

Nanoparticle Technology

Lecture 05: 1-D Nanostructures Fabrication

Lecture 05: table of contents

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Introduction to 1-D nanostructures fabrication

2

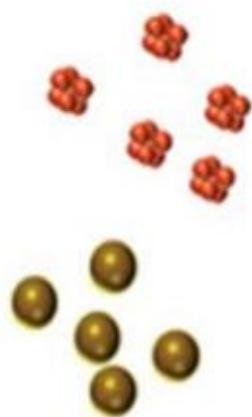
Fabrication methods and case study

Introduction to 1-D nanostructures fabrication

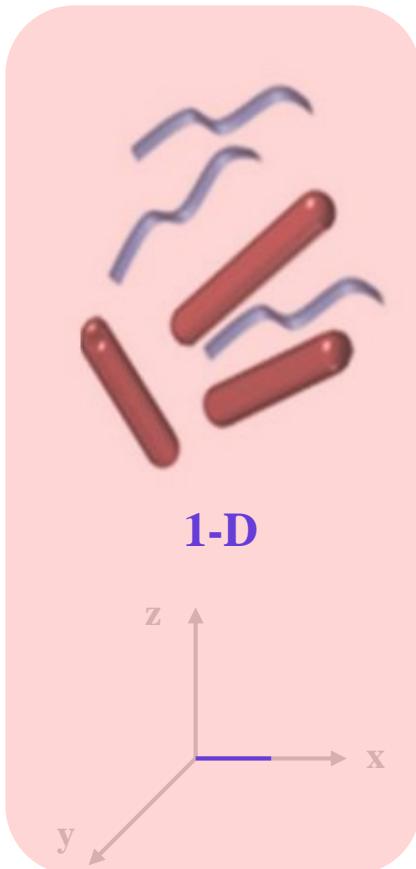
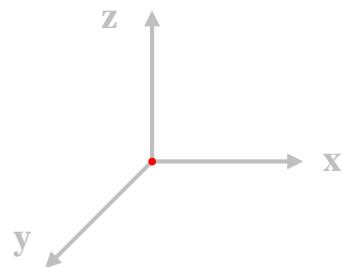
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Classification of nanomaterials

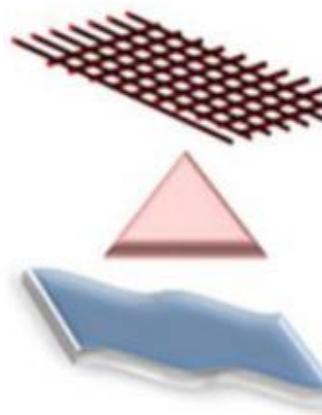
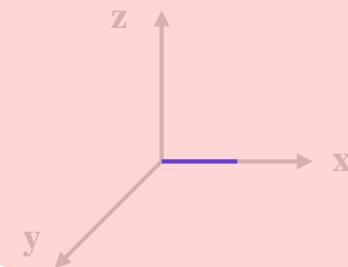
Dimensional classification



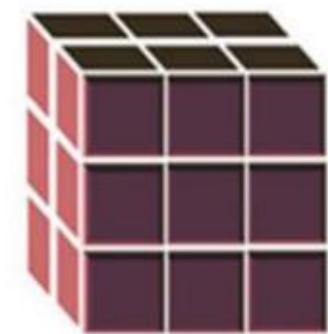
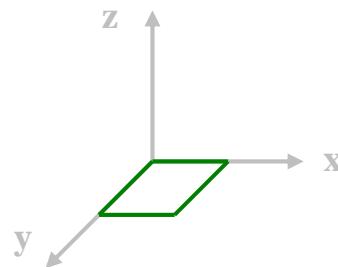
0-D



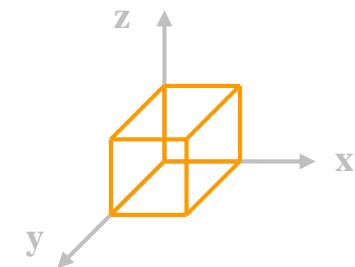
1-D



2-D



3-D

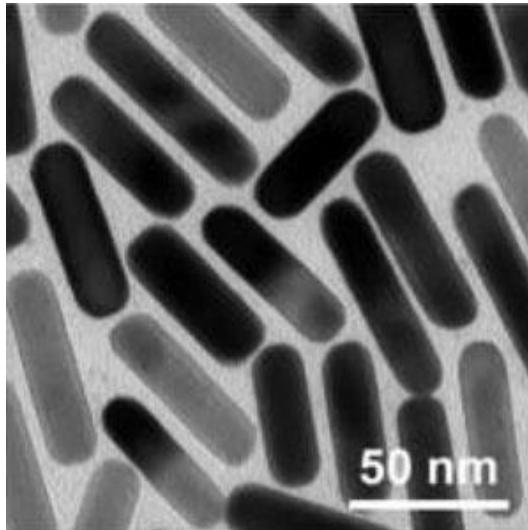


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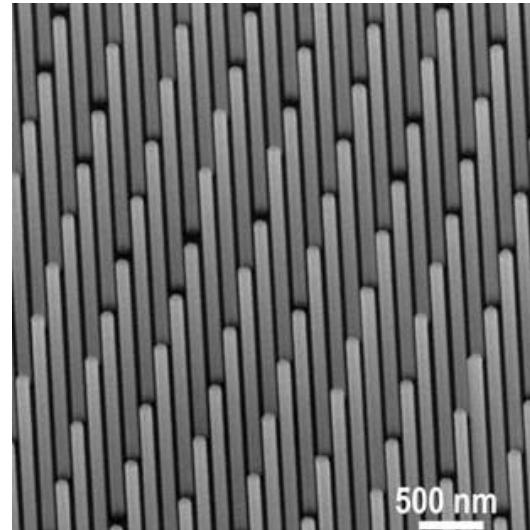
Classification of nanomaterials

One-dimensional (1-D) structures

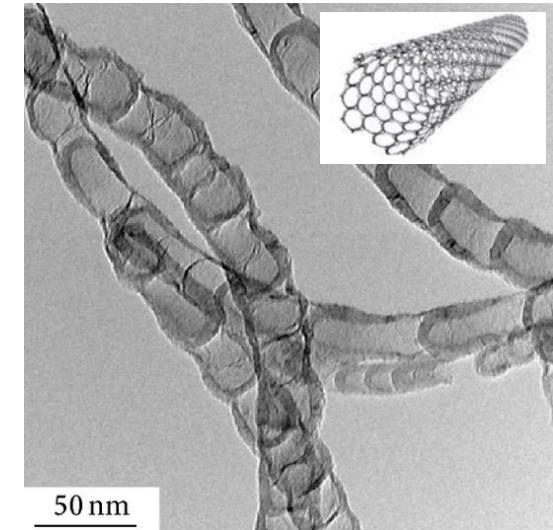
- Nanorods -



- Nanowires -



- Nanotubes -



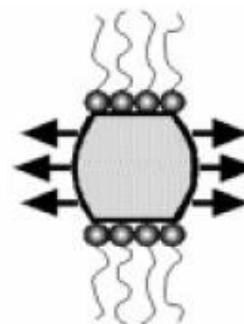
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Strategies to fabricate 1-D nanostructures

Spontaneous anisotropic crystal structures



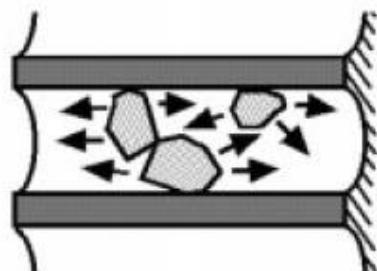
Kinetic control by organic surfactants



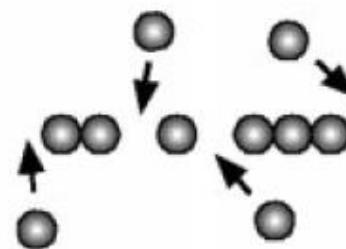
Seed-initiated growth



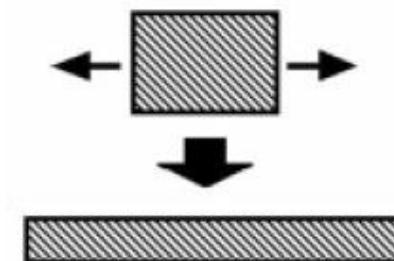
Templating



Self-assembly



Size reduction

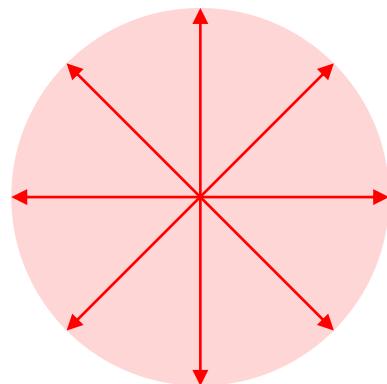


Fabrication methods and case study

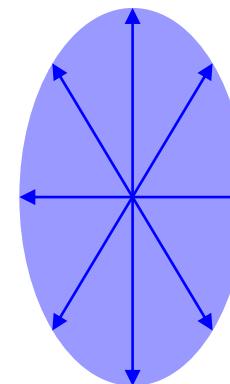
1. Spontaneous anisotropic crystal structures

Isotropic vs. Anisotropic

Isotropic



Anisotropic



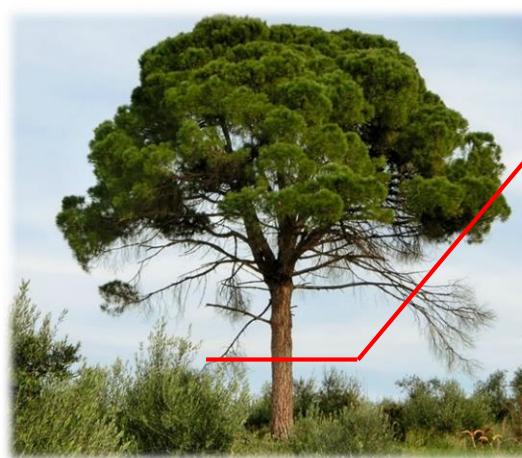
Isotropic: the properties of a material are the same in all directions.

Anisotropic: the properties of a material vary with different crystallographic orientations.

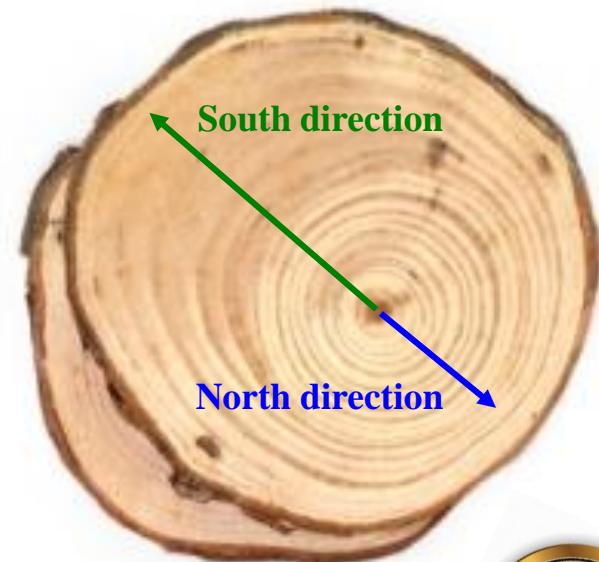
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1. Spontaneous anisotropic crystal structures

Example of anisotropic growth in nature



Anisotropic growth ring of tree



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1. Spontaneous anisotropic crystal structures

Unique crystal structure of chalcogens

Periodic Table of the Elements																			
Atomic Number	Symbol	Name	Atomic Mass	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	H	Hydrogen	1.008	Li	Li	Magnesium	24.305	Na	Magnesium	Magnesium	Oxygen	16.000	Ne	Neon	20.180	He	Helium	4.003	
2	Be	Boron	9.012	3	Na	Sodium	22.990	4	Mg	Magnesium	12.011	5	Al	Aluminum	26.982	6	C	Carbon	12.011
5	Mg	Magnesium	24.305	6	VIIIB	4B	7	Cr	Chromium	51.996	8	Fe	Ferromagnetic	55.913	9	Mn	Manganese	54.938	
9	K	Potassium	39.098	10	Ca	Calcium	40.078	11	Ti	Titanium	47.88	12	Sc	Scandium	44.956	13	V	Vanadium	50.942
13	Rb	Rubidium	84.968	14	Sr	Samarium	87.63	15	Y	Yttrium	88.906	16	Zr	Zirconium	81.224	17	Nb	Nobium	91.966
17	Cs	Cesium	132.905	18	Ba	Barium	137.321	19	Ta	Tantalum	169.343	20	W	Tungsten	183.855	21	Tc	Techneum	91.224
21	Fr	Francium	223.029	22	Hf	Hafnium	178.49	23	V	Vanadium	50.942	24	Cr	Chromium	51.996	25	Mn	Manganese	54.938
25	Db	Dubnium	261.000	26	W	Tungsten	183.855	27	Fe	Ferromagnetic	55.913	28	Ni	Nickel	58.693	29	Cu	Copper	63.546
28	Rf	Rutherfordium	261.001	30	Zn	Zinc	65.409	31	Ga	Gallium	69.732	32	Ge	Germanium	72.61	33	As	Arsenic	74.922
31	Ac	Actinium	227.029	32	Se	Selenium	78.972	33	Br	Bromine	79.873	34	Te	Tellurium	127.6	35	At	Astatine	210.000
34	Th	Thorium	232.038	35	Pb	Lead	207.2	36	I	Iodine	126.904	37	Rb	Rubidium	84.968	38	Sr	Samarium	87.63
38	Pa	Protactinium	231.036	39	W	Tungsten	183.855	40	Os	Osmium	190.23	41	Ta	Tantalum	169.343	42	Mo	Molybdenum	95.98
41	U	Uranium	238.029	42	Ir	Iridium	192.22	43	Pt	Platinum	191.00	44	Hs	Hassium	264.000	45	Ru	Ruthenium	101.07
45	Bh	Bohrium	251.000	46	Pd	Palladium	106.42	47	Pt	Platinum	191.00	48	Cd	Cadmium	114.411	49	In	Inertium	118.71
47	Pu	Plutonium	244.004	50	Sn	Stannum	112.40	51	Sn	Stannum	112.40	52	Te	Tellurium	127.6	53	I	Iodine	126.904
51	Cm	Cerium	243.061	52	Te	Tellurium	127.6	54	Br	Bromine	79.873	55	Sb	Sbismuth	212.000	56	Xe	Xenon	131.30
55	Fr	Francium	223.029	56	Ba	Barium	137.321	57	Tl	Thallium	204.363	58	Pb	Lead	207.2	59	Bi	Bismuth	208.980
57	Fr	Francium	223.029	58	Db	Dubnium	261.000	59	W	Tungsten	183.855	60	Sm	Samarium	150.36	61	Pm	Promethium	144.913
59	Pa	Protactinium	231.036	60	W	Tungsten	183.855	61	Sm	Samarium	150.36	62	Eu	Europium	151.966	63	Gd	Gadolinium	157.25
61	U	Uranium	238.029	62	Os	Osmium	190.23	63	Tb	Terbium	158.925	64	Tb	Terbium	158.925	65	Dy	Dysprosium	162.50
63	Np	Neptunium	237.049	64	Ir	Iridium	192.22	65	Ho	Holmium	164.930	66	Er	Erbium	167.26	67	Lu	Lutetium	174.967
65	Pu	Plutonium	244.004	66	Pt	Platinum	191.00	66	Tm	Thulium	163.934	68	Yb	Ytterbium	173.04	69	Yb	Ytterbium	173.04
67	Cm	Cerium	243.061	68	Dy	Dysprosium	162.50	69	Yb	Ytterbium	173.04	70	Lu	Lutetium	174.967	71	Lu	Lutetium	174.967
69	Bk	Berkelium	247.070	70	Yb	Ytterbium	173.04	71	Lu	Lutetium	174.967	72	Cf	Cfetium	241.000	73	Es	Einsteinium	243.061
71	Lr	Lanthanide Series	242.062	72	Fm	Fermium	257.095	73	Am	Americium	243.061	74	Md	Mendelevium	258.1	75	No	Noberium	259.101
73	Ac	Actinium	227.029	74	Th	Thorium	232.038	75	U	Uranium	238.029	76	Cf	Cfetium	241.000	77	Uuo	Ununoctium	291.000
75	Th	Thorium	232.038	76	Pa	Protactinium	231.036	77	Np	Neptunium	237.049	78	Pu	Plutonium	244.004	79	Cm	Cerium	243.061
77	U	Uranium	238.029	78	Hs	Hassium	264.000	79	Mt	Methylum	212.000	80	Hg	Mercury	200.59	81	Tl	Thallium	204.363
79	Bh	Bohrium	251.000	80	Os	Osmium	190.23	81	Tl	Thallium	204.363	82	Pb	Lead	207.2	83	Po	Poisonium	229.000
81	Pu	Plutonium	244.004	82	Pt	Platinum	191.00	83	Bi	Bismuth	208.980	84	At	Atmosine	210.000	85	At	Atmosine	210.000
83	Cf	Cfetium	241.000	84	Hg	Mercury	200.59	85	Rn	Radiation	222.000	86	Rn	Radiation	222.000	87	Fr	Francium	223.029
85	Ac	Actinium	227.029	86	Th	Thorium	232.038	87	Pa	Protactinium	231.036	88	U	Uranium	238.029	89	Ac	Actinium	227.029

Chalcogens (oxygen family)

32.066
34 Se
Selenium 78.972

34

Se

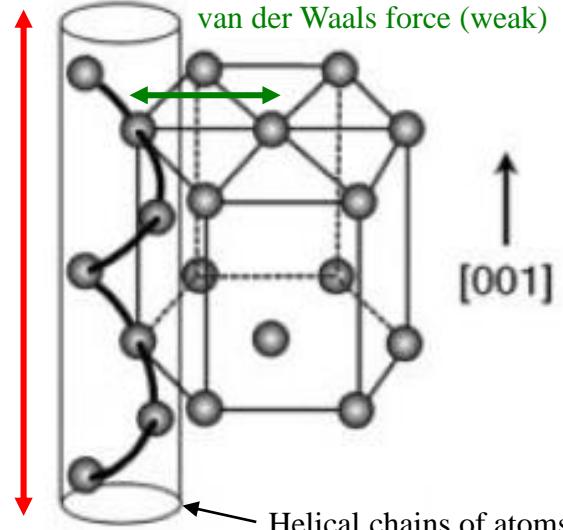
Selenium
78.972

52

Te

Tellurium
127.6

Hexagonal crystal structure
(selenium and tellurium)



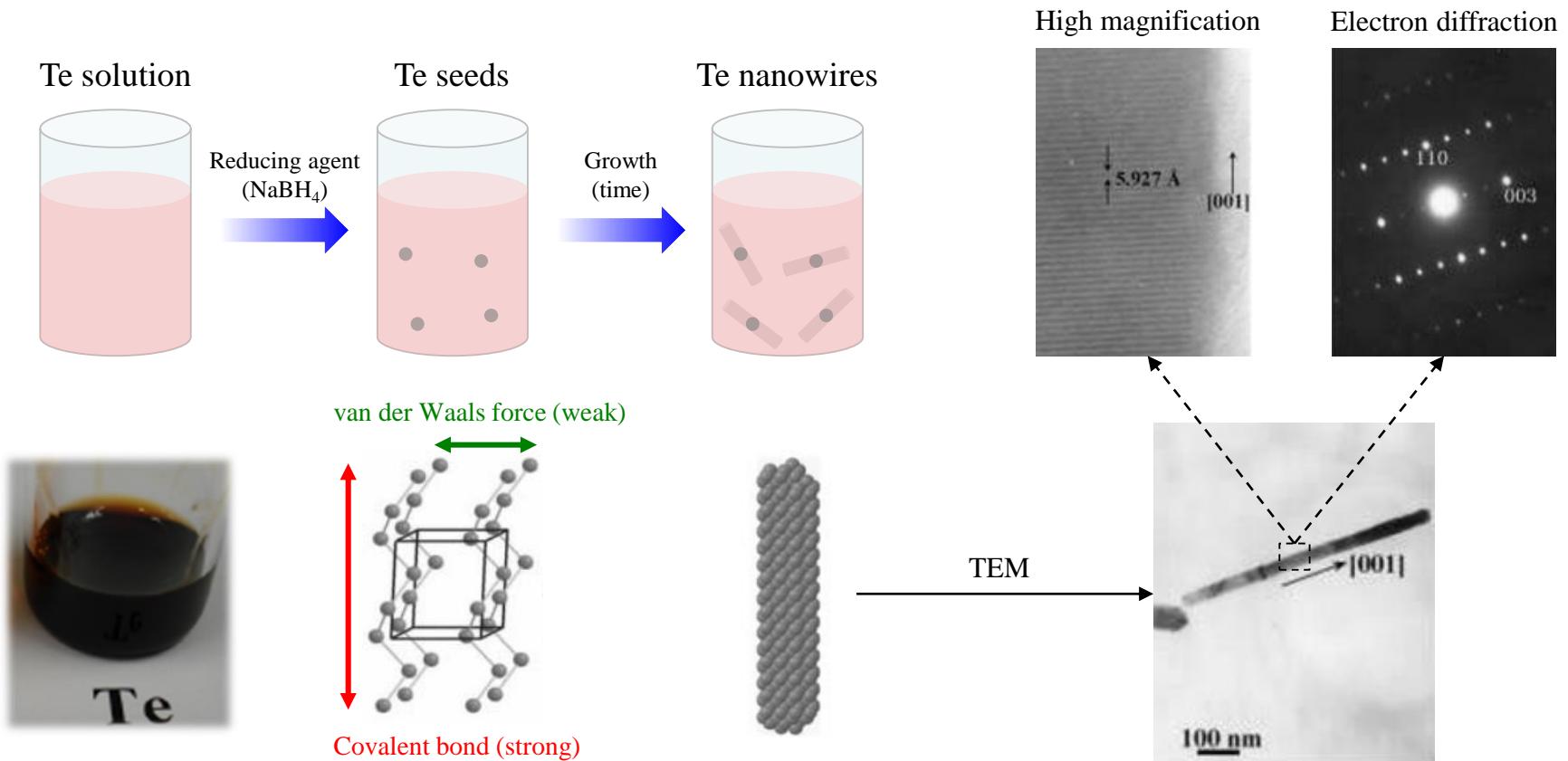
Chalcogens: the chemical elements in group 16 of the periodic table

Anisotropic bond strength of atoms

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1. Spontaneous anisotropic crystal structures

Tellurium (Te) nanowire fabrication

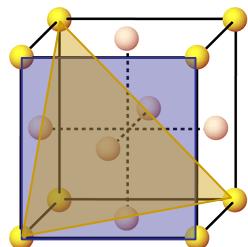


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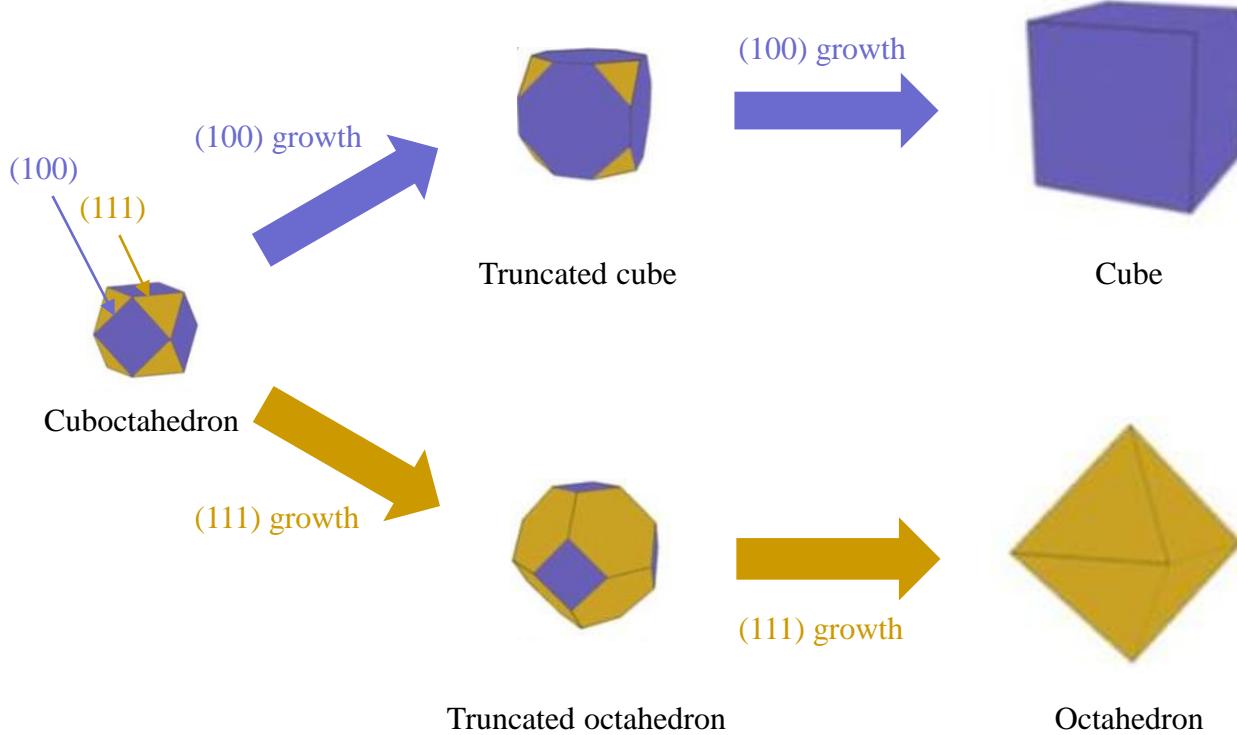
2. Kinetic control by organic surfactants

- To decrease the surface energy of cuboctahedron nanoparticle, the growth of (111) plane is mostly advantageous to form the octahedron nanoparticle.

$$\frac{4\epsilon}{a^2} = 4.00 \times \frac{\epsilon}{a^2}$$



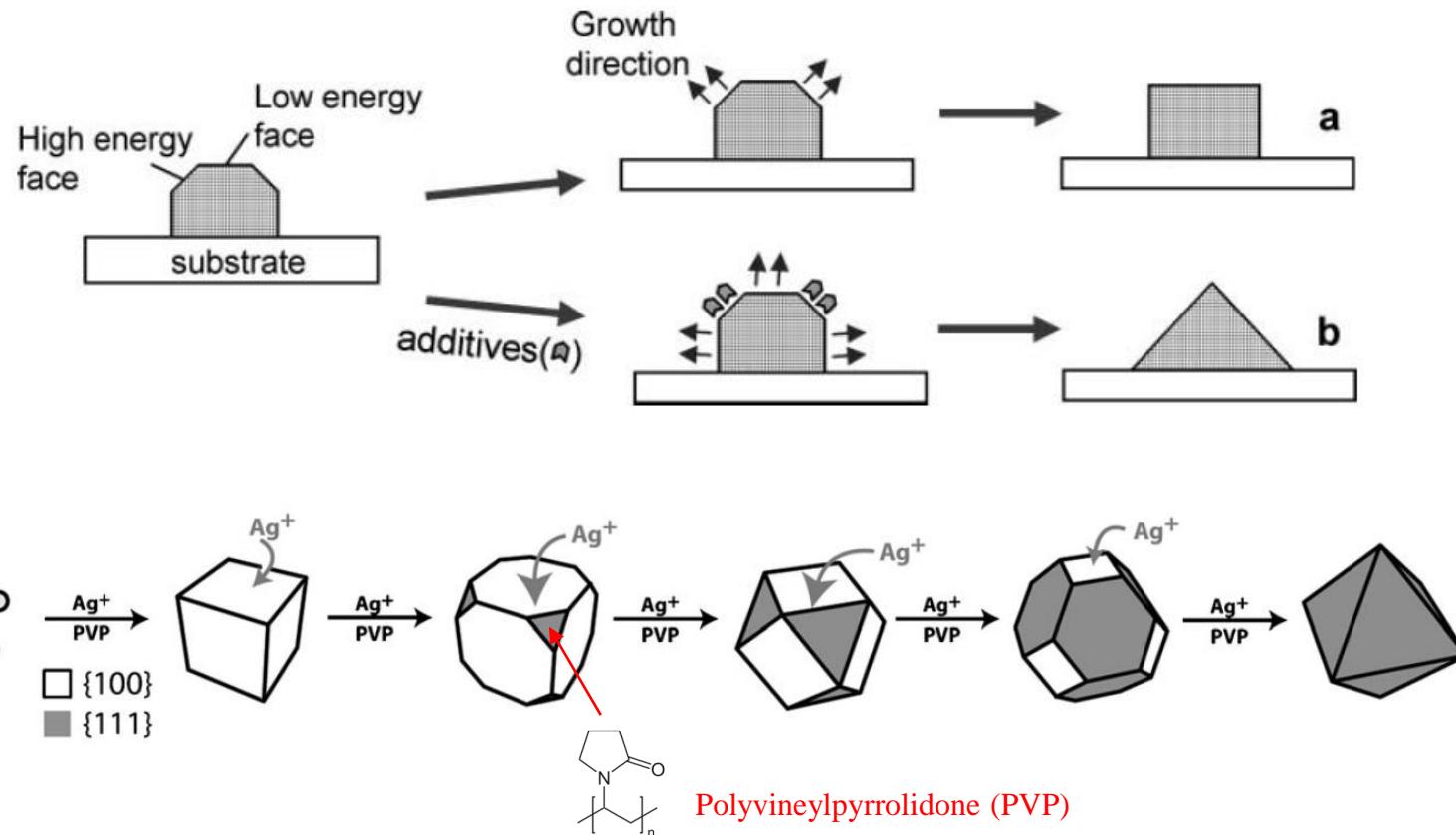
$$\frac{2\sqrt{3}\epsilon}{a^2} \approx 3.46 \times \frac{\epsilon}{a^2}$$



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2. Kinetic control by organic surfactants

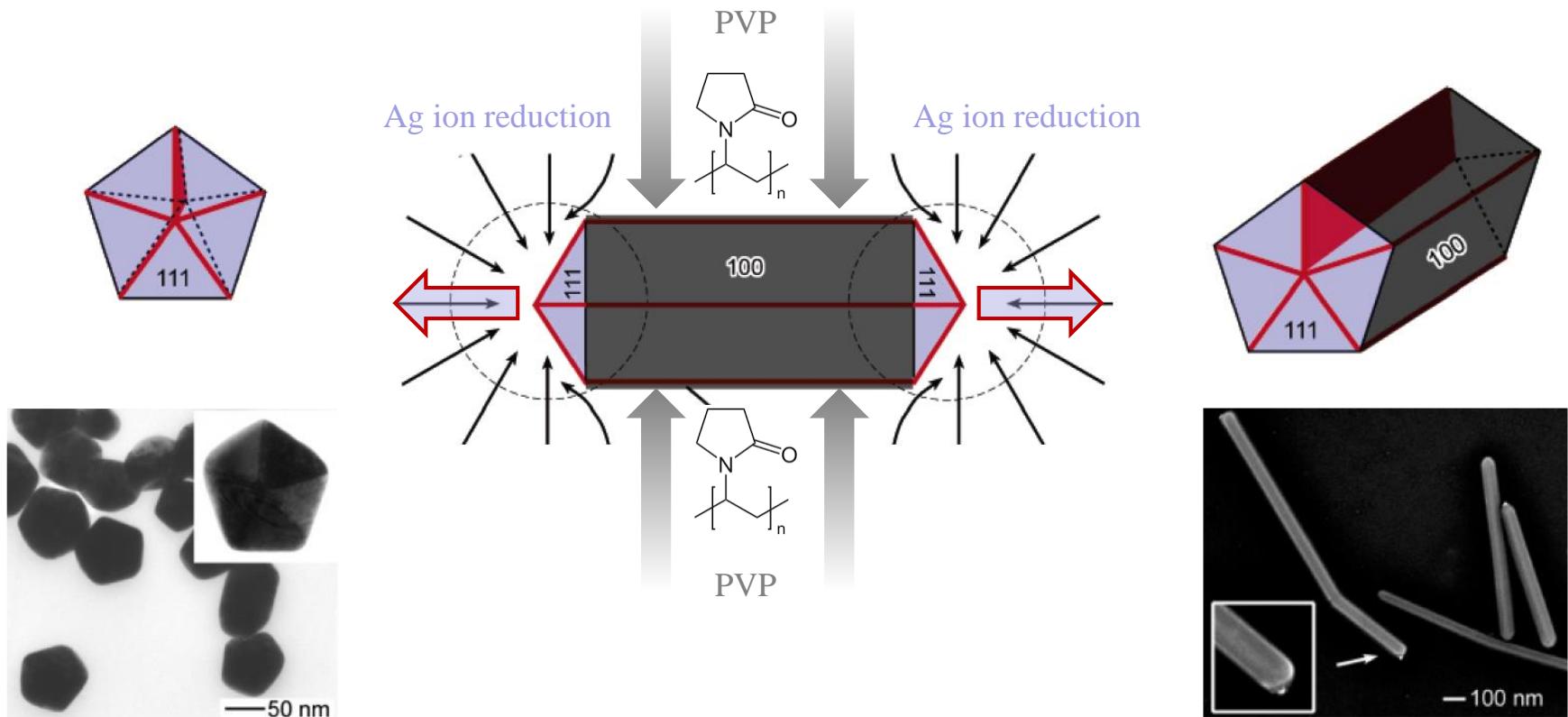
Kinetic control of crystal orientation growth by adsorption of organic surfactants



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2. Kinetic control by organic surfactants

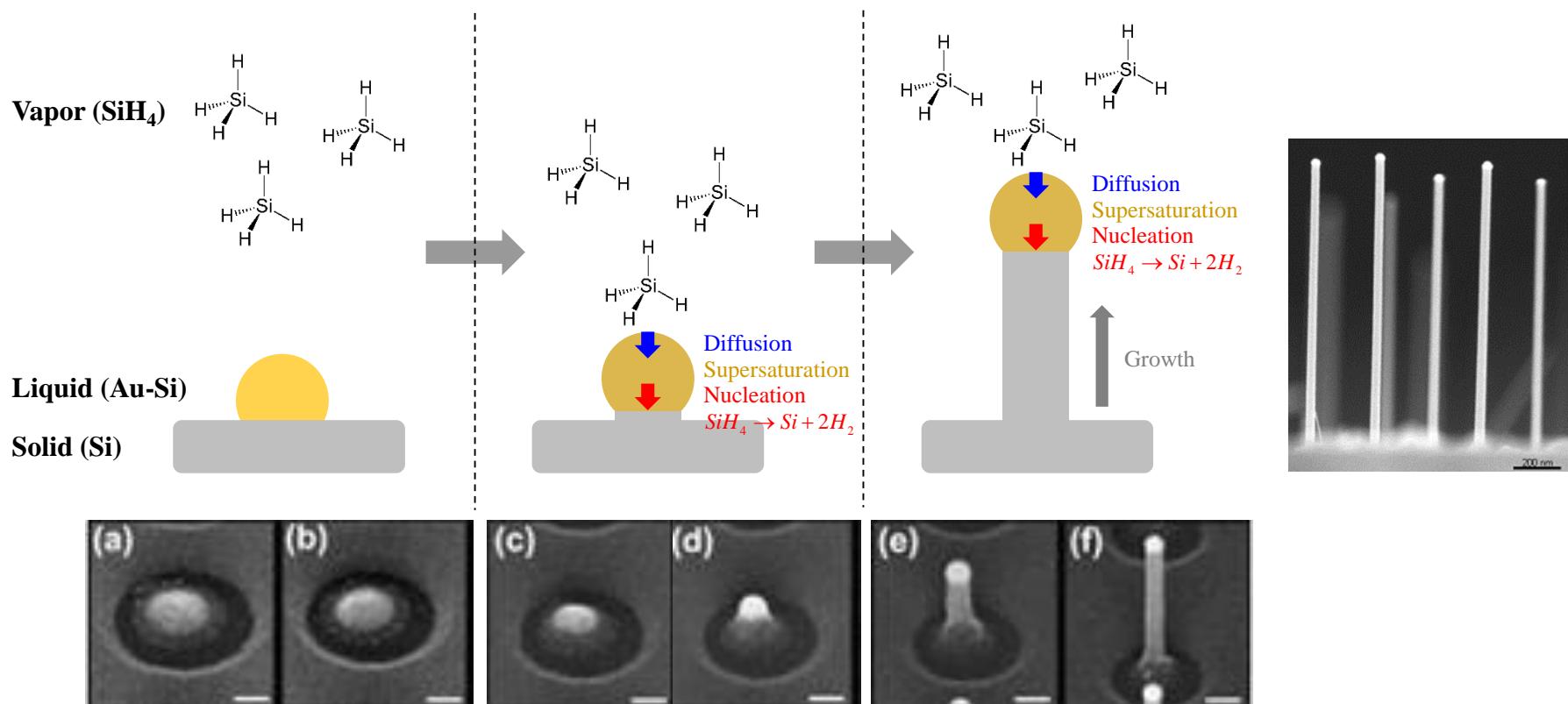
Silver (Ag) nanowire growth with polyvinylpyrrolidone (PVP)



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3. Seed-initiated growth

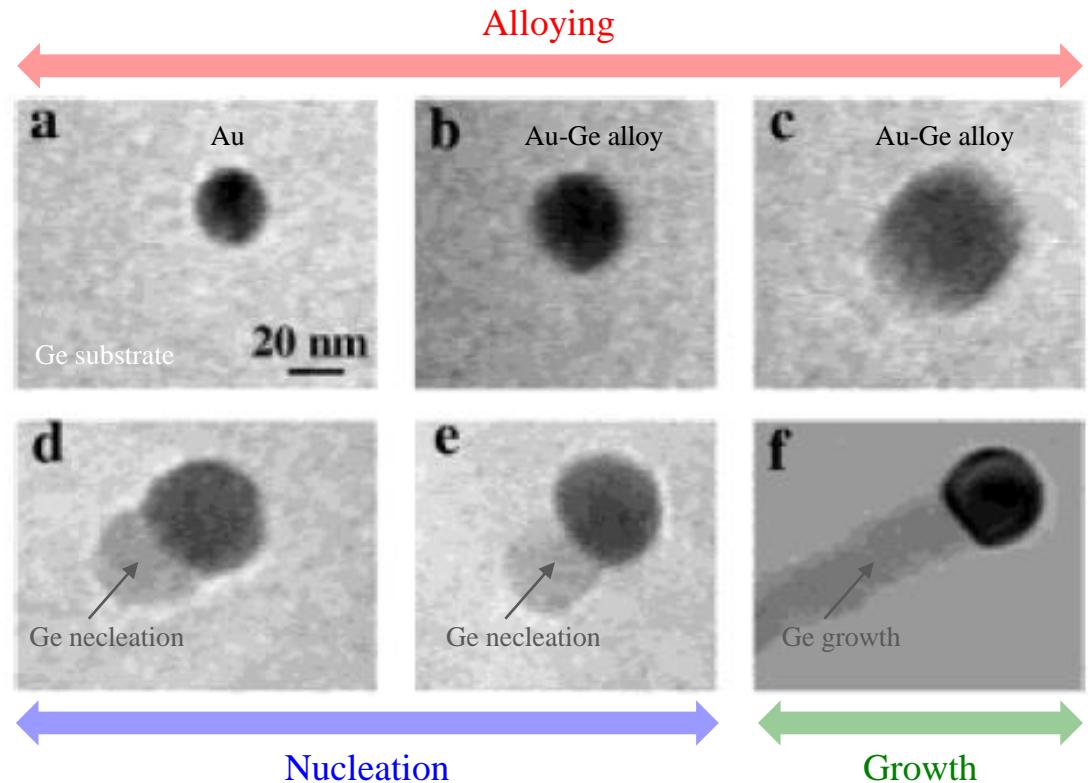
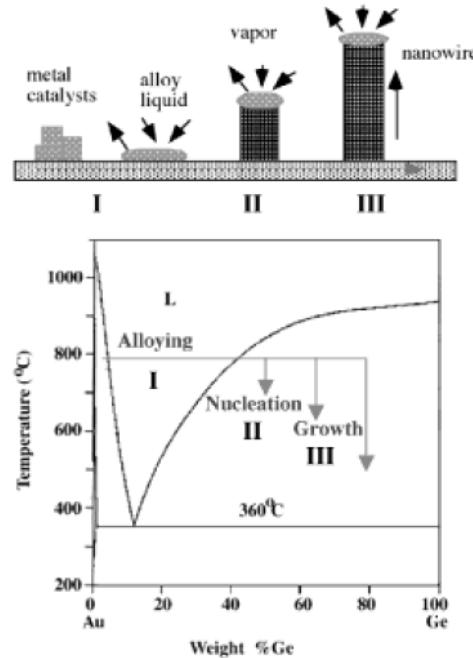
Vapor-Liquid-Solid (VLS) growth of silicon (Si) nanowire with gold (Au) seed



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3. Seed-initiated growth

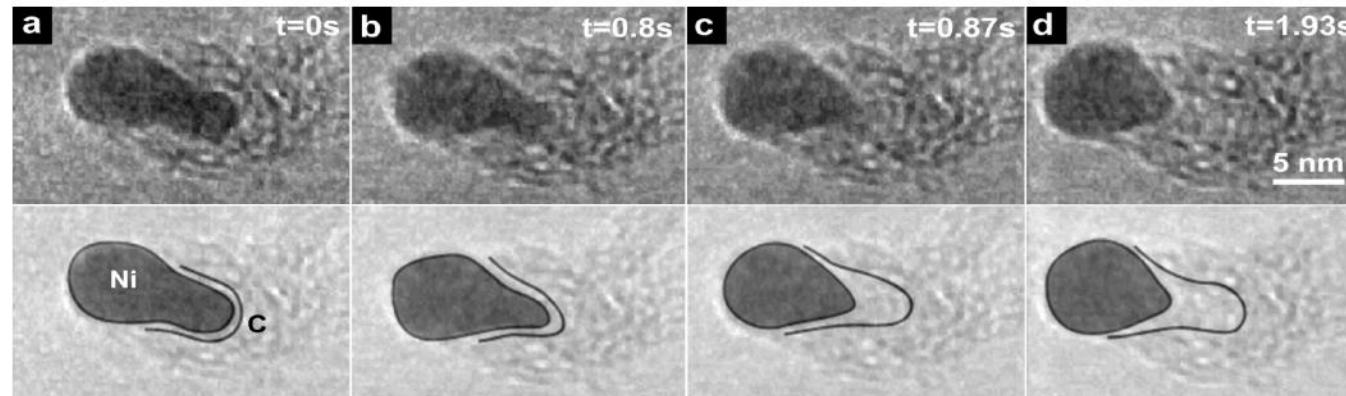
Vapor-Liquid-Solid (VLS) growth of germanium (Ge) nanowire with gold (Au) seed



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3. Seed-initiated growth

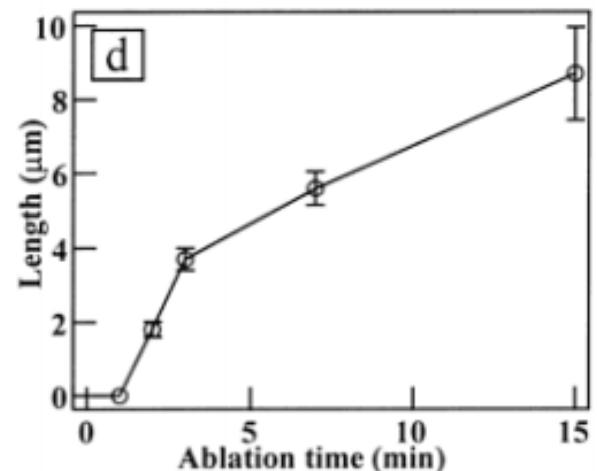
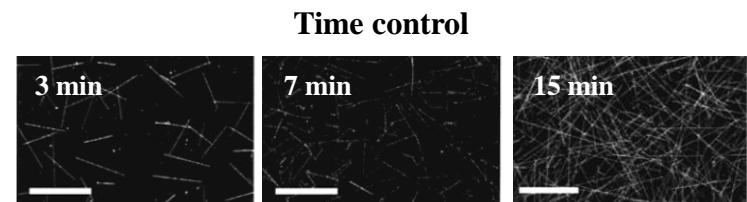
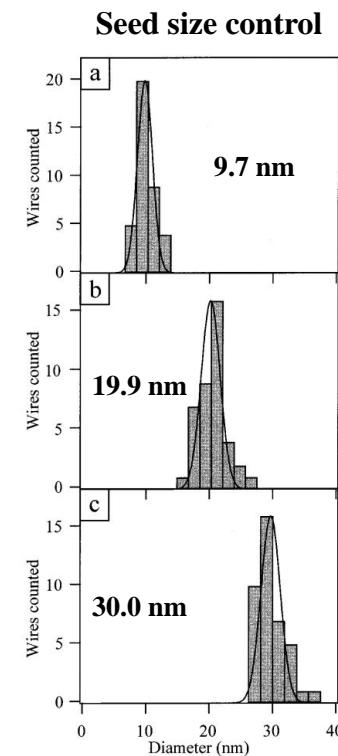
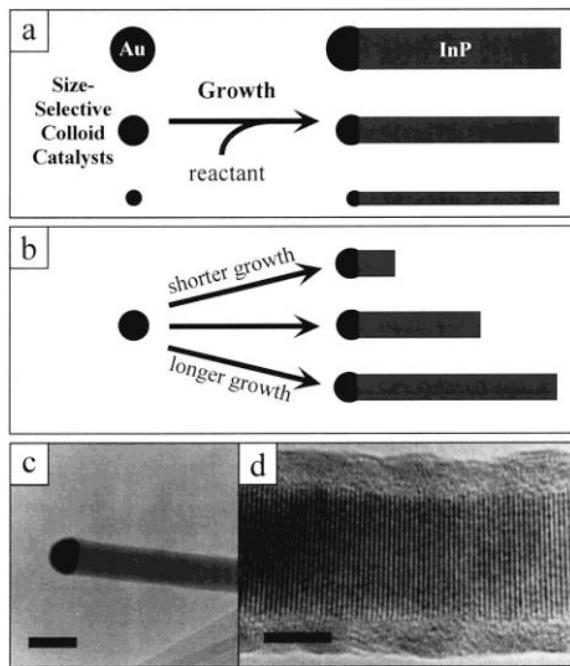
Vapor-Liquid-Solid (VLS) growth of carbon nanotube (CNT)



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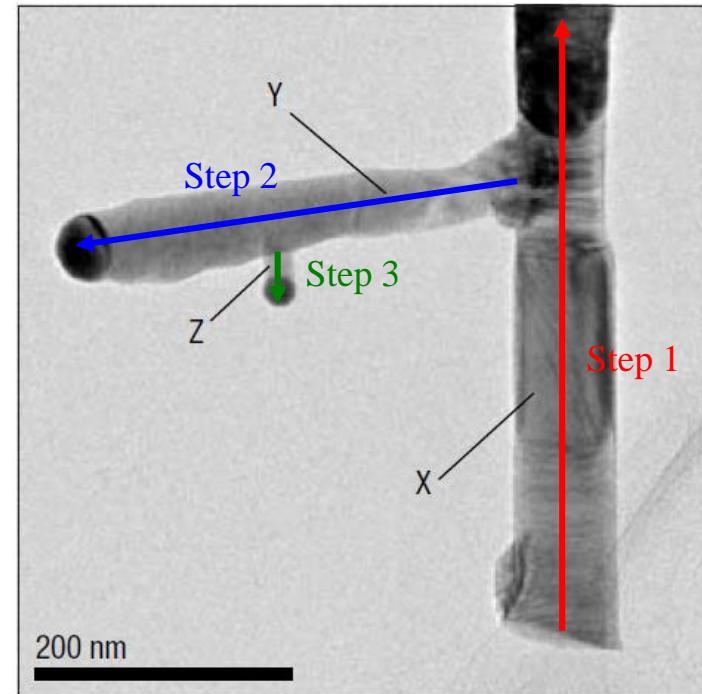
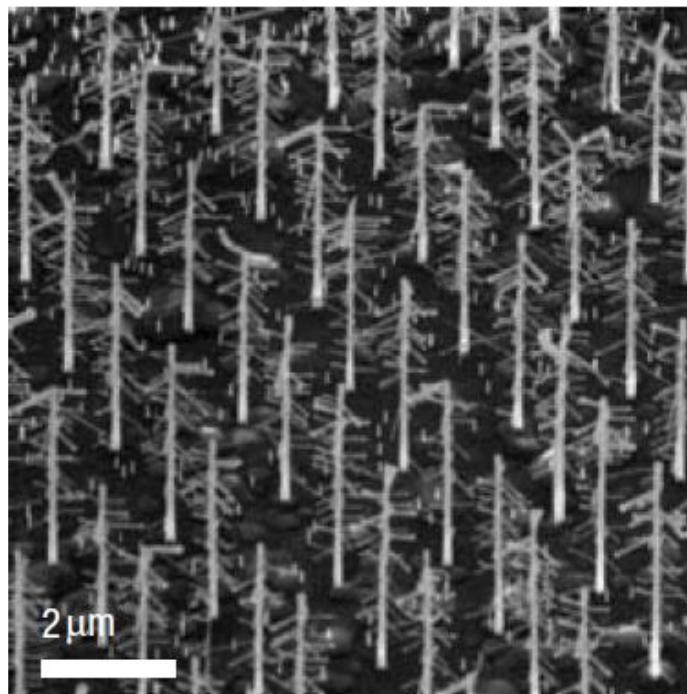
3. Seed-initiated growth: size control

Vapor-Liquid-Solid (VLS) growth of indium phosphide (InP) nanowire



3. Seed-initiated growth: shape control

Vapor-Liquid-Solid (VLS) growth of “Ge nanotrees” (3 steps)



4. Templatting

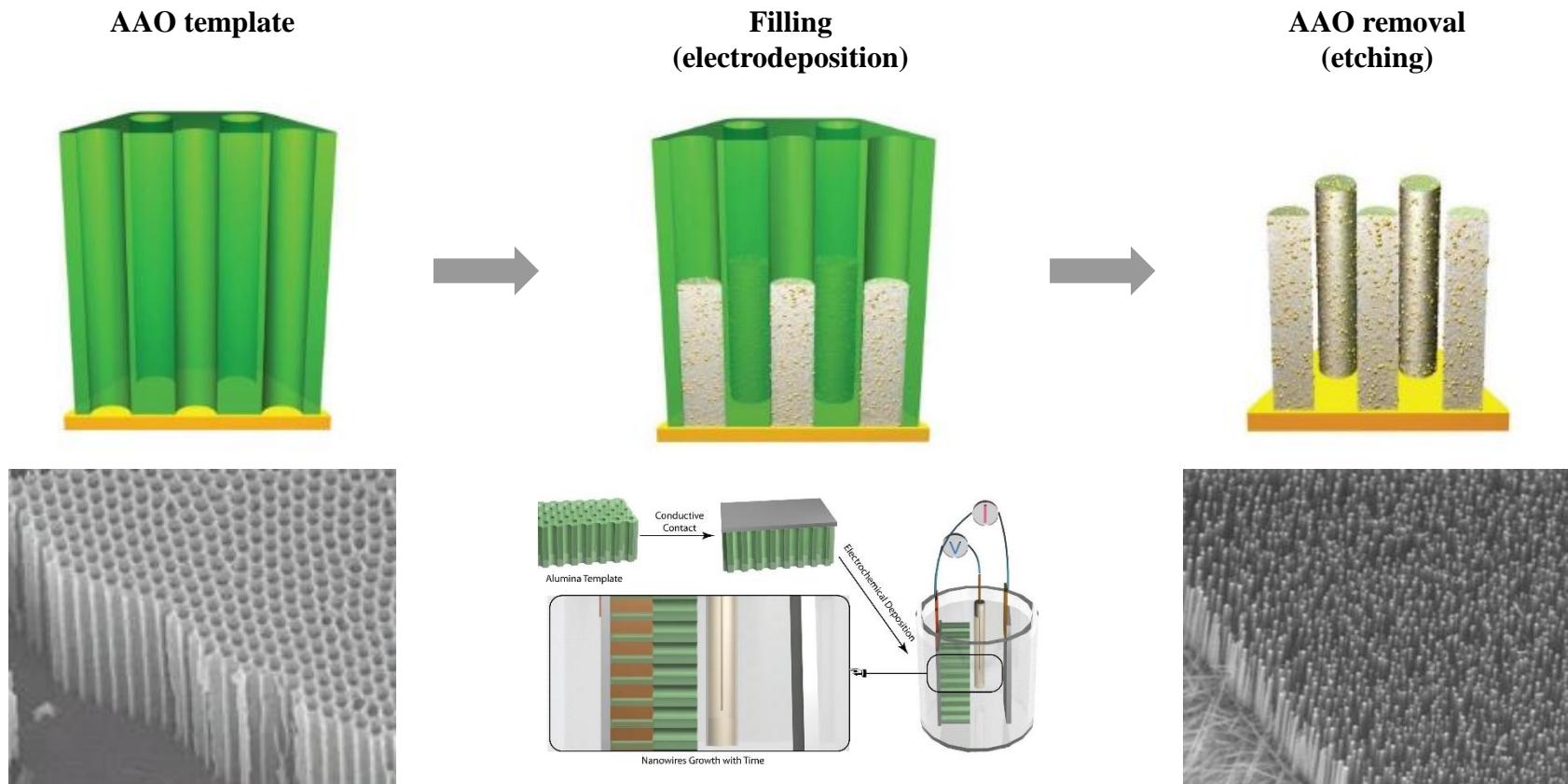
A mould for bronze sword



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4. Templating

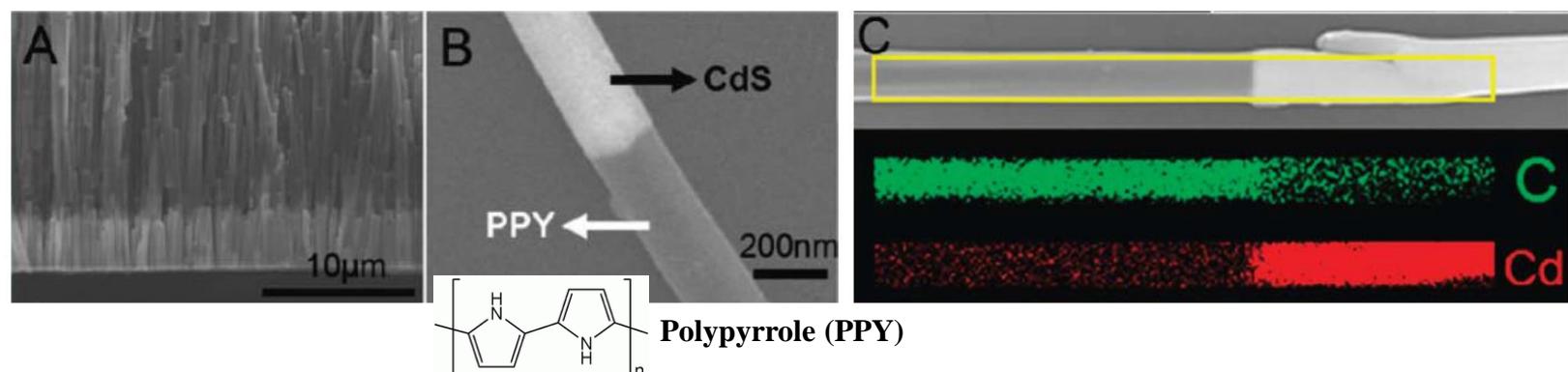
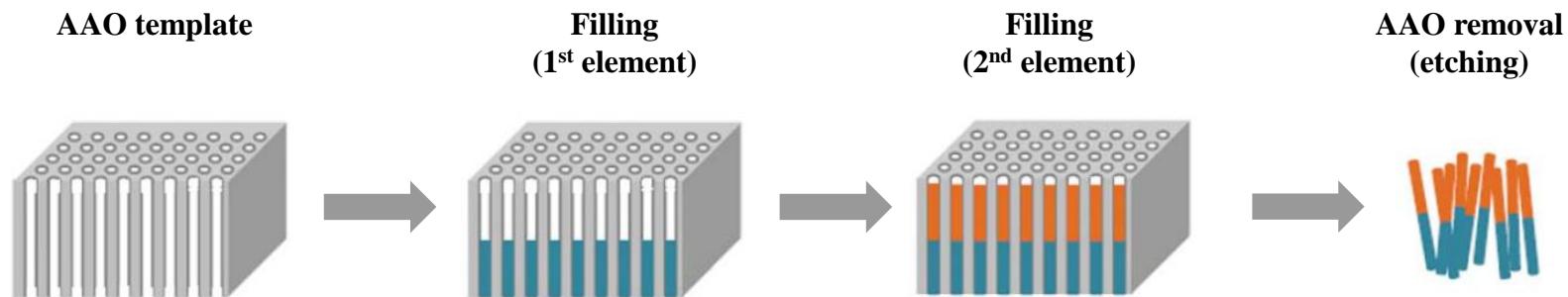
Nanowire growth with anodic aluminum oxide (AAO) template



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4. Templating

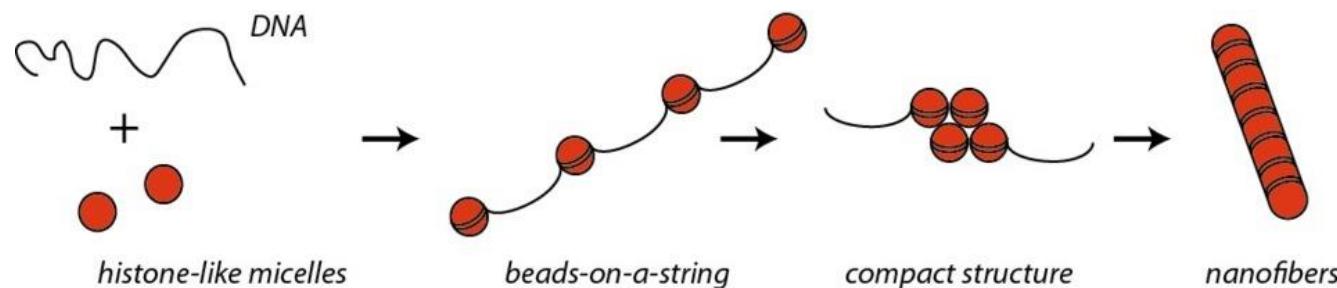
Two elements nanowire growth with anodic aluminum oxide (AAO) template



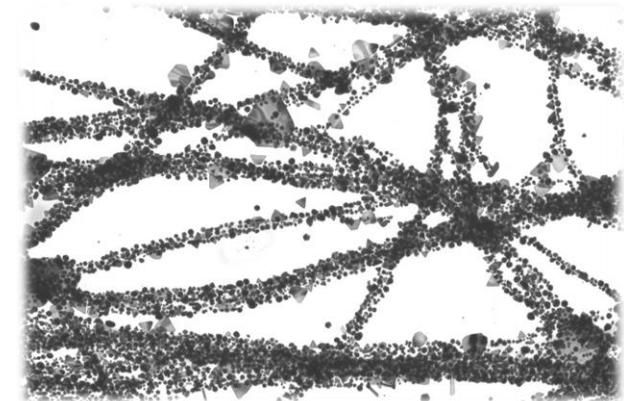
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5. Self-assembly

DNA/polymeric micelle self-assembly

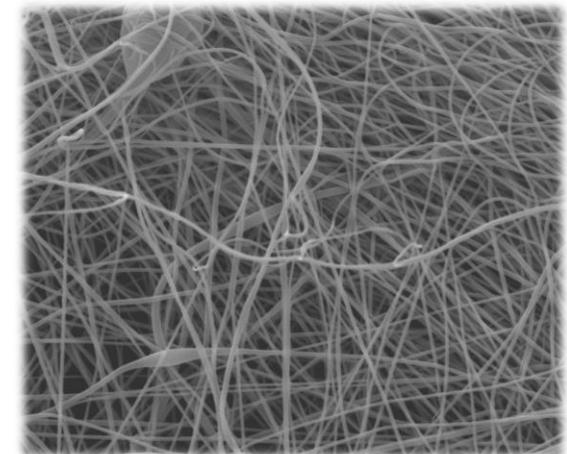
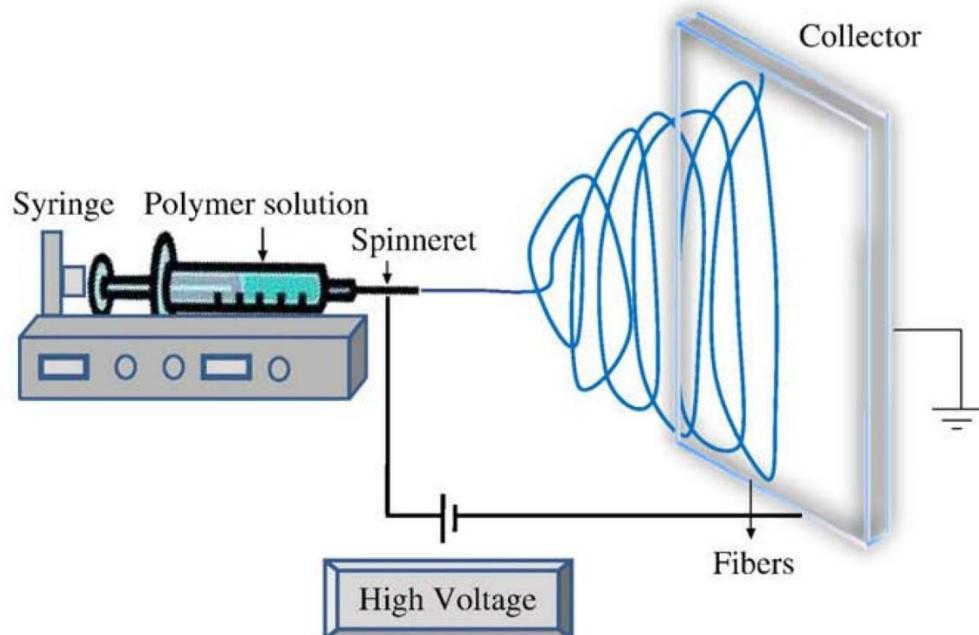


Self-assembly



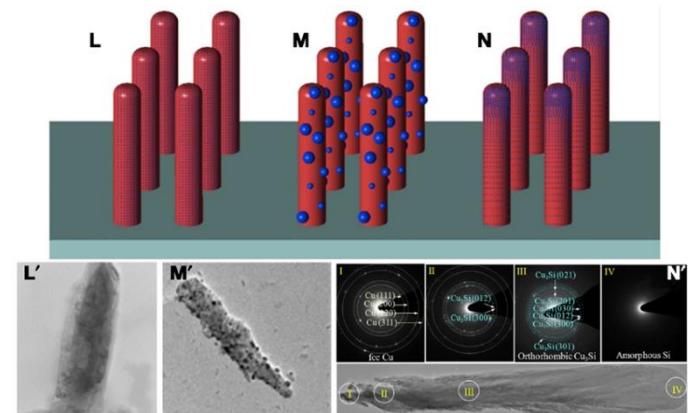
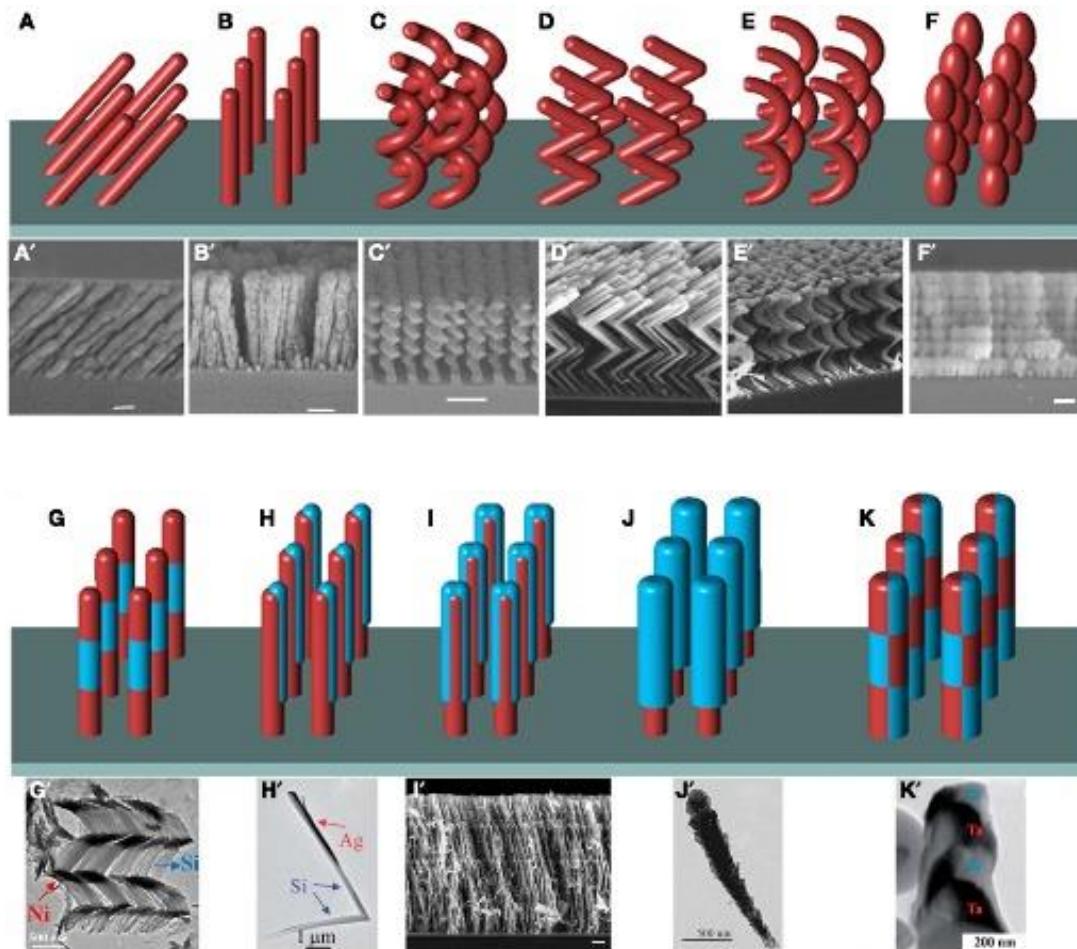
6. Size reduction

Electrospinning



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Summary of 1-D nanostructures fabrication



- (A) tilted nanorods
- (B) vertically aligned nanorods
- (C) helical nanorods
- (D) zigzag nanorods
- (E) C-shape nanorods
- (F) bead-like nanorods
- (G) multilayer nanorods
- (H) side-coated nanorods
- (I) sandwiched nanorods
- (J) core-shell nanorods
- (K) checkerboard nanorods
- (L) homogenous composite nanorods
- (M) nanoparticle-decorated nanorods
- (N) composition-graded nanorods