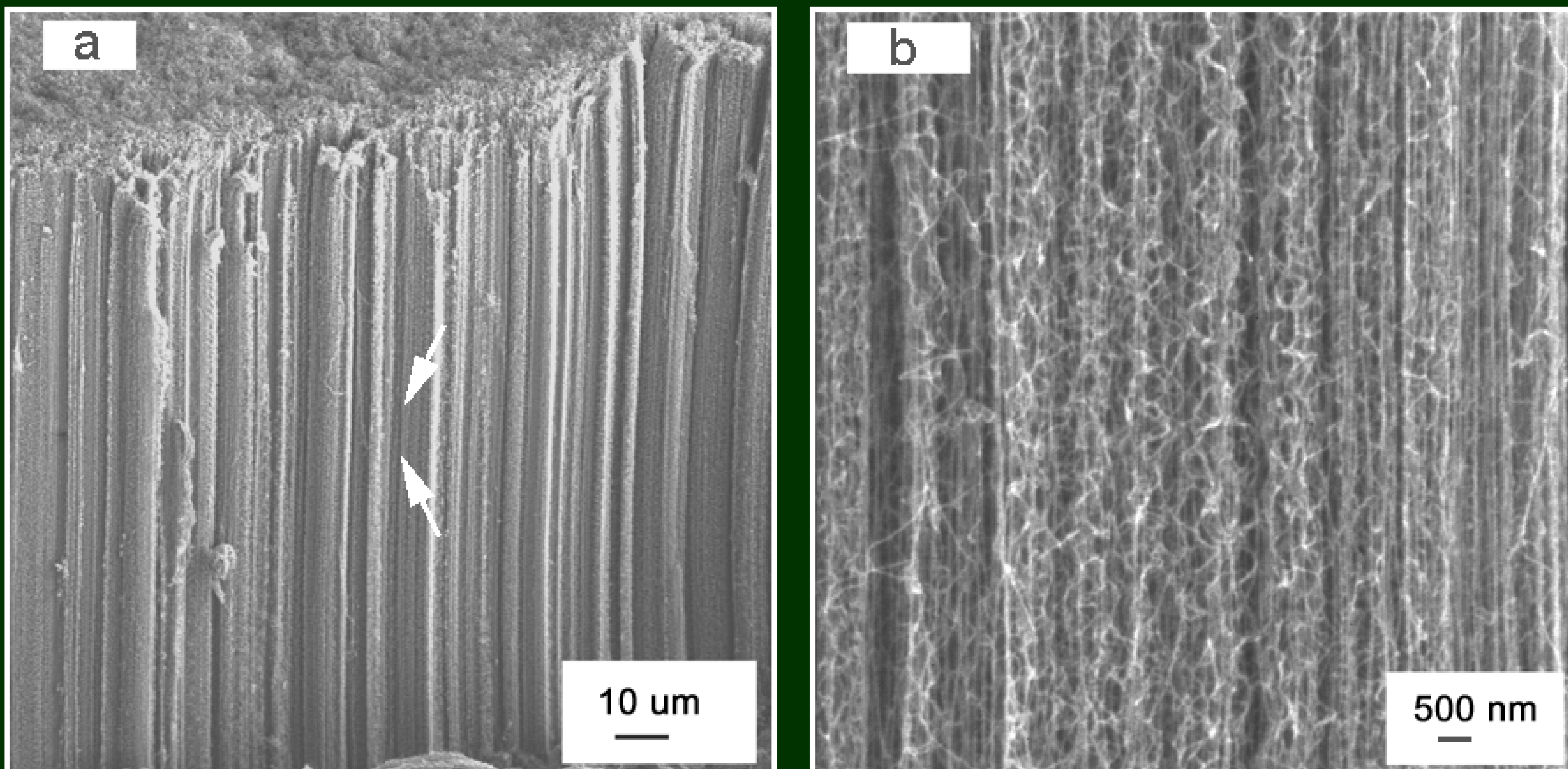
- The field-emission properties of nanotubes and nanowires, as a function of the configuration and composition of the emitters, are not systematically characterized. The emission mechanism of the emitters in relation to the emission environment is not well understood.

Ion / Electron Beam Induced Catalyst Deposition

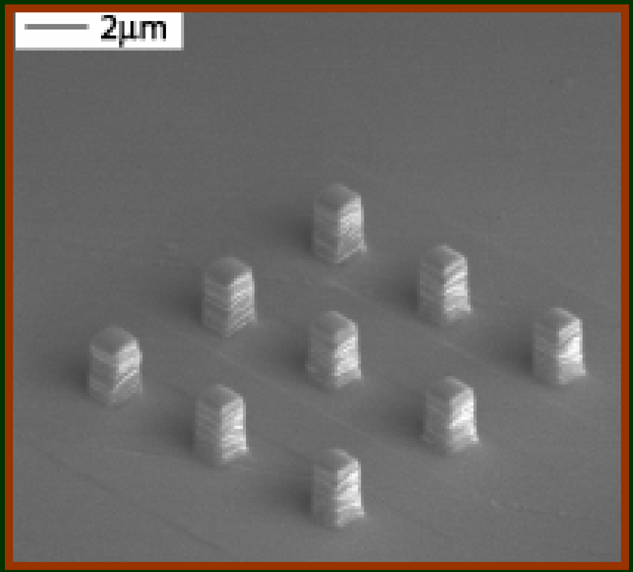


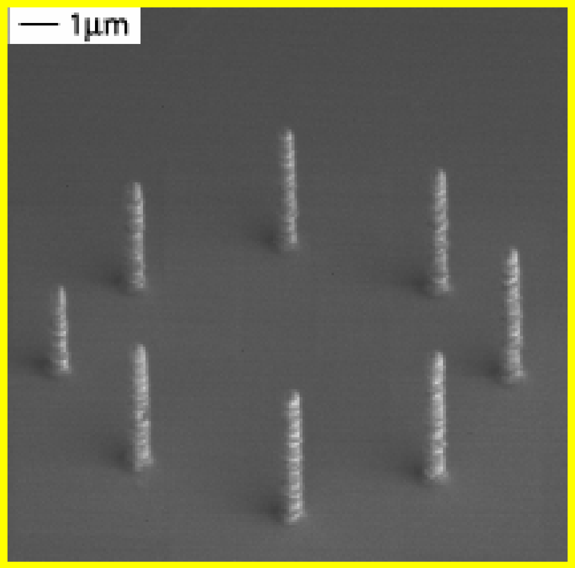
Precursor Gas: $W(CO)_6$, $C_7H_7F_6O_2Au$, $AlH_3N(CH_3)_3$, $(CH_3)_3Al$, $C_7H_{17}Pt$

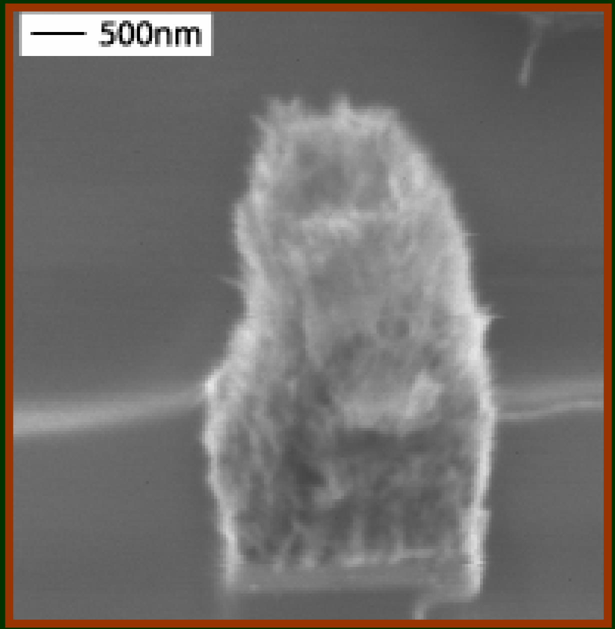
Vertically Aligned Carbon Nanotubes

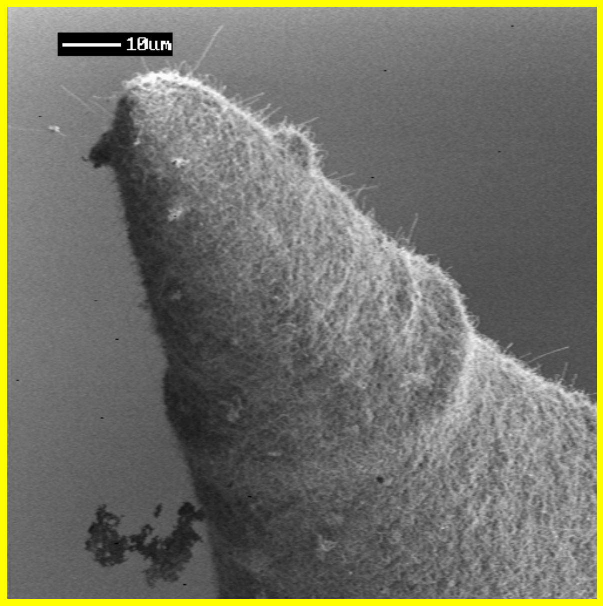


Position Controlled Growth of Carbon Nanotubes

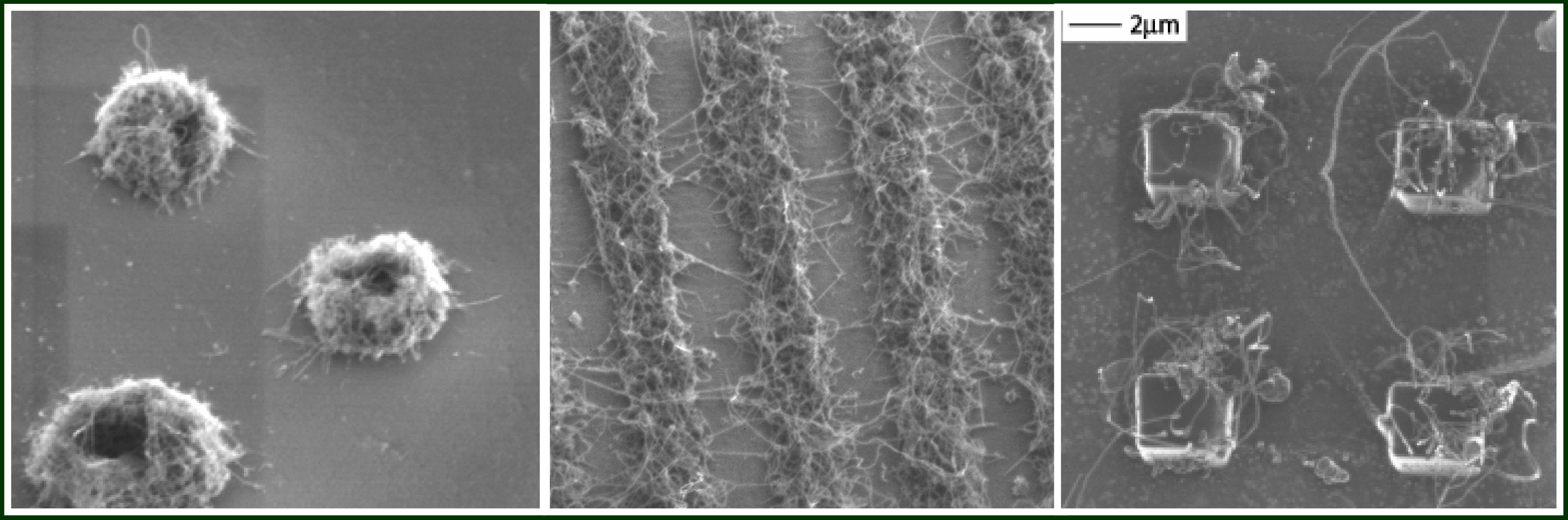




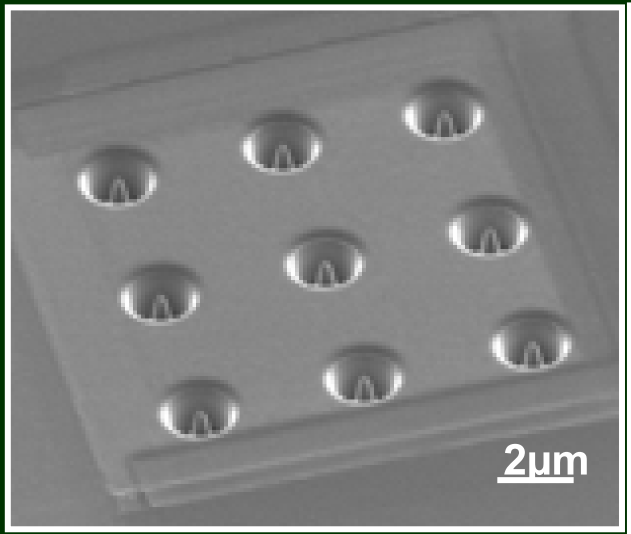




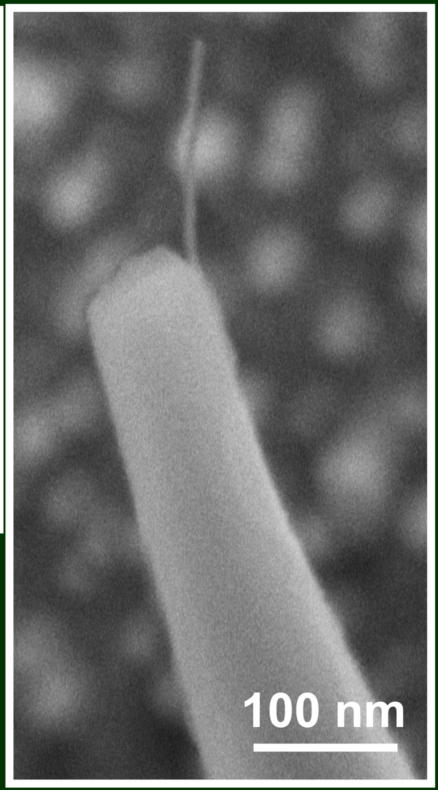
Position Controlled Growth of Carbon Nanotubes

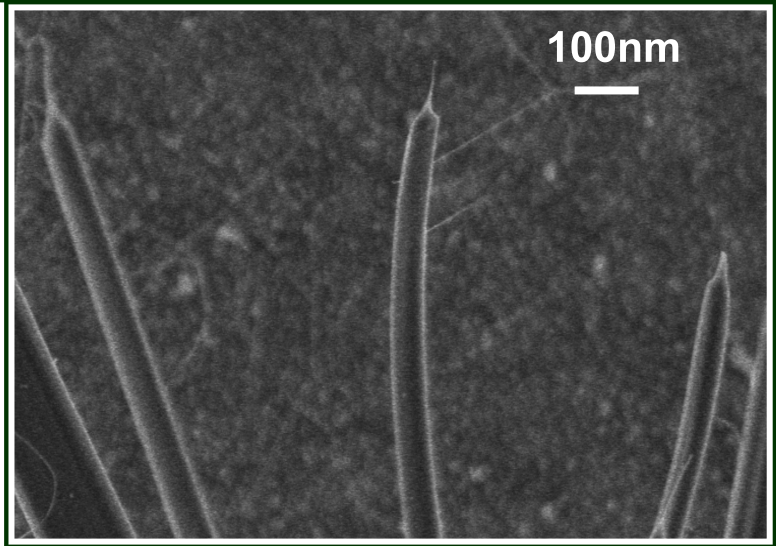


Nanotube and Nanowire Electron Field Emitter Arrays



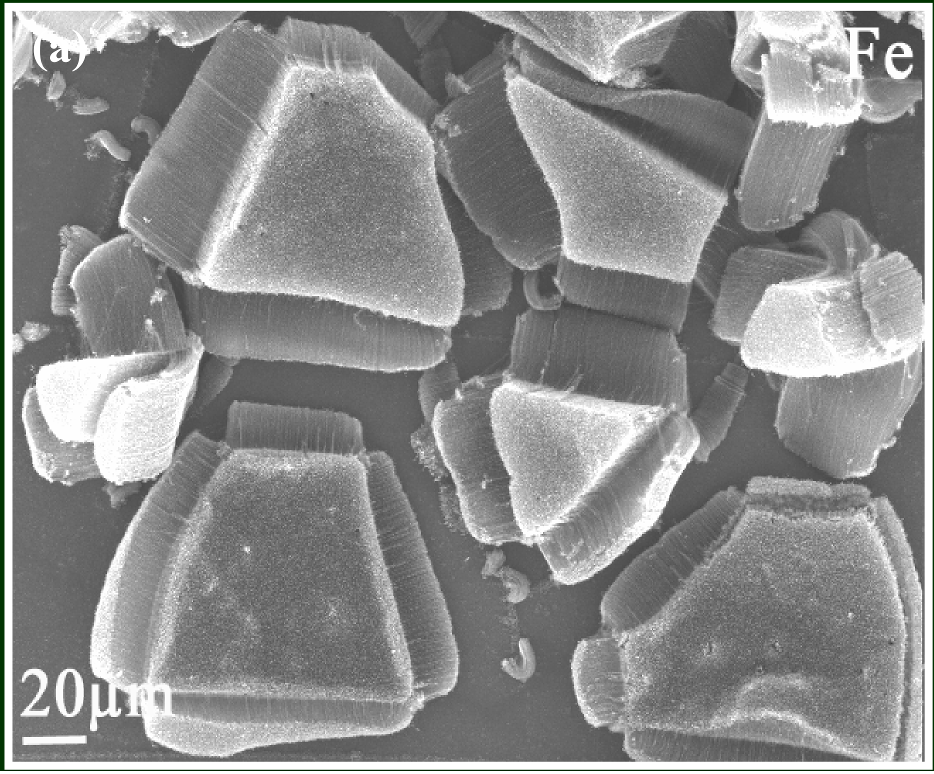
Nanoemitter arrays fabricated by FIB

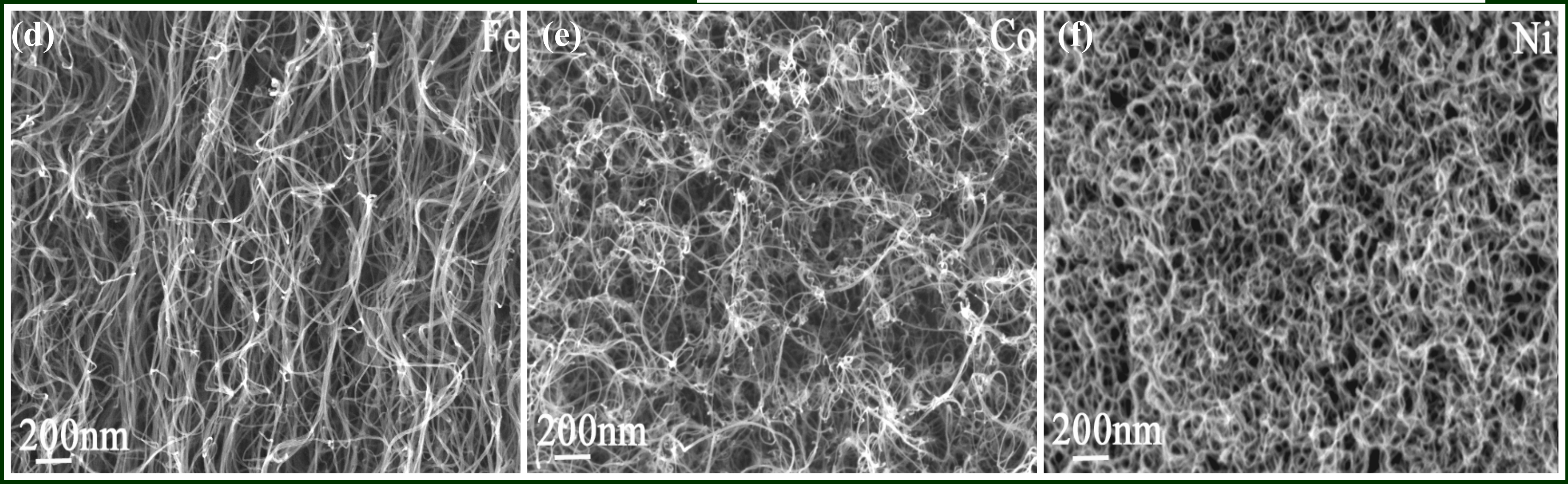




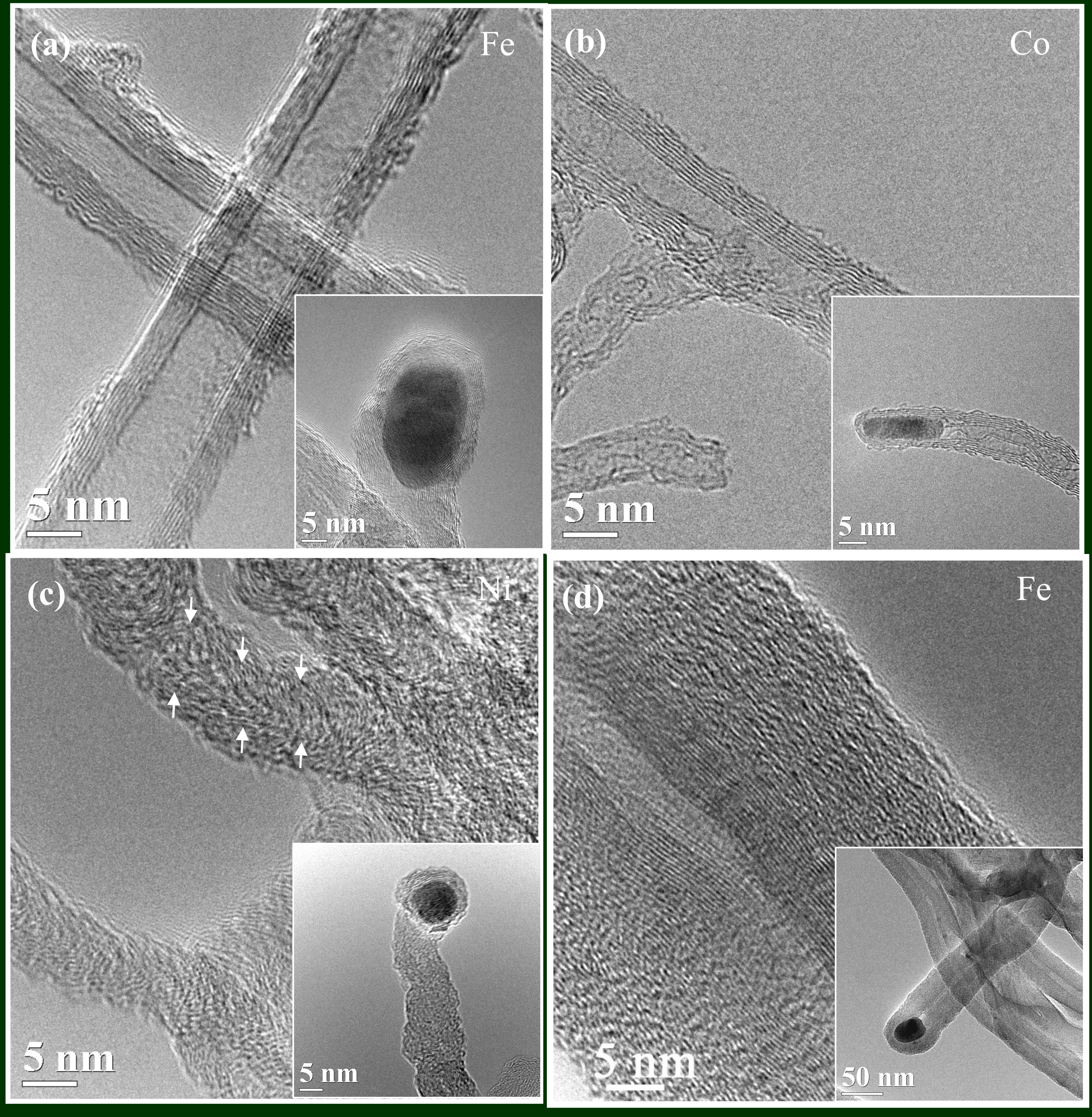
SiO_2 nanowire emitters

Carbon Nanotube Thin Films Catalyzed by Fe, Co, and Ni

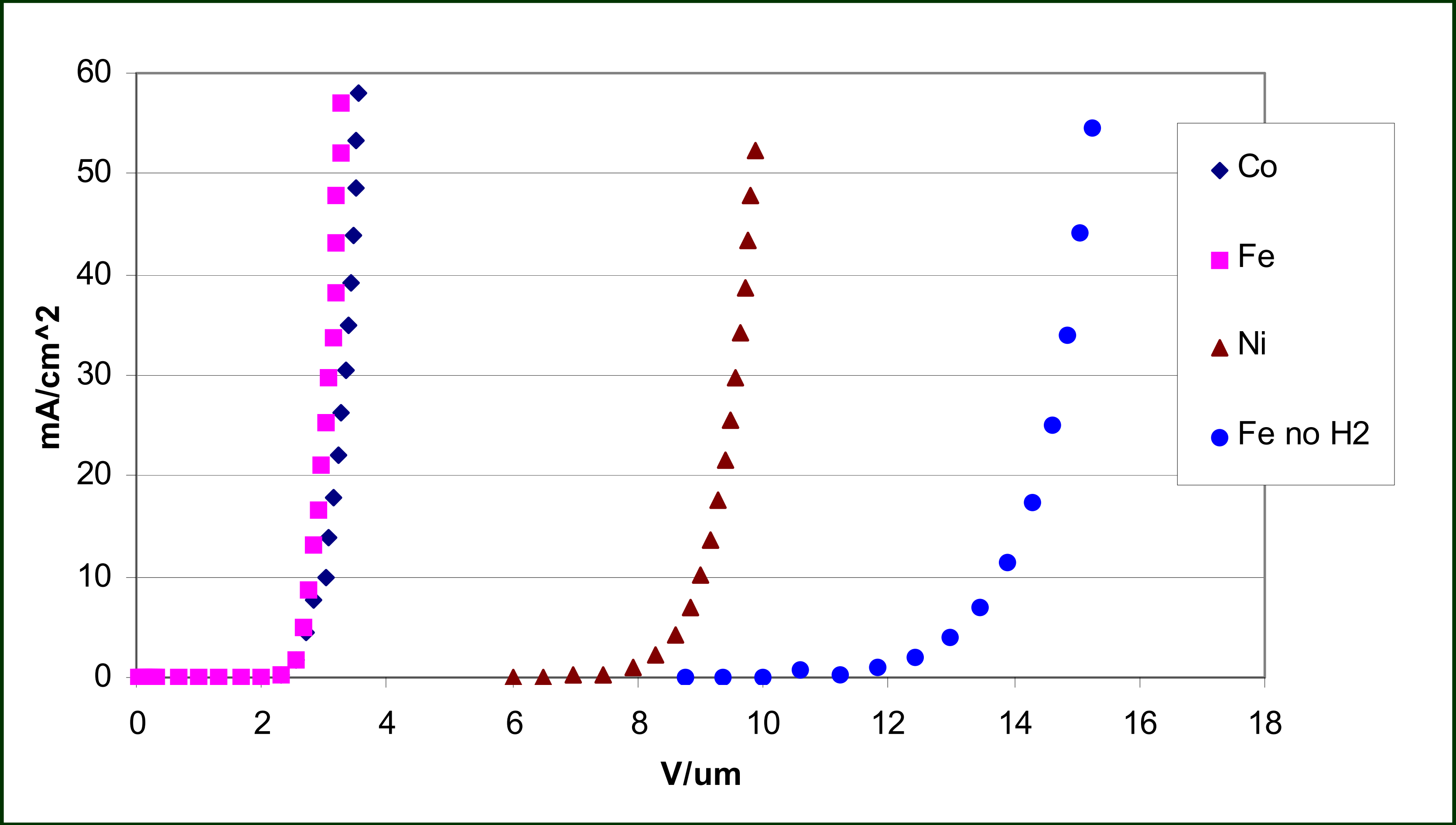




Internal Structures of Carbon Nanotubes Synthesized from Different Catalysts



I-V Characteristics of Various Carbon Nanotubes Synthesized from Different Catalysts

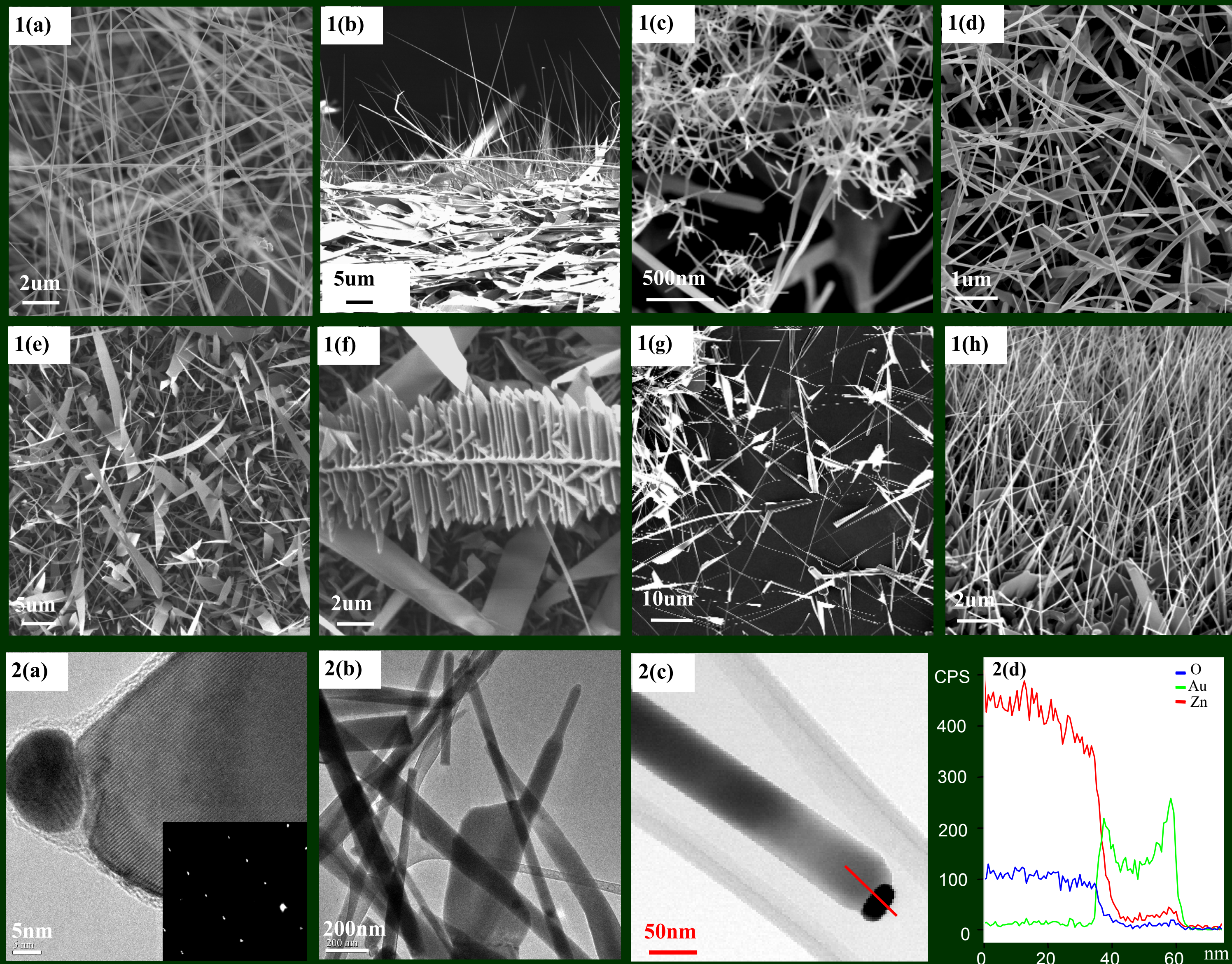


Turn-on Field, Threshold Field and Enhancement Factor for Nanotubes from Different Catalysts (Fe, Co and Ni)

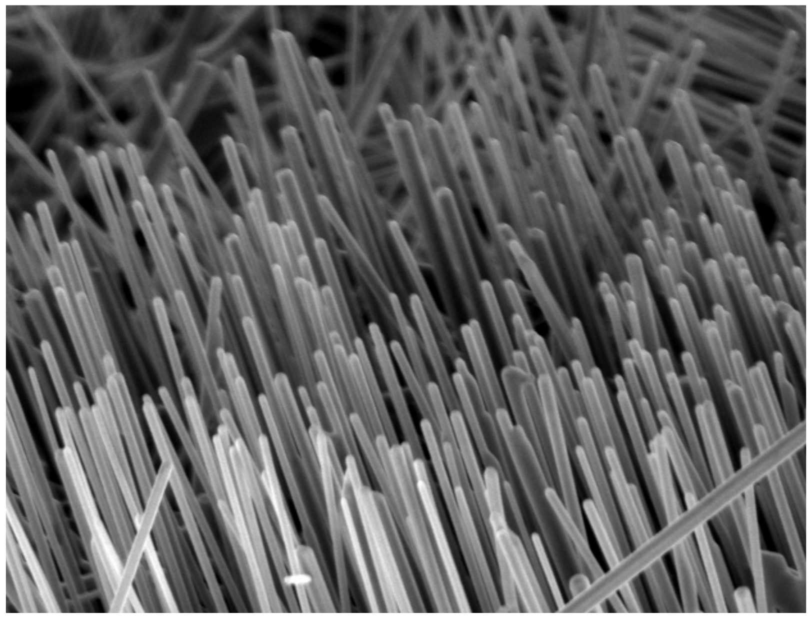
Type of nanotubes	Turn-on field V/µm	Threshold field V/µm	Enhancement factor
Nanotubes from Fe	~0.35	2.8	2300
Nanotubes from Co	~0.4	3	2600
Nanotubes from Ni	5	9	1500
Nanotubes from Fe without H_2	9.1	14	700

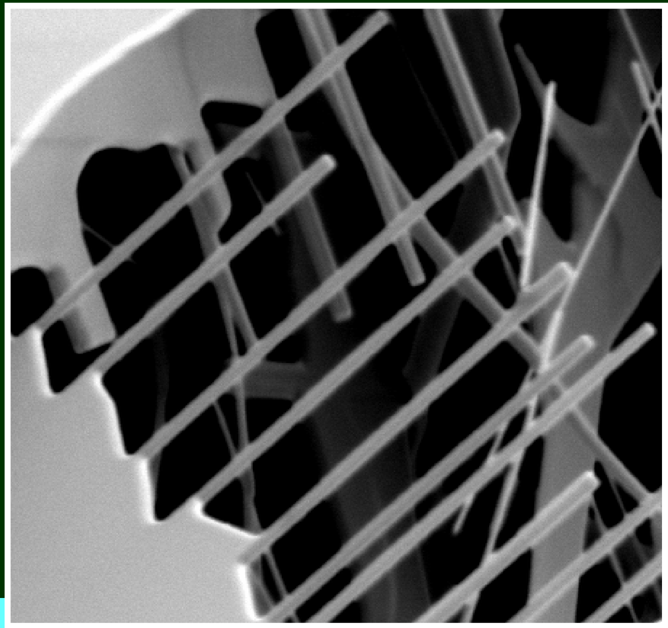
The turn-on field and threshold field of a film emitter are defined as the macroscopic external field needed to extract a current density of 10 $\mu A/cm^2$ and 10 mA/cm^2, respectively.

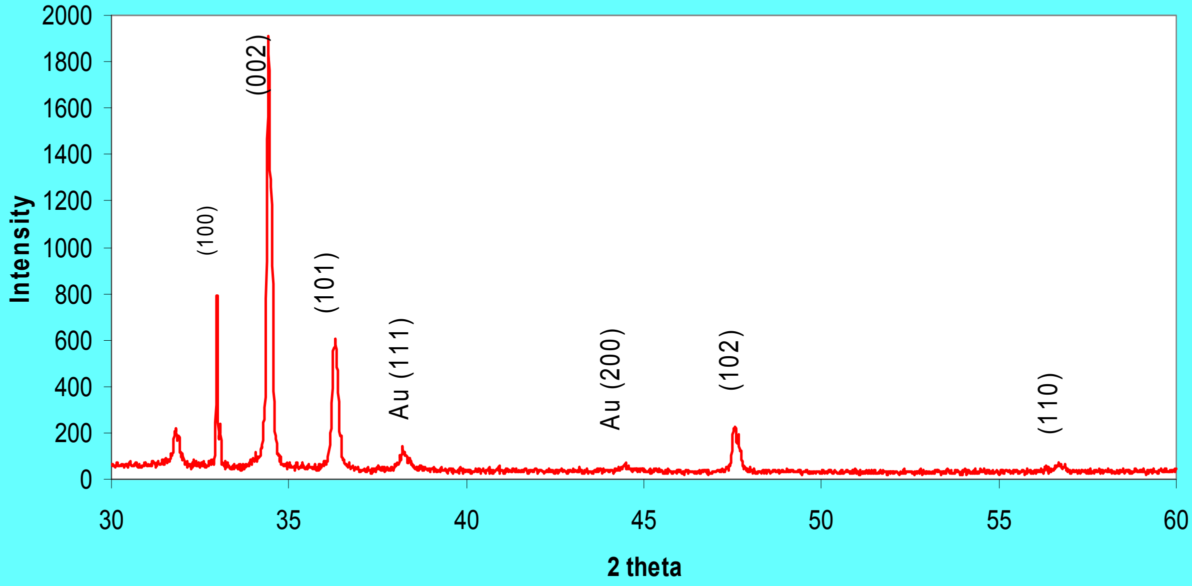
Effect of Catalysts on the Formation of ZnO Nanowires



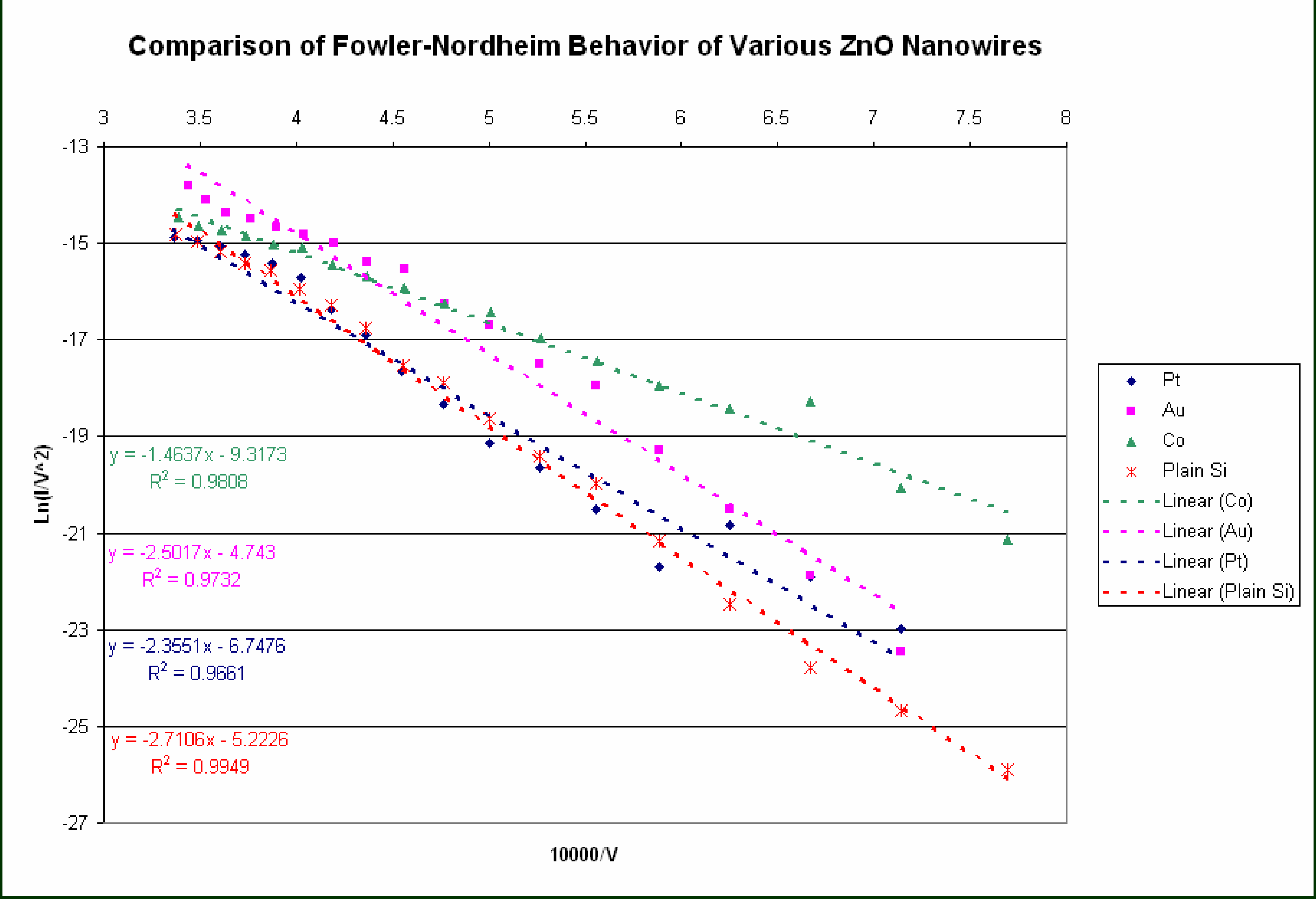
ZnO Nanowires grown on silicon substrate







The X-ray diffraction peaks of ZnO nanowire sample can be indexed to a hexagonal phase.



Comparison of Fowler-Nordheim Behavior of Various ZnO Nanowires
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
-13
-15
-17
-19
-21
-23
-25
-27
Ln(I/V^2)
10000/V
y = -1.4637x - 9.3173
R2 = 0.9808
y = -2.5017x - 4.743
R2 = 0.9732
y = -2.3551x - 6.7476
R2 = 0.9661
y = -2.7106x - 5.2226
R2 = 0.9949
Pt
Au
Co
Plain Si
Linear (Co)
Linear (Au)
Linear (Pt)
Linear (Plain Si)

Field Emission Comparison of Different ZnO Nanowires

Nanowire Growth Method	Turn-On Field (V/μm)	Threshold Field (V/μm)	Enhancement Factor
Pt Catalyst	9.3	14.4	530
Au Catalyst	9.5	13.1	670
Co Catalyst	6.8	12.5	850
Plain Si	8.5	12.2	540

Conclusion

- In this report, we demonstrate the challenges and progress of the preparation and characterization of carbon nanotubes and nanowires of designed specifications.

- The results suggest that the effect of the catalysts and substrates have to be taken into consideration when using the CVD and thermal evaporation methods for the growth of nanotubes and nanowires.

- The temperature distribution in the reaction chamber (furnace) has an impact on the nucleation of nanowires of different morphology and composition.

- The electron field emission of the carbon nanotubes and ZnO nanowires was significantly affected by the morphologies of the nanostructures.

- Both carbon nanotubes and ZnO nanowires are promising nanoemitter candidates.

Acknowledgements

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