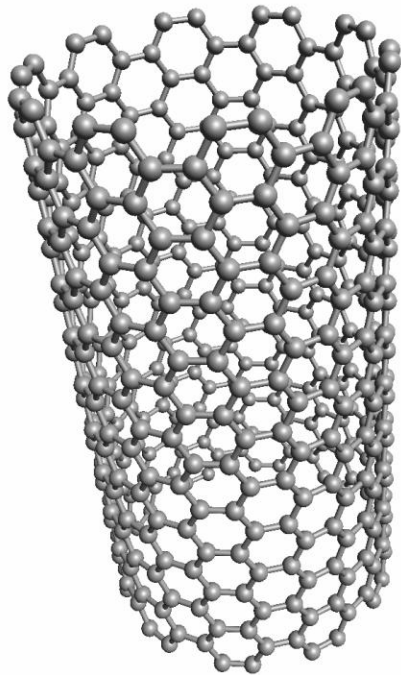
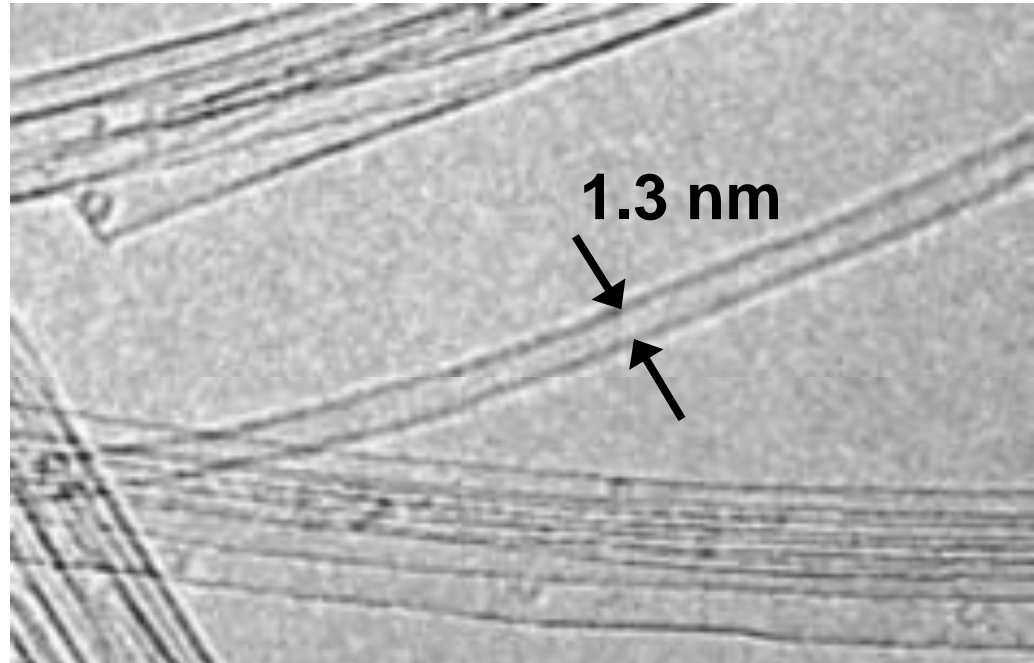


単層カーボンナノチューブ SWNT

1993 : Single-Walled Carbon Nanotubes

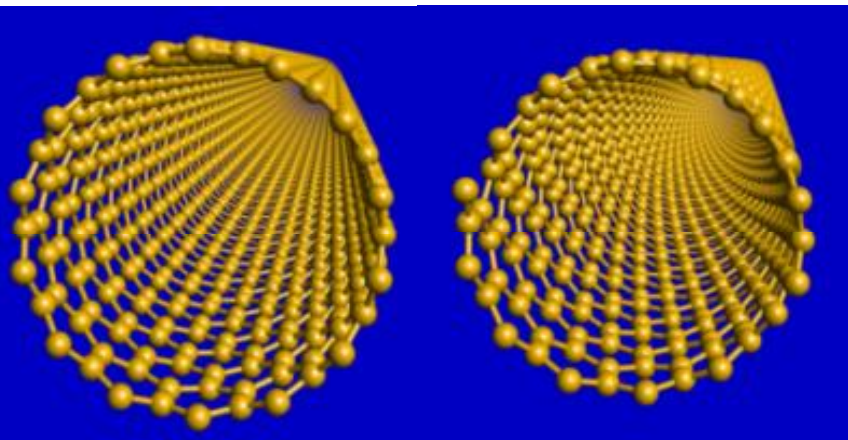


S. Iijima, T. Ichihashi, *Nature* 363, 603, 1993.
D. S. Bethune et al. *Nature* 363, 605, 1993.



A graphene sheet forms a cylinder.
Diameter : 1.3 nm (0.4 ~ 2 nm)
Length : Micrometer order

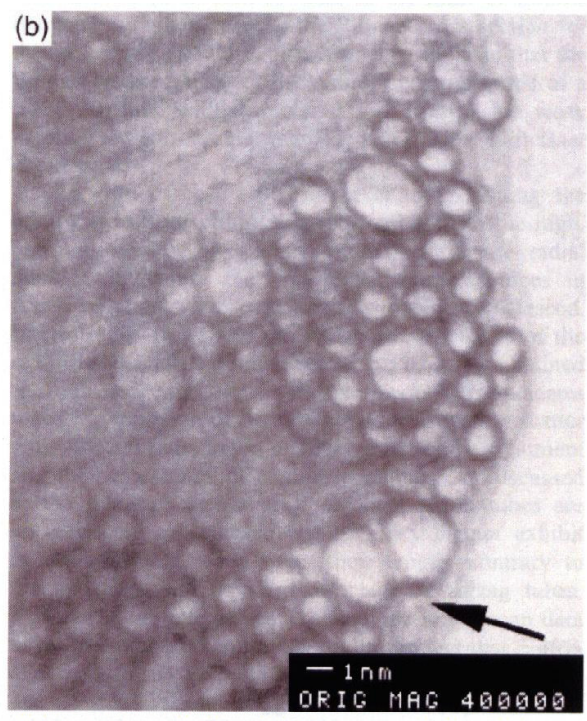
STABLE



Φ 1.3 nm: 40 C-atoms at edge

TEM Images of Single-Wall Carbon Nanotubes

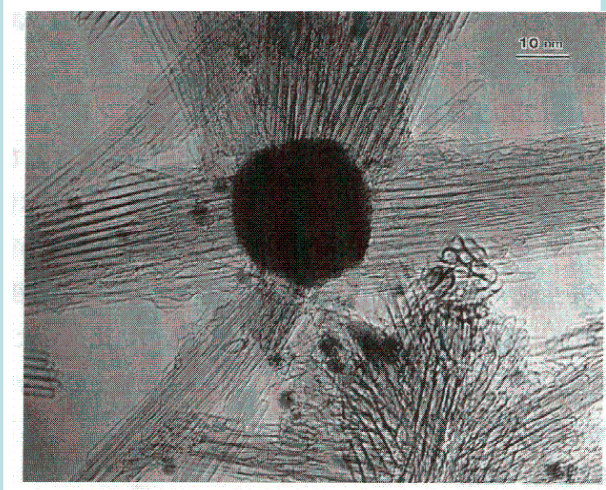
Expressway-like Aggregates (ropes) : High Yield
NiCo



Fang et al. J. Mter. Res.
13(1998)2407.

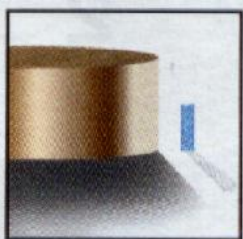
Sea Urchin-like
Aggregates : Low Yield

La



(Y. Saito)

They are not the same tubes. They have names



大きさ

0.4~1.8 nm

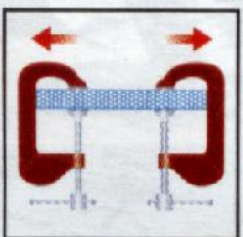
(電子線露光配線:
最小で幅50 nm, 厚さ2~3 nm)



密度

1.33~1.40 g/cm³

(アルミニウム:2.7 g/cm³)



引っ張り強度

45 GPa

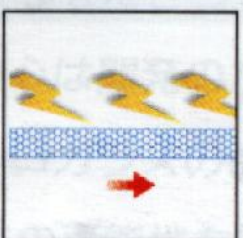
(高力鋼合金:約2 Gpaで破断)



弾性限界(復元力)

大きな角度で曲げても損傷せず復元する。

(金属や炭素繊維:結晶粒界で割れる。)

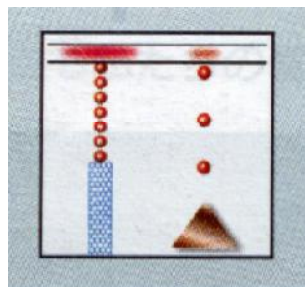


電流輸送量

推定 1 GA/cm²

(銅線:1 MA/cm²)

SWNTの特徴 (日経サイエンスから引用)



電界放出特性

両電極を1μm離して設置して1~3 V印加で, 発光活性化。
(モリブデンチップ:50~100 V/μm必要で、寿命も短い)



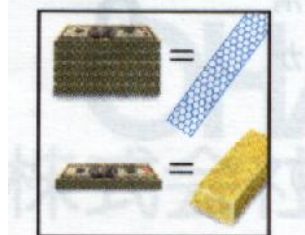
熱伝導度

室温で6000 W/m・Kとよそくされている。
(ほぼ純粋なダイヤモンド:3320 W/m・K)



耐熱性

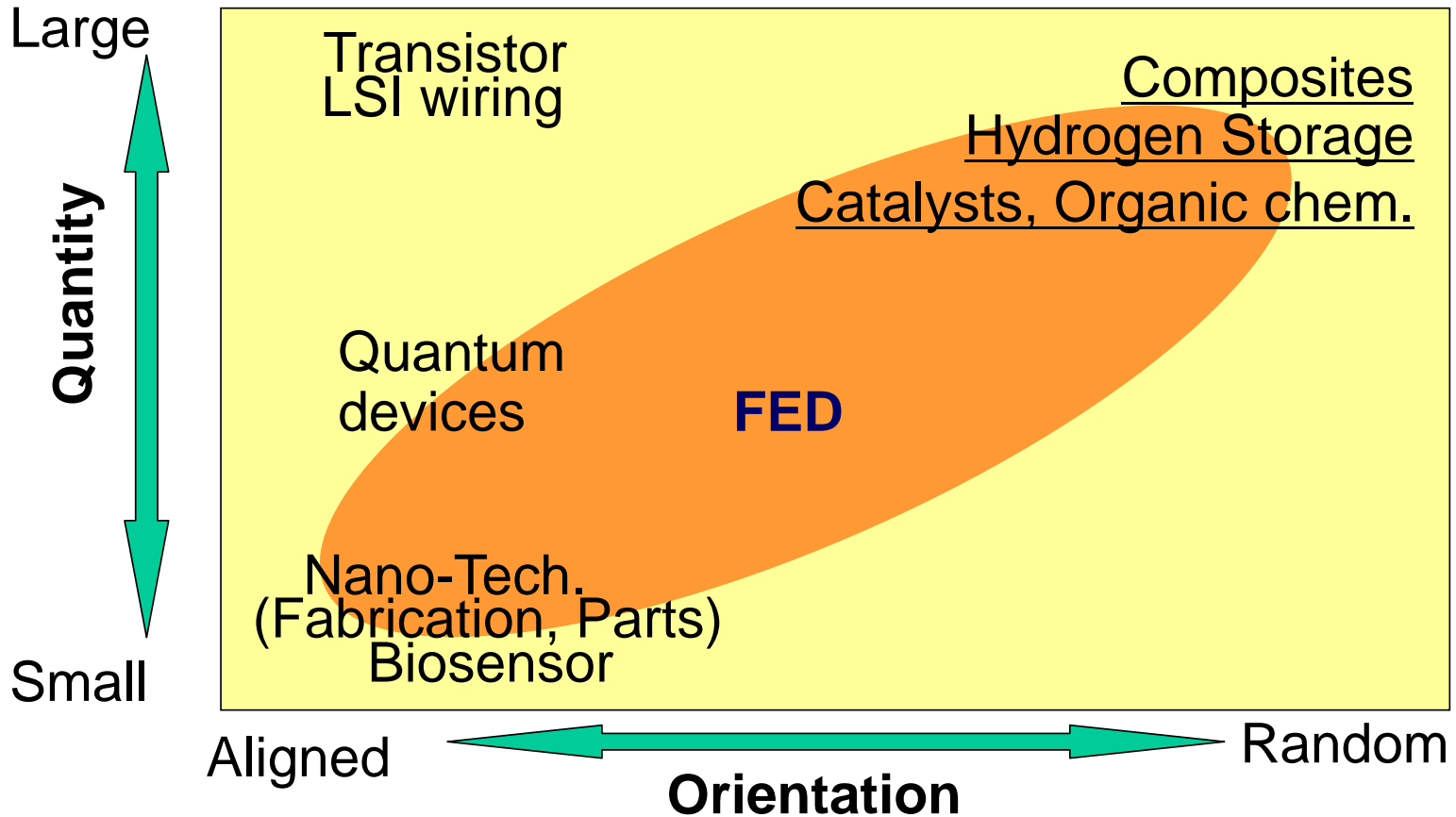
真空中で2800°C、空気中で750°Cまで安定。
(半導体チップ中の銅線:
600~1000°Cで融解)



コスト

1g/500ドル :ヒューストン、CNI 社
(金線:約10ドル)

Application of SWNTs



Hydrogen storage capacity of CNTs and vapor-grown fibers

1. 0.018 wt.% Graphite flakes
2. 0.041 wt.% Activated carbon
3. 0.020 wt.% Graphitized PYROGRAF VGCF
4. 0.070 wt.% Air-etched PYROGRAF VGCF
5. <0.2 wt.% CO₂-etched PYROGRAF VGCF
6. 0.042 wt.% 昭和電工 VGCF
7. 0.028 wt.% MER MWNT (Ball milled)
8. 0.050 wt.% Rice University **SWNT**

水素吸蔵量(室温、3.59 MPa) 0.1 wt.% 以下

G.G. Tibbets, et al. (General Motors)
Carbon 39(2001) 2291-2301

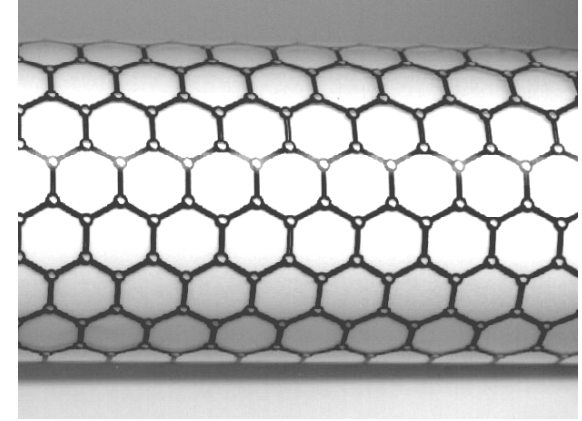
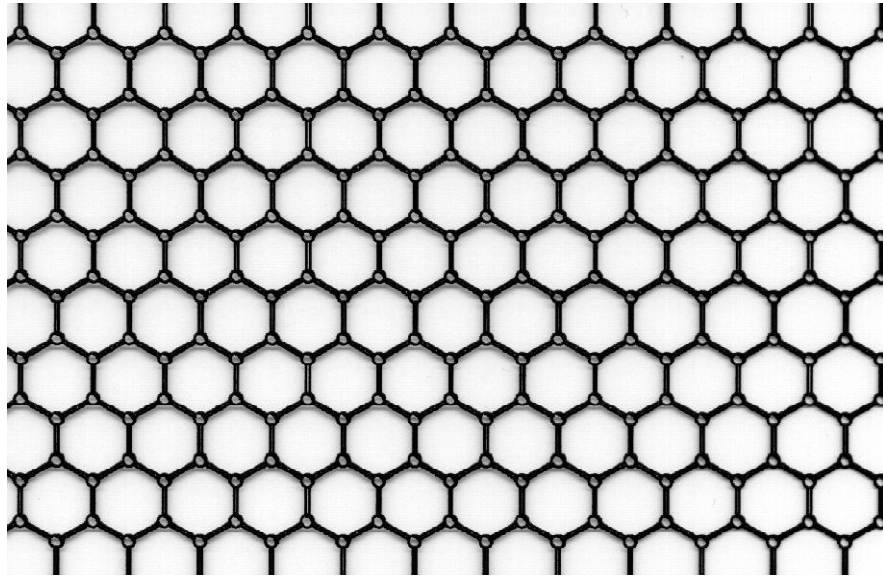
1. HiPco NT
2. SWNH

水素吸蔵量
(室温、5 MPa)
1 wt.% 以下

Murata et al (千葉大)
Yang et al (千葉大学)

Application of SWNTs utilizing their unique properties?

グラファイトシート 1枚からなる円筒が構造単位



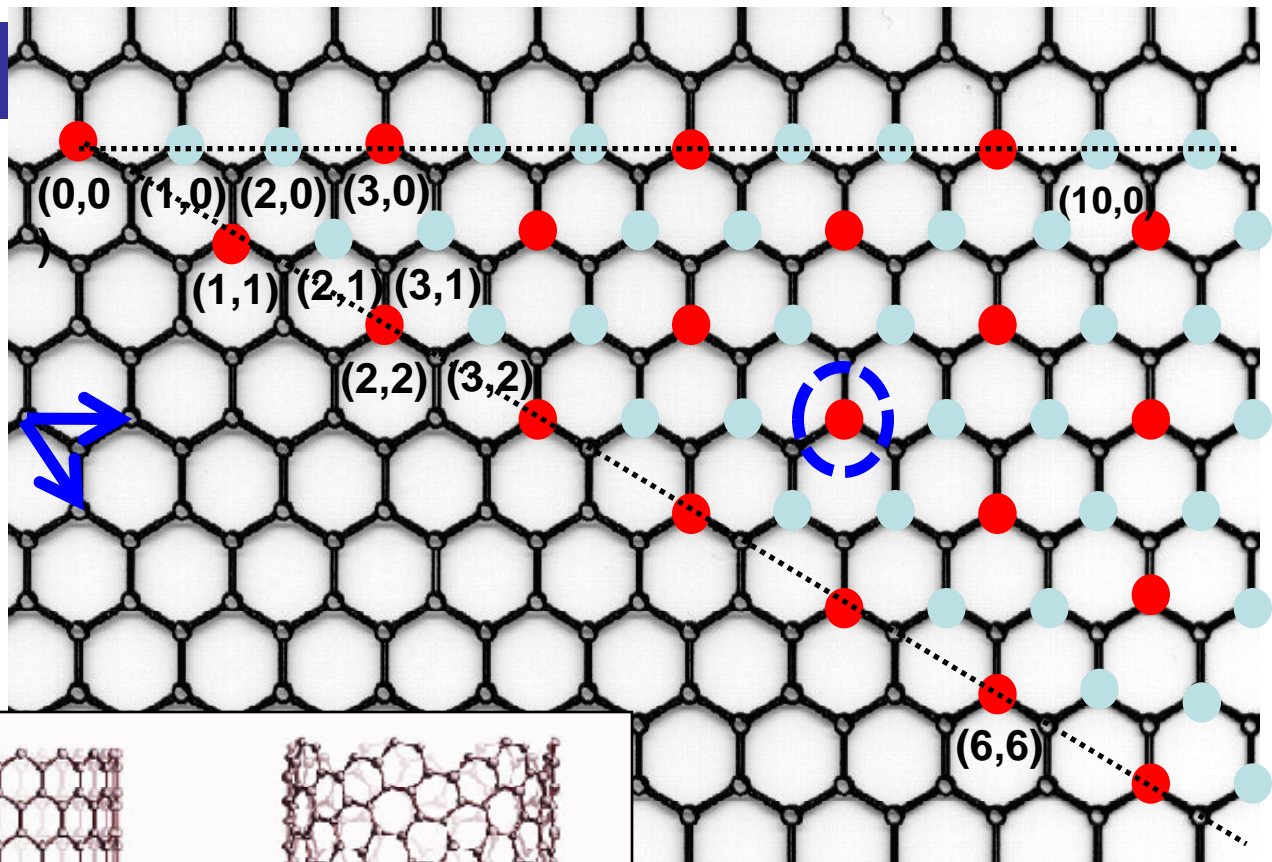
単層炭素ナノチューブ (Single-wall carbon nanotube, SWNT)

多層炭素ナノチューブ (Multi-wall carbon nanotube, MWNT)

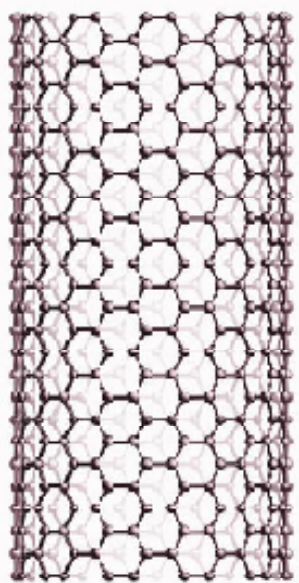
単層カーボンナノホーン (Single-Wall carbon Nanohorn, SWNH)

Chiral index (n, m)

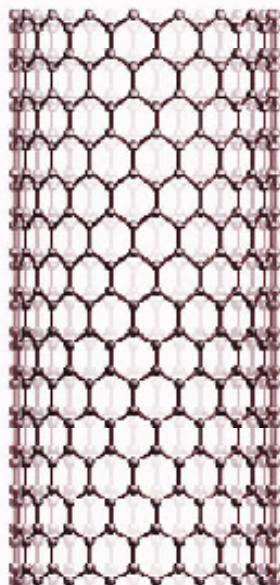
R. Saito Appl. Phys. Lett.
60, 2204 (1992).



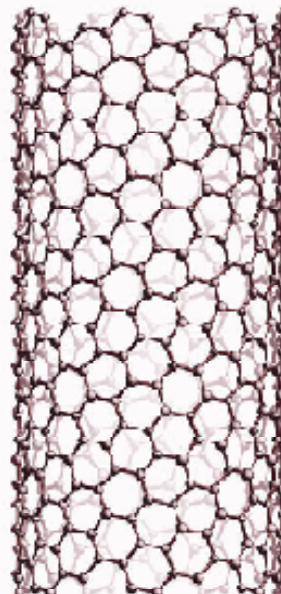
Drawn by K.Hirahara



(9,9)



(17,0)



(15,2)

- Metallic
- Semiconducting

n-m: 3の整数倍 → 金属
それ以外: 半導体

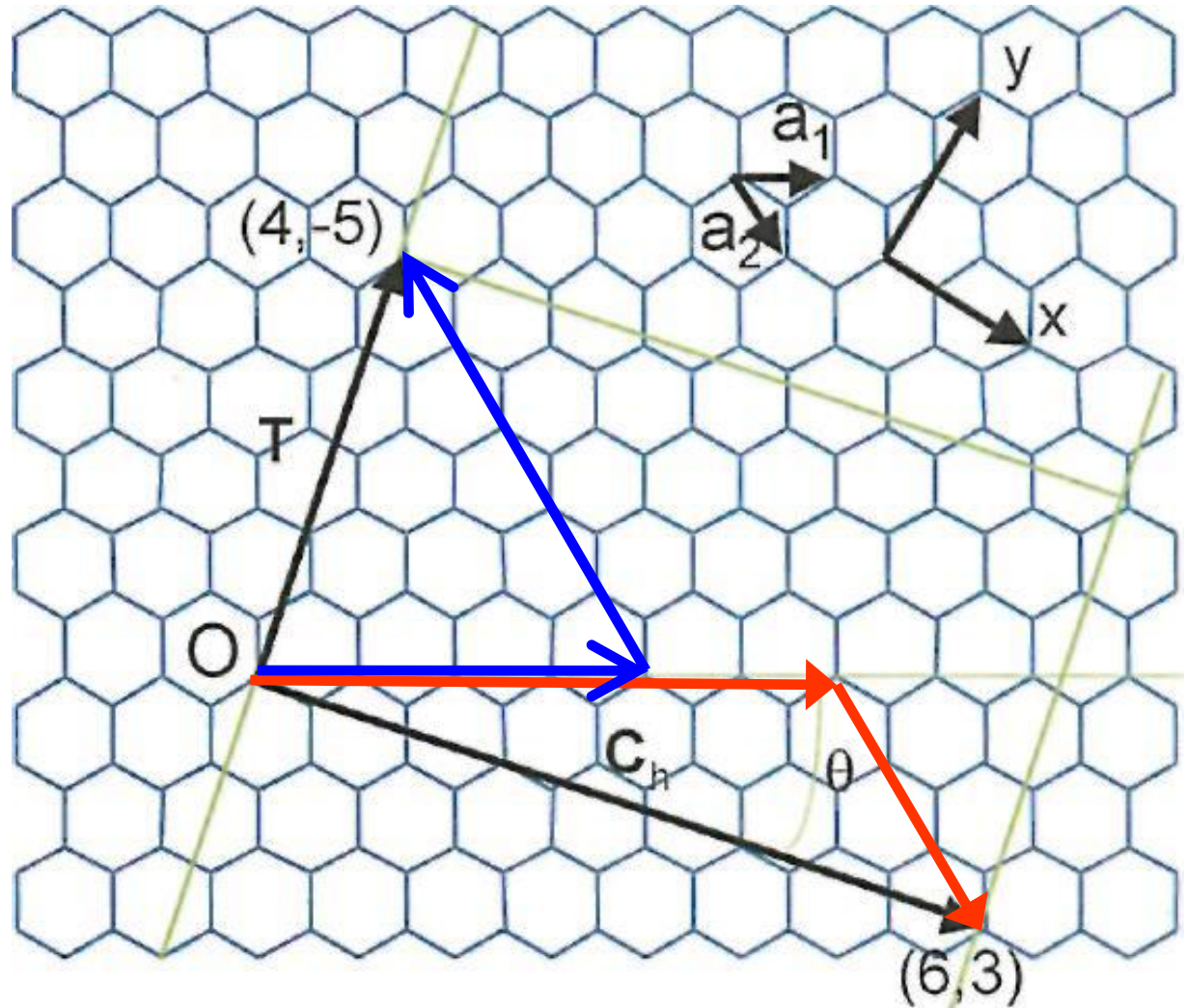
グラファイト格子、SWNTのカイラルベクトル

(n, m) チューブの円周の長さ

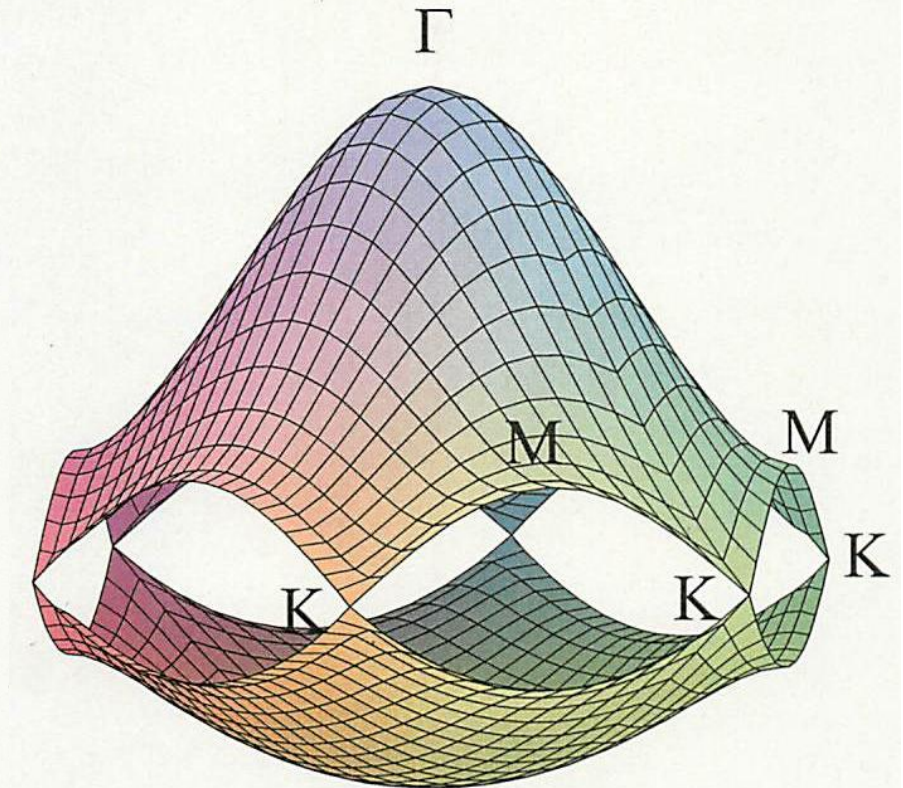
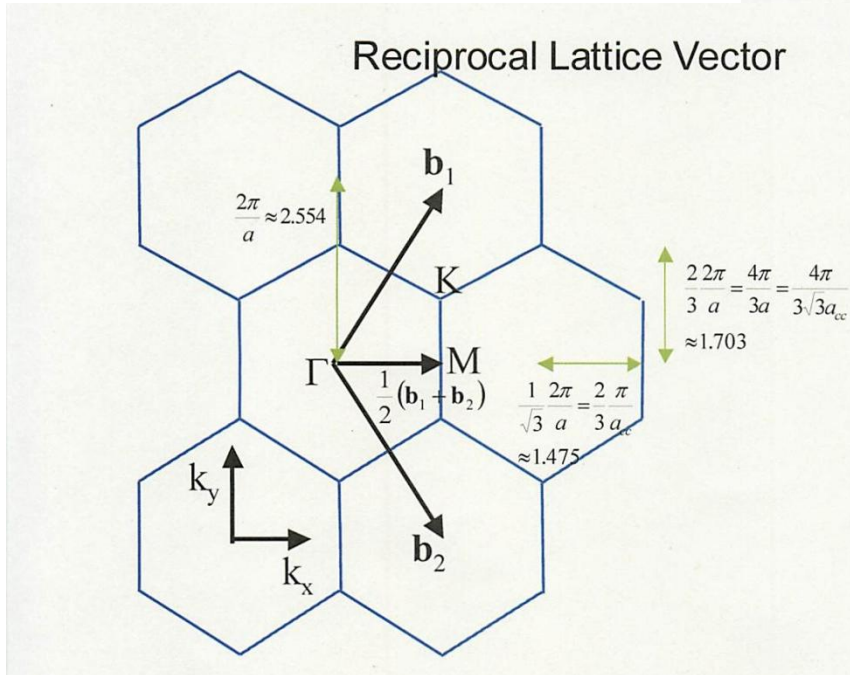
$$|\vec{C}_h| = \frac{\sqrt{3}d_{c-c}}{\pi} \sqrt{n^2 + nm + m^2}$$

$$d_{c-c} = 0.144 \text{ nm}$$

$$|a_1| = |a_2| = 0.249 \text{ nm}$$



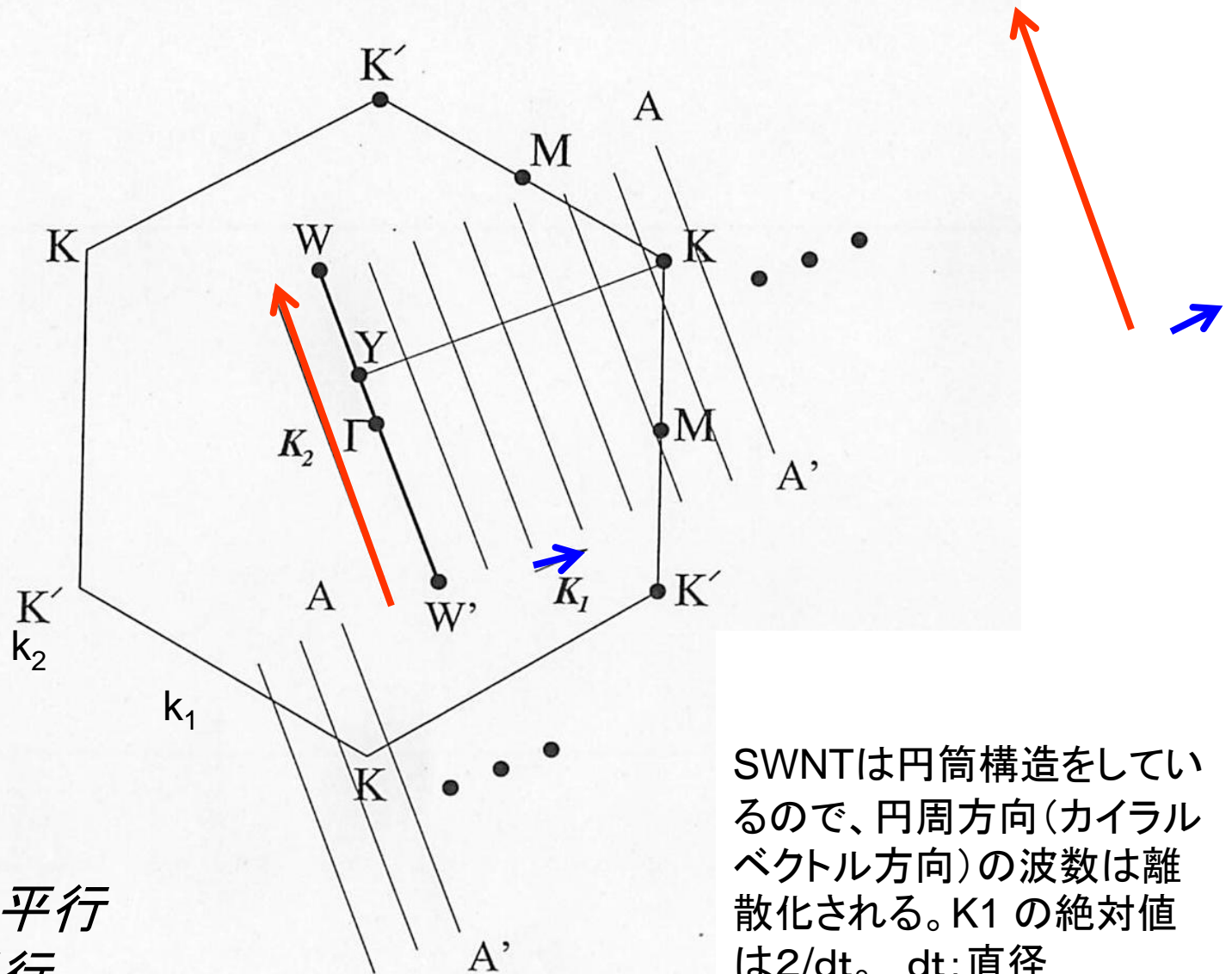
グラファイトの逆格子ベクトルとエネルギーダイアグラム



From: R. Saito, G. Dresselhaus, and M. S. Dresselhaus,
 Review B, vol. 61, no. 4, 2981 (2000).

[Color picture was from Professor [R. Saito](#)]

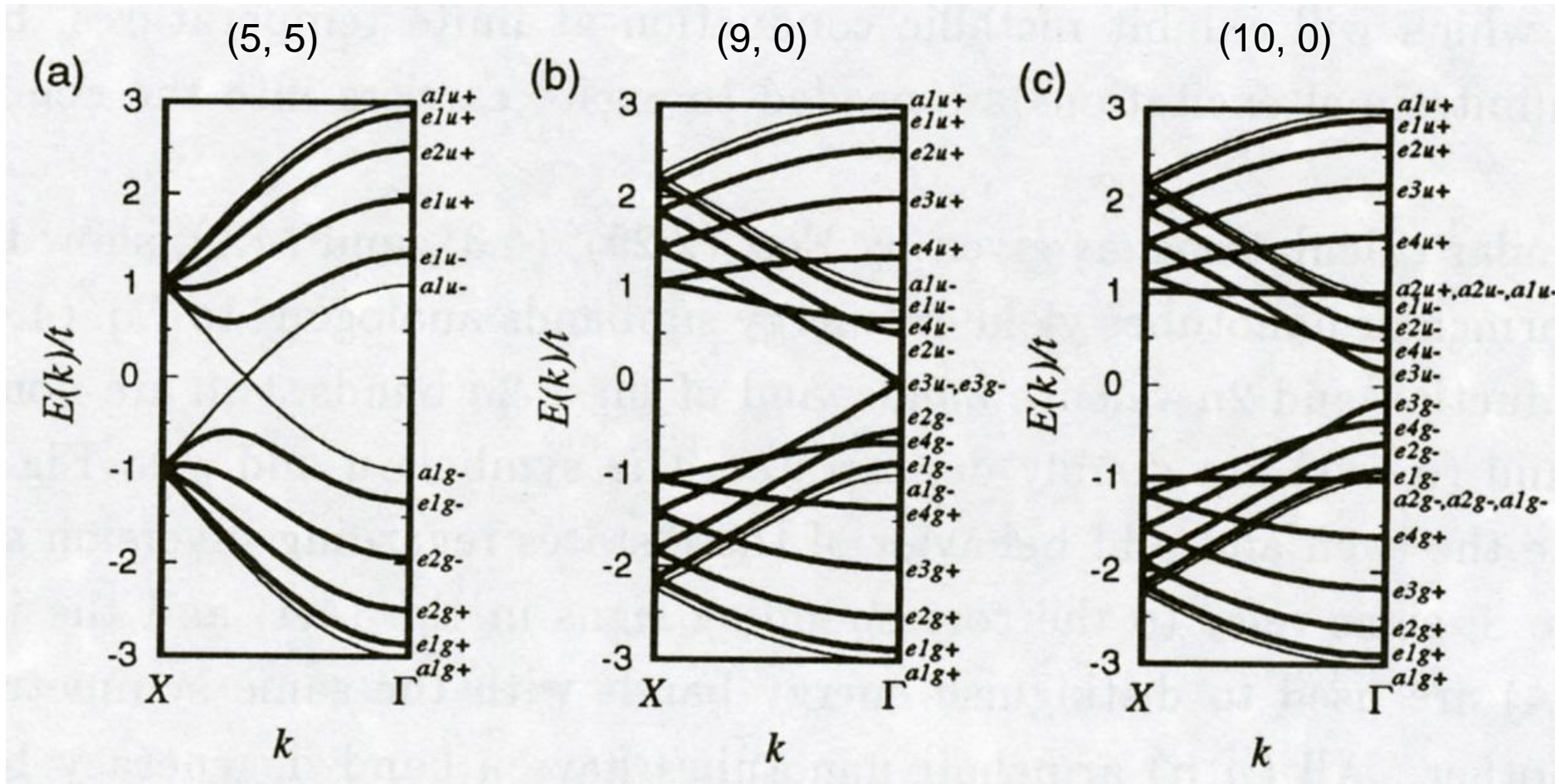
SWNTのBrillouin Zone



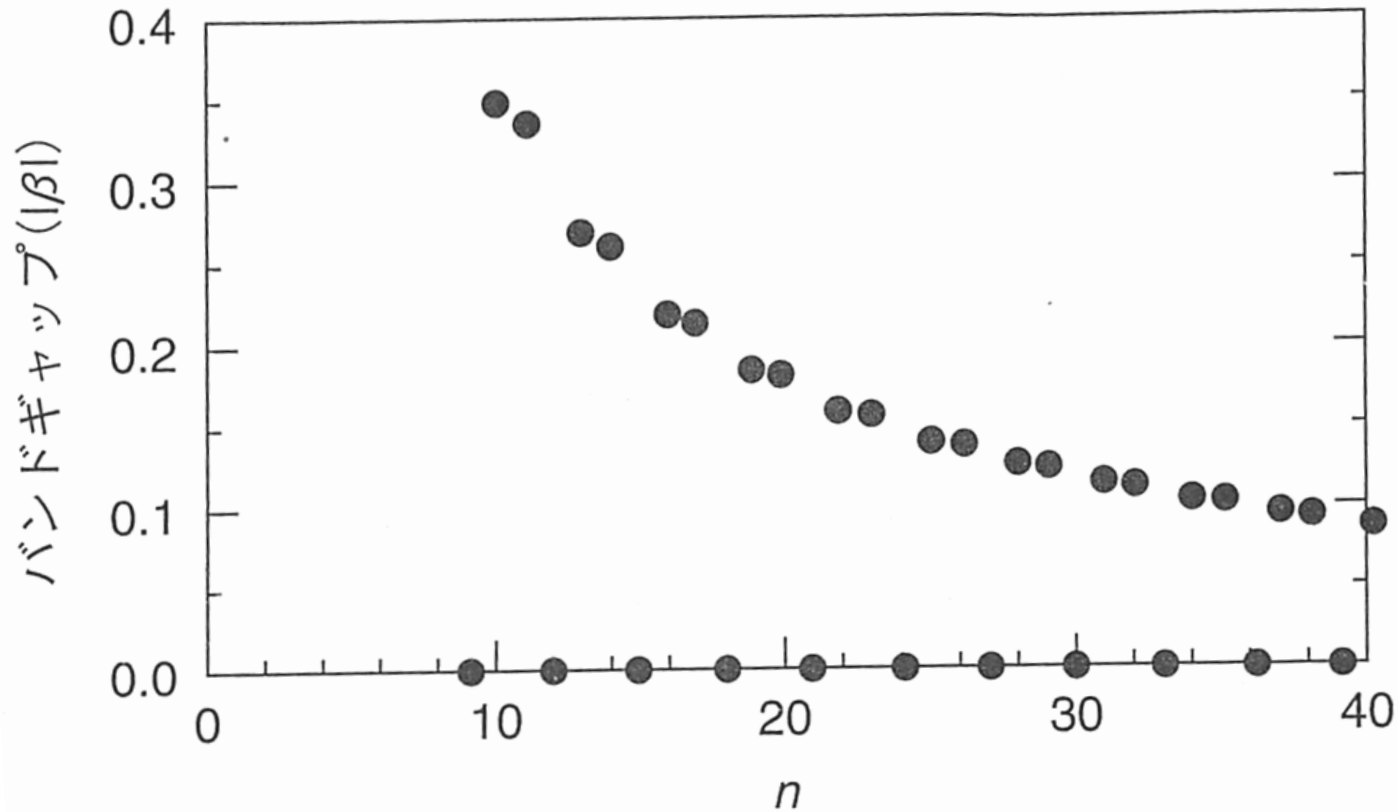
K_1 と Ch は平行
 K_2 と T は平行

SWNTは円筒構造をしているので、円周方向(カイラルベクトル方向)の波数は離散化される。 K_1 の絶対値は $2/dt$ 。 dt :直径

SWNTのエネルギーバンド構造



ジグザグ型チューブ(n, 0)のバンドギャップ

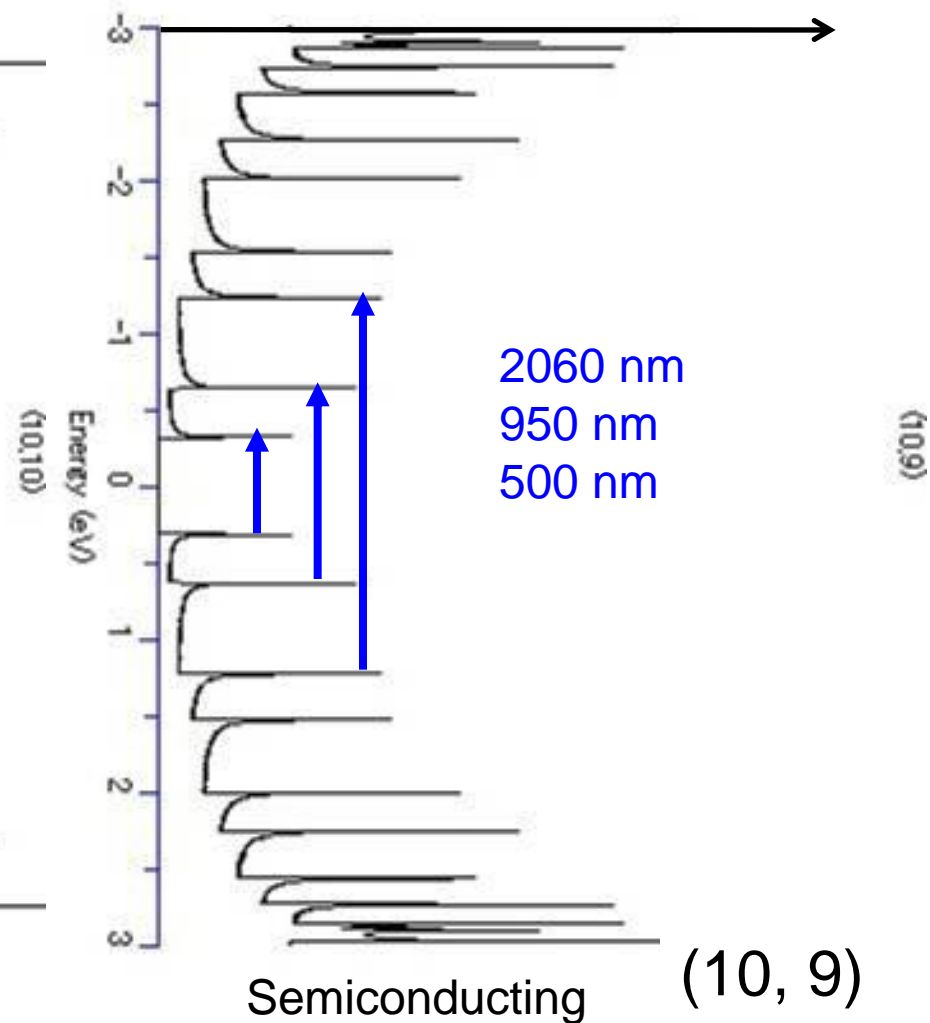
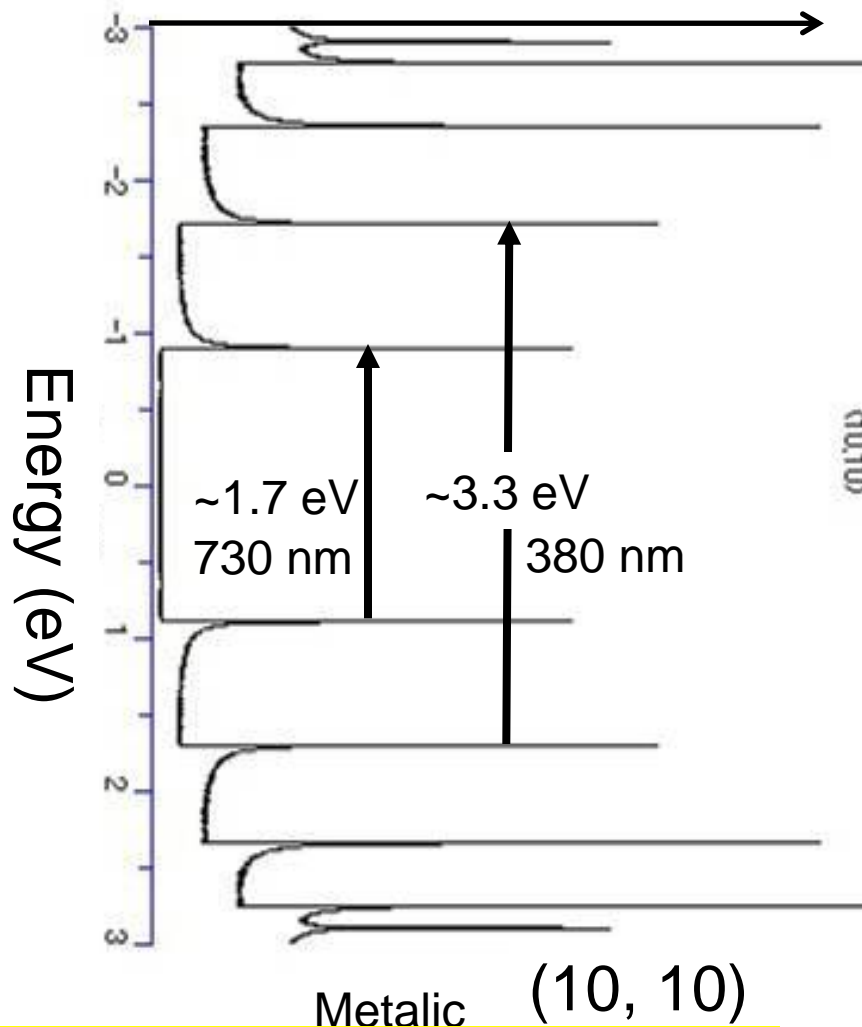


β : 隣接炭素原子軌道間の共鳴積分

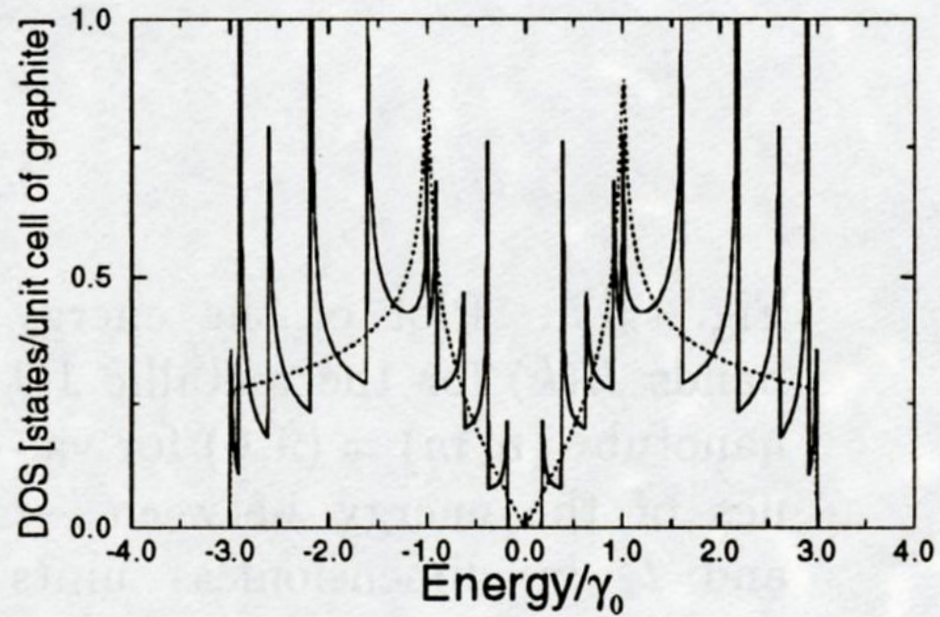
状態密度と van Hove 特異性

$$N(E) = C \frac{1}{\left(\frac{dE}{dk}\right)}$$

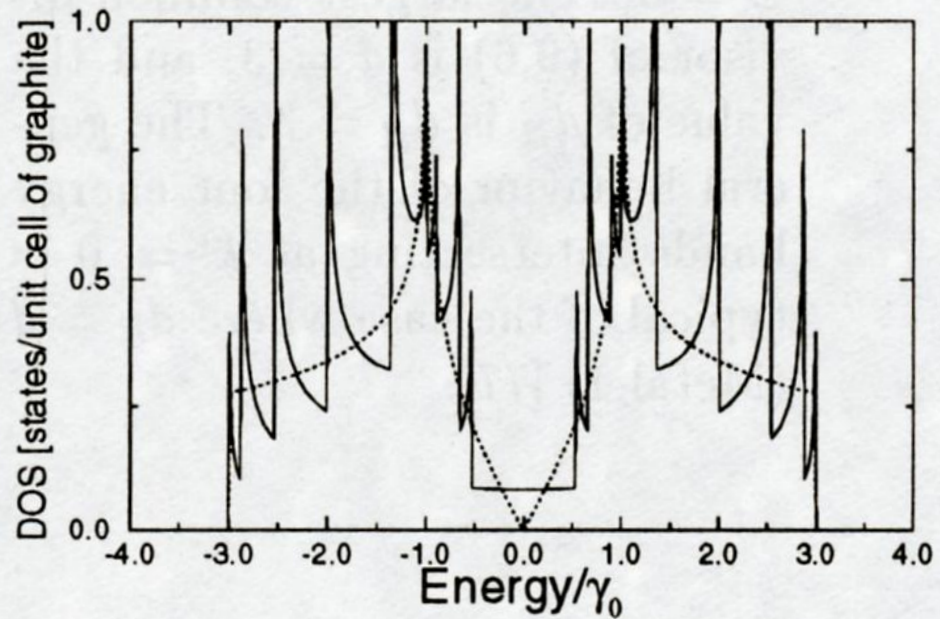
Density of states (states/ unit cell of graphite)



(a) $(n,m)=(10,0)$

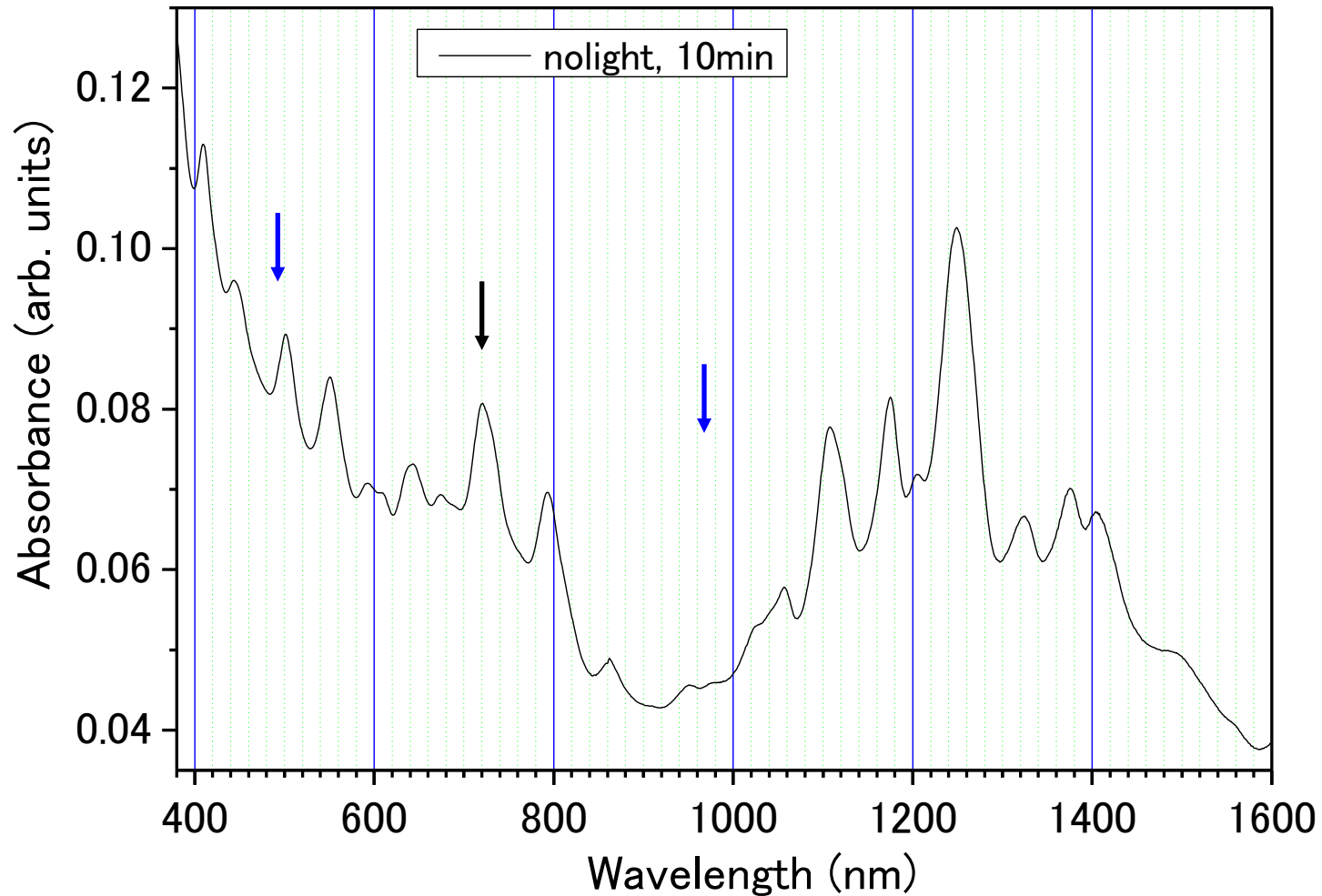


(b) $(n,m)=(9,0)$



R. Saito et al "Physical Properties of Carbon Nanotubes"

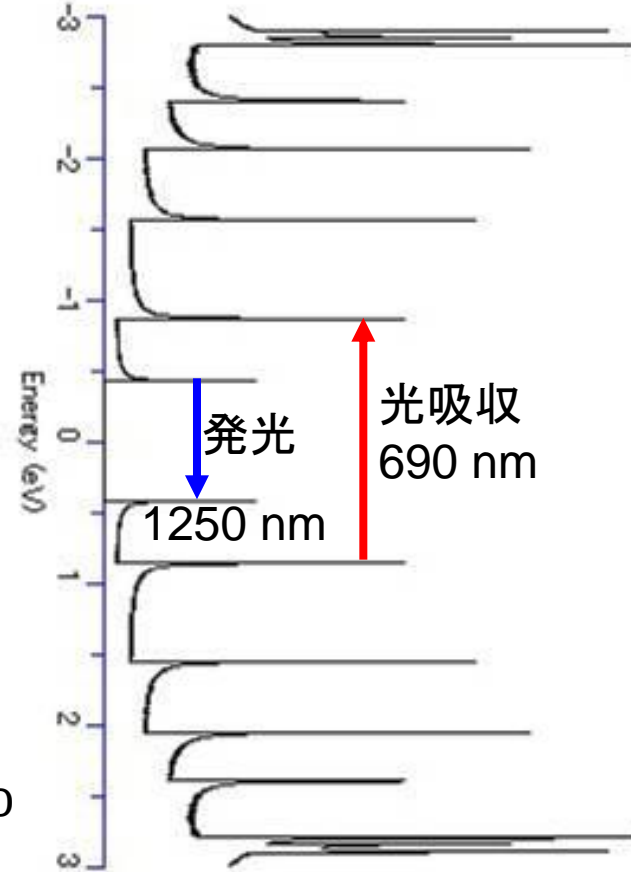
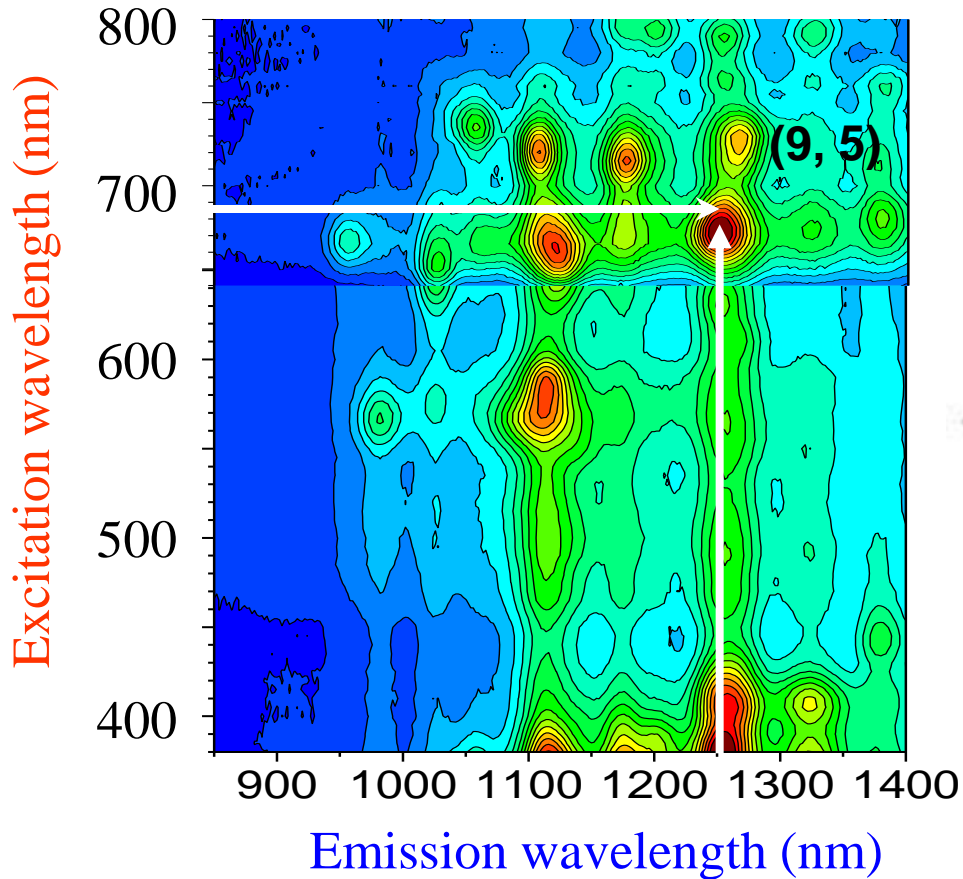
SWNTの光吸収スペクトル



HiPco(CM260007)--300oC,20min, HCl treatment--H2O2 treatment--
dried at 200oC in vac.--dispersed in 0.5% NaDDBS/D2O

蛍光スペクトルによるカイラルインデックスの決定

(9, 5)



(9, 5)

Possibility of Chirality-Controlling Growth of SWNTs.

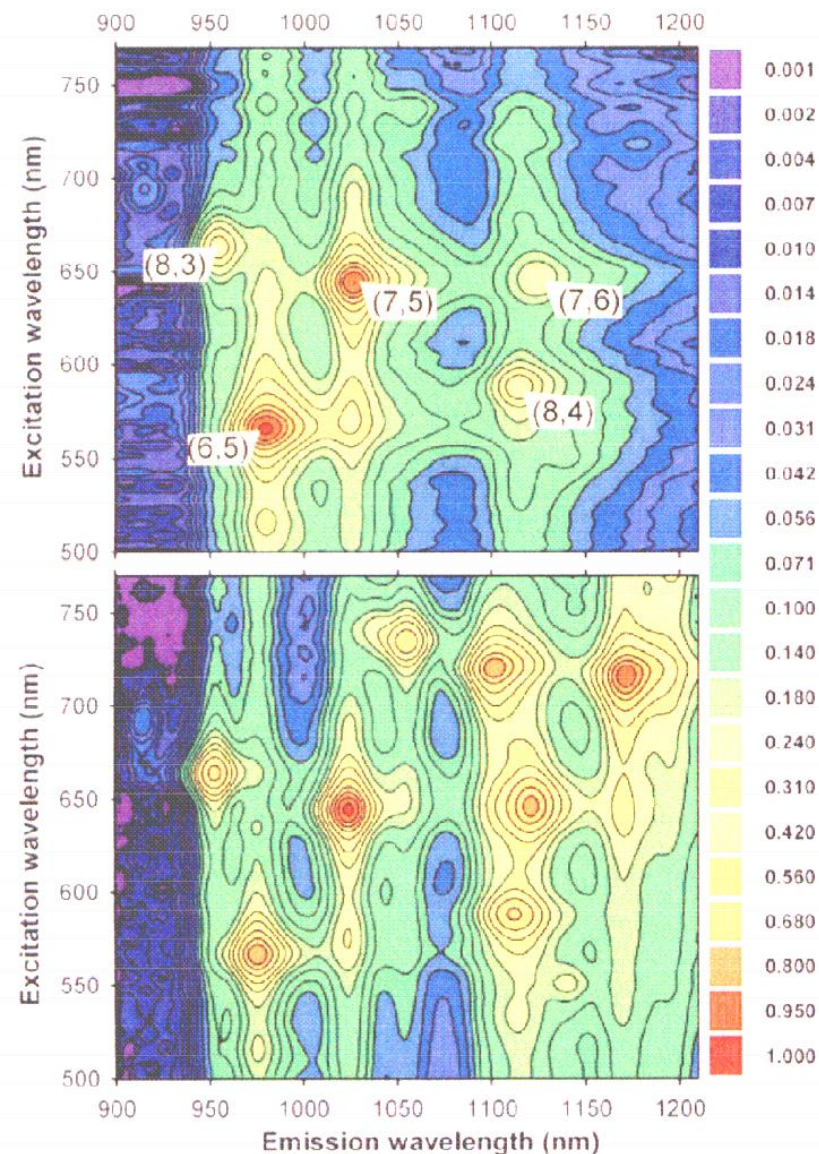
Silica support (6 nm average pore size)

2 wt% **Co:Mo=1:3**

H₂ 500°C, He 750°C, CO(pure) 5 atm,

Silica elimination by HF 3h 25°C

Bachilo, Balzano, Herrena, Pompeo, Resasco,
Weisman: JACS, ja036622c



Contour plots of normalized fluorescence intensities for the CoMoCAT sample (Top frame) and the HiPco (bottom frame).

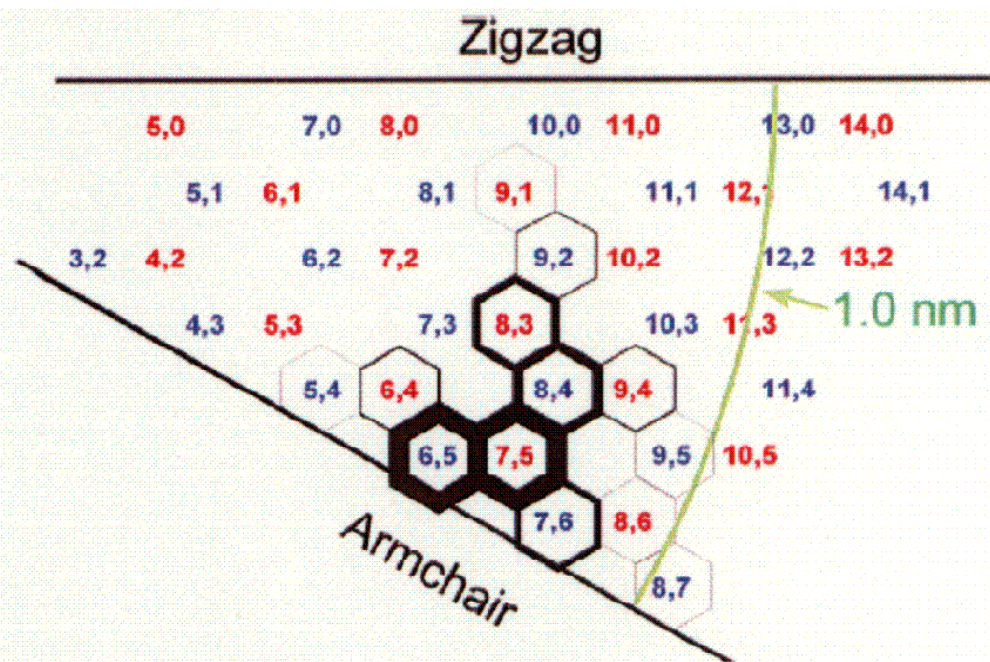
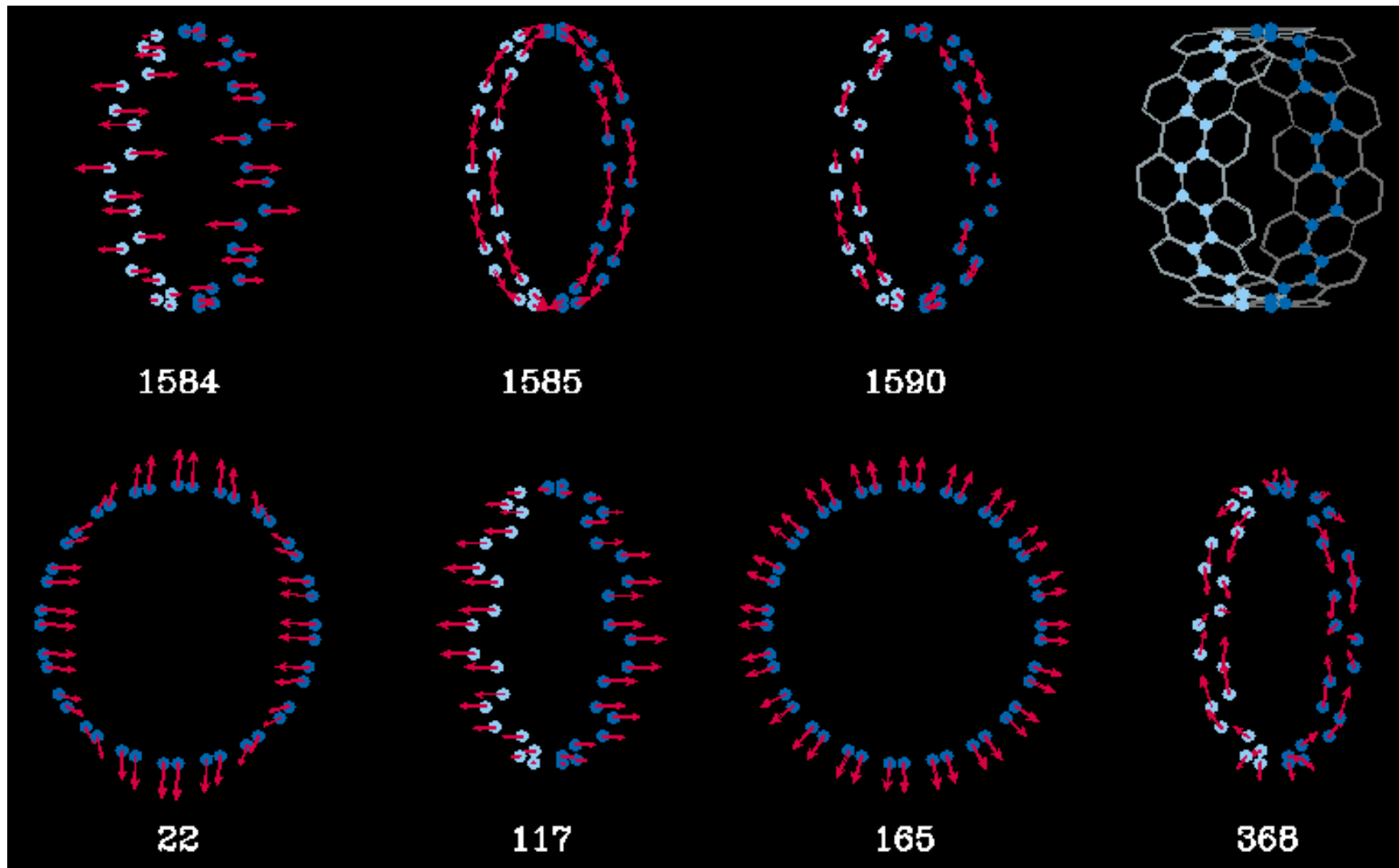


Figure 2. (n,m) -Resolved intensity map for the CoMoCAT sample. The thickness of each hexagonal cell in the graphene sheet is proportional to the observed intensity for that structure. Red and blue labels code for $\text{mod}(n-m, 3)$ families, and the arc indicates tube diameters of 1.0 nm.

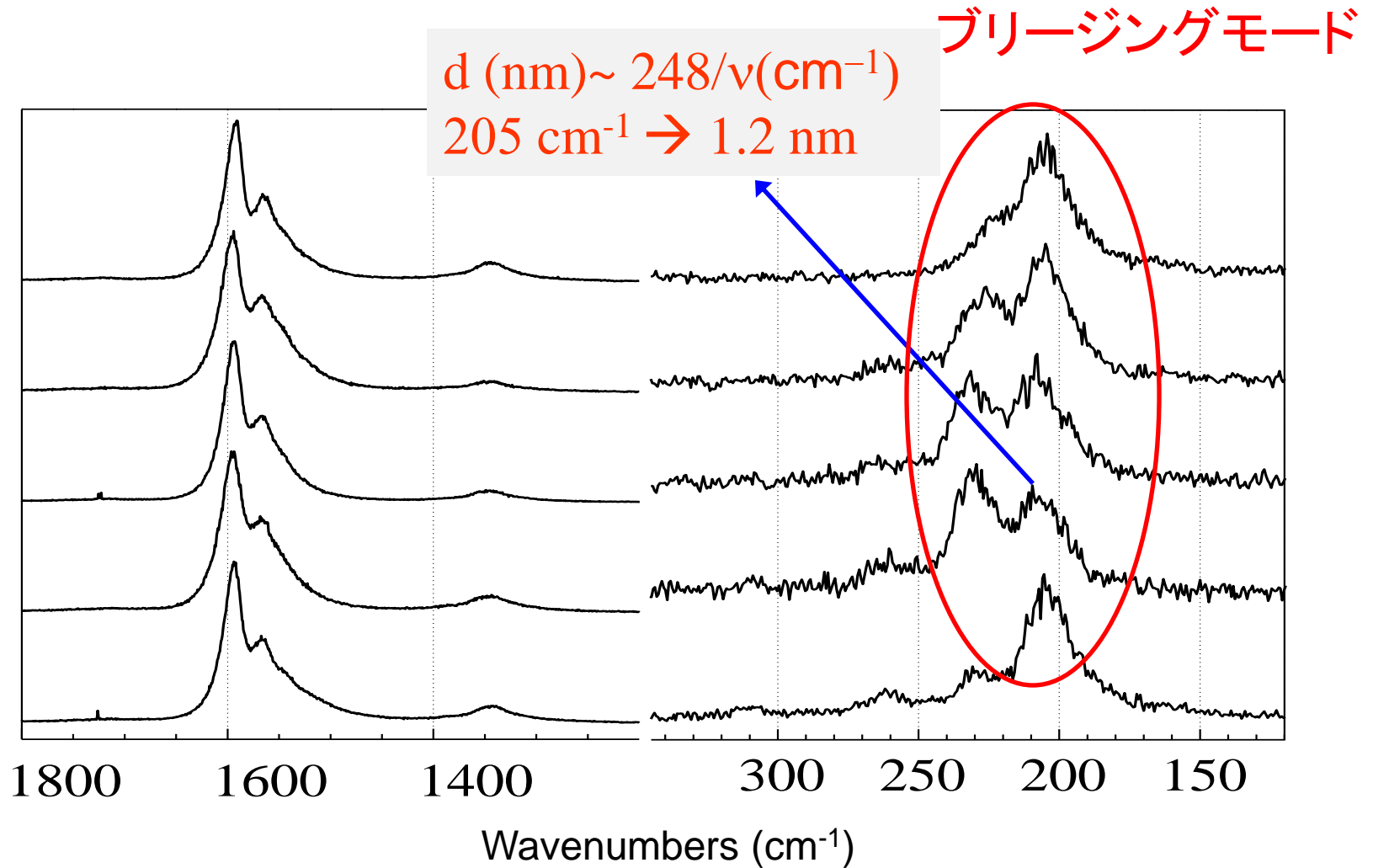
カーボンナノチューブの振動モード



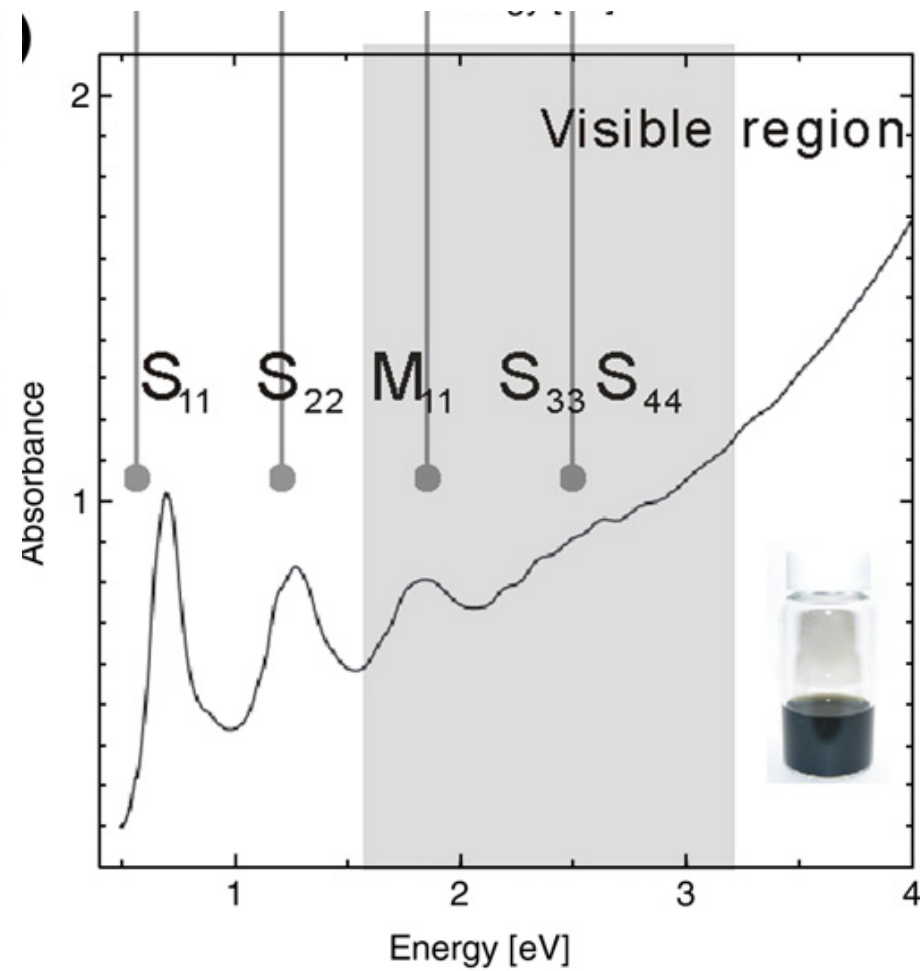
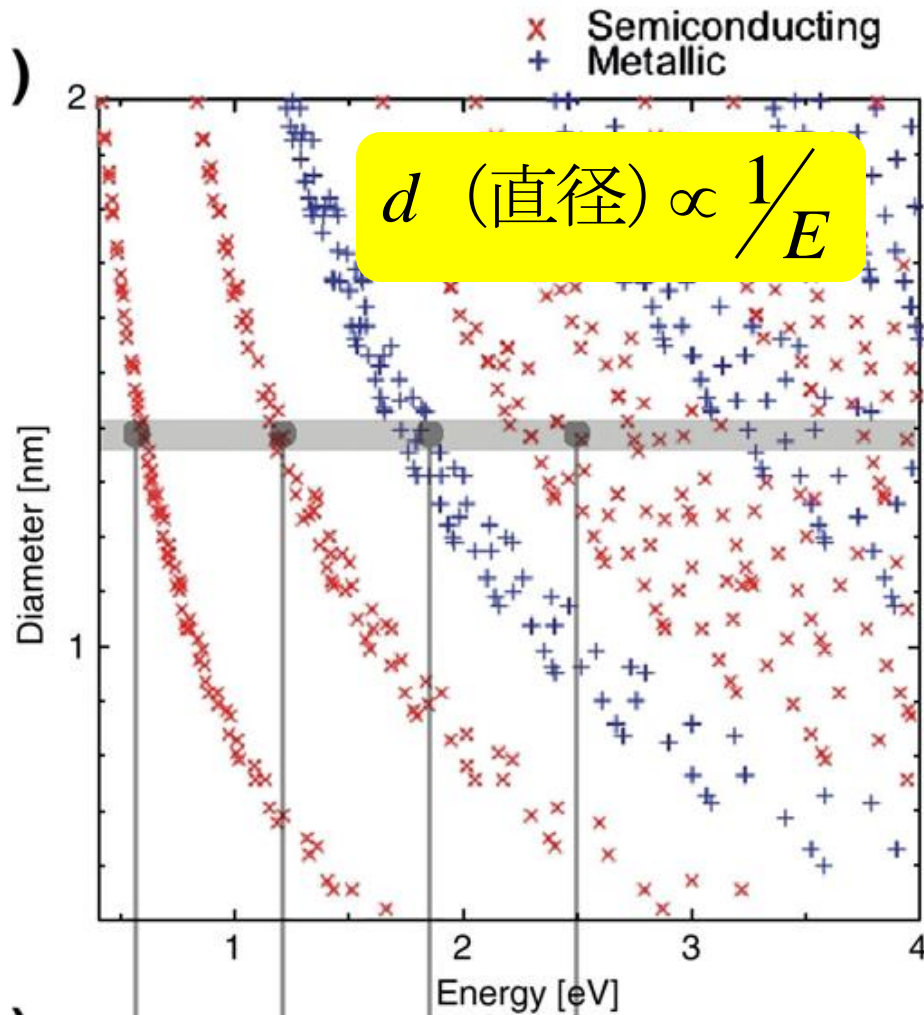
振動数の単位は cm^{-1} である

SWNTの共鳴ラマンスペクトルと直径の見積もり

共鳴ラマン散乱の効果



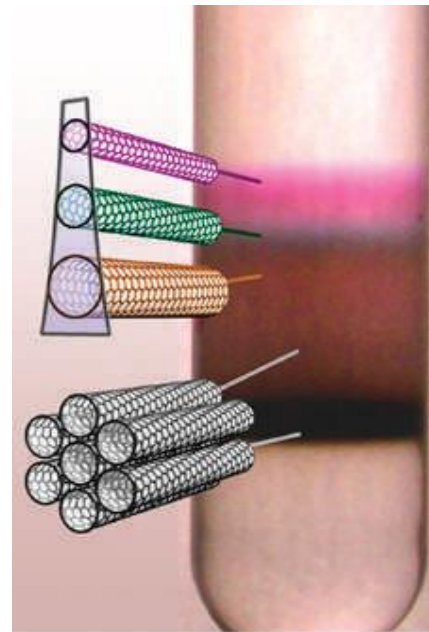
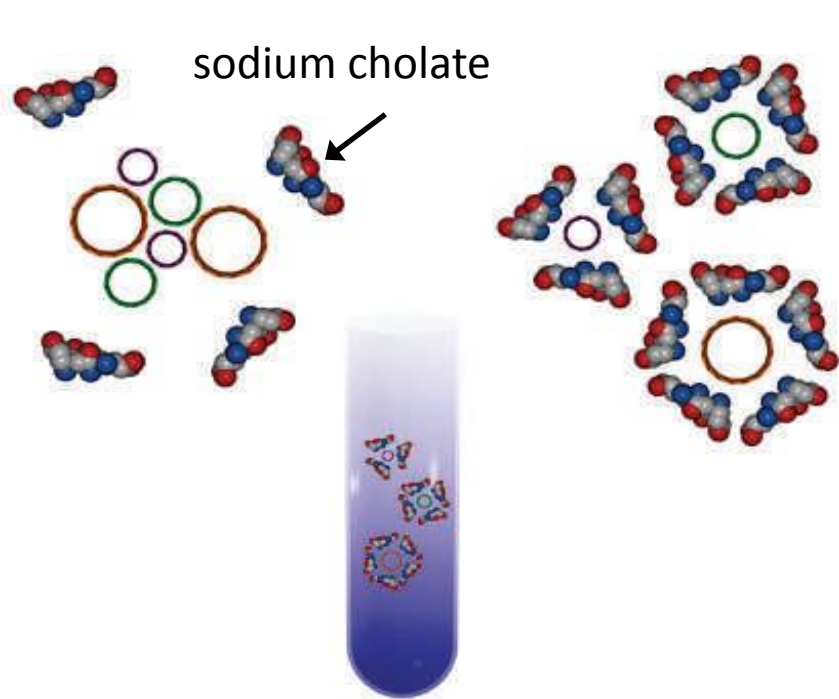
チューブの直径とエネルギーバンドギャップ



Sorting carbon nanotubes by electronic structure using density differentiation

ARNOLD, GREEN, HULVAT, STUPP AND HERSAM

Nature Nanotechnology 1(2006) 60.

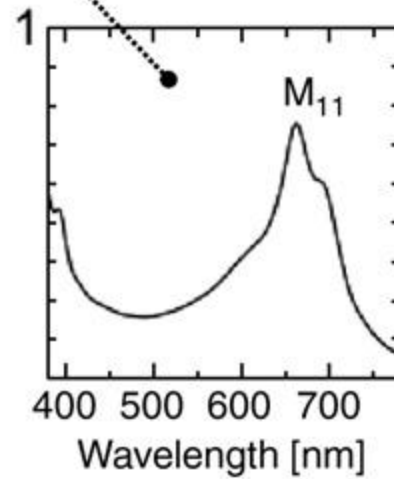
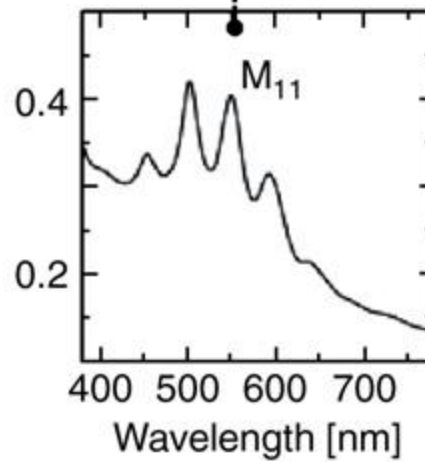
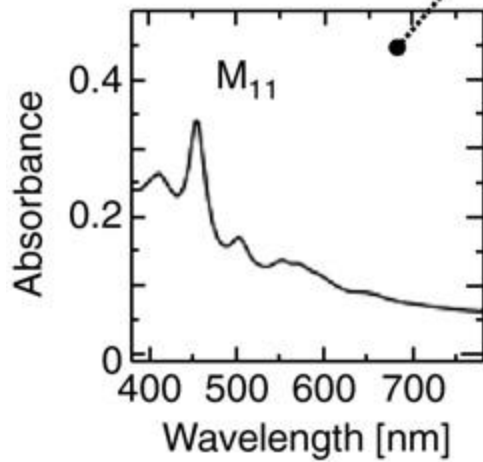
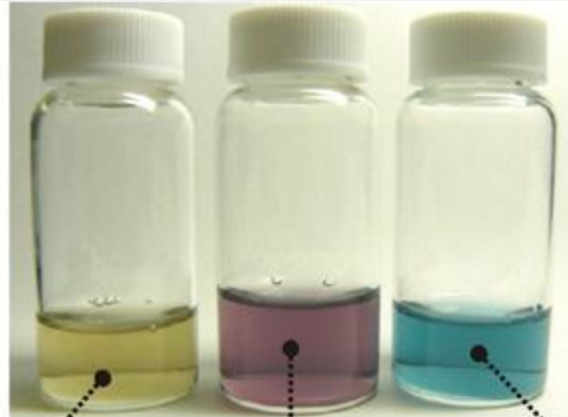


sodium cholate



Sodium
dodecylbenzene
sulphonate
(SDBS)

Diameter of SWNTs 0.8 nm 1.0 nm 1.4 nm





Colors of metallic (M) and semiconducting (S) SWCNTs. From left to right, S and M of LV, S and M of HiPco, S and M of Arc SWCNTs