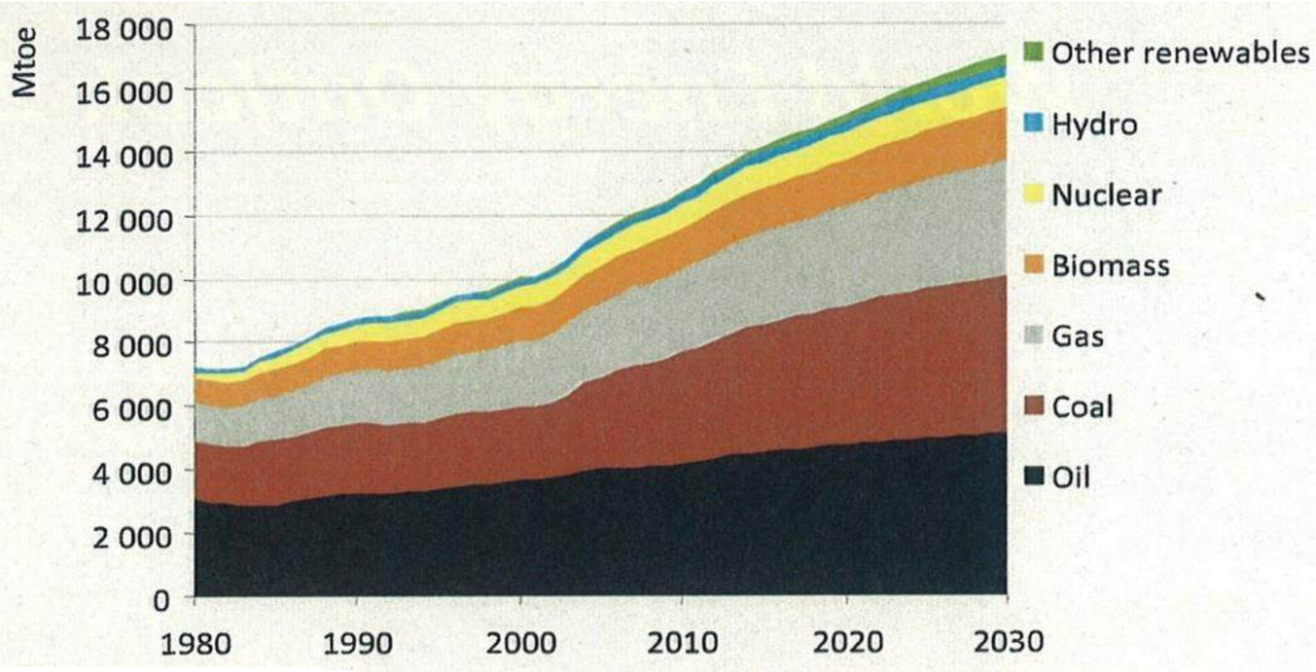
先端炭素材の調製と応用

1. バインダー、ニードルコークス
2. Li-ion電池用負極材
3. ピッチ系炭素繊維
4. 活性炭及び活性炭素繊維

九州大学先導物質化学研究所、教授
尹　聖昊

2013年9月27日

先端炭素材開発のNeedsとSeeds



	1980	2000	2006	2015	2030	Annual average increase rate 2006-30
Coal	1788	2295	3053	4023	4908	2.0%
(US)			551	580	633	0.6%
(China)			1214	1898	2441	4.0%
(India)			223	315	579	6.0%
Petroleum Oil	3107	3649	4029	4525	5109	1.0%
Gas	1235	2088	2407	2903	3670	1.8%
Nuclear Power	186	675	728	817	901	0.9%
Hydraulic Power	148	225	261	321	414	1.9%
Biomass	748	1045	1186	1375	1662	1.4%
Other Renewables	12	55	66	158	350	7.2%
Total	7223	10034	11730	14121	17014	1.6%

Approx. 45% increase

Three countries - U.S., China, and India - account for 75% in 2030

先端炭素材開発のNeedsとSeeds

•Marked Increase of Energy Demand in Asia and Africa in 21st Century

❖ Population x Demand/Head

❖ Three to Four Times of Current Demands of Fossil Fuels ⇒ Increasing By-products of Fossil Fuels

Issues

- Supply
- CO_2 Emission Enhances Global Warming
- Effective utilization of by-products of fossil fuels

Raw materials and precursors for carbons

Raw materials

Coal tar

Polymer: Thermosetting and thermoplastic

Heavy oil and residues

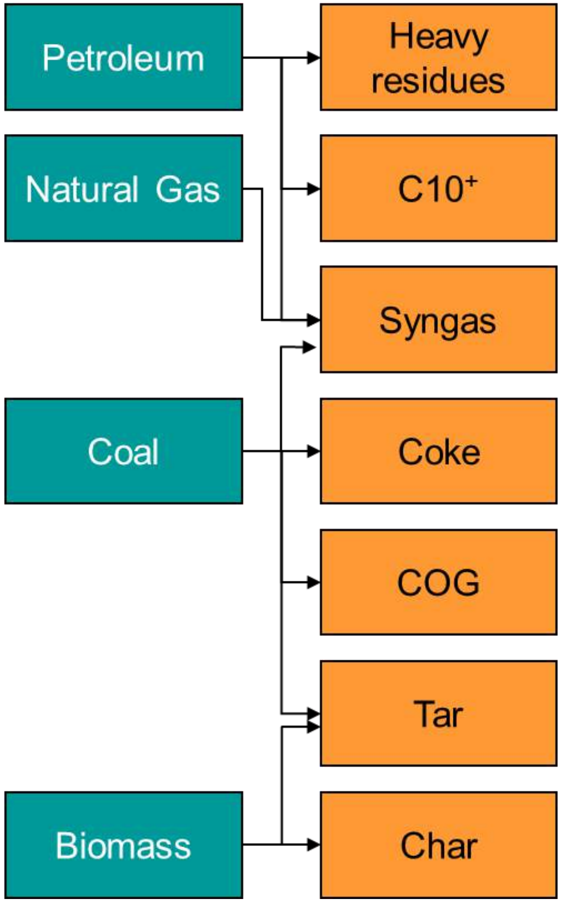
Biomass

Precursor

- Pitches: CF, ACF, MCMB, Ball type AC, Binder pitch, Additives
- Polymer: AC, ACF, Glassy carbon, CF
- Cokes: Electrode, Capacitor, Battery anode, AC, Additives
- Char: AC, Additives, Reducer for Solar cell

From fossil fuel to functional carbons

Carbonaceous resources | Side products



Advanced Carbon Materials for Energy Saving, Storing, And Environmental Protections and Improvements

Effective conversion and utilization of fossil fuels and their residues

Energy Saving

Fuel Cell
- Catalyst
- Separator
- Bipolar Plate

Advanced Generation
- Structural Materials For IGCC, IGFC
- Structural Materials For Atomic Reactor

Light Weight
- Carbon Fibers Synthetic Carbon

Energy Storing

Battery
- Li-ion battery
- Na-S battery
- Air battery

Super capacitor
- EDLC for EV, FV

Hydrogen
- H-storing Bombe

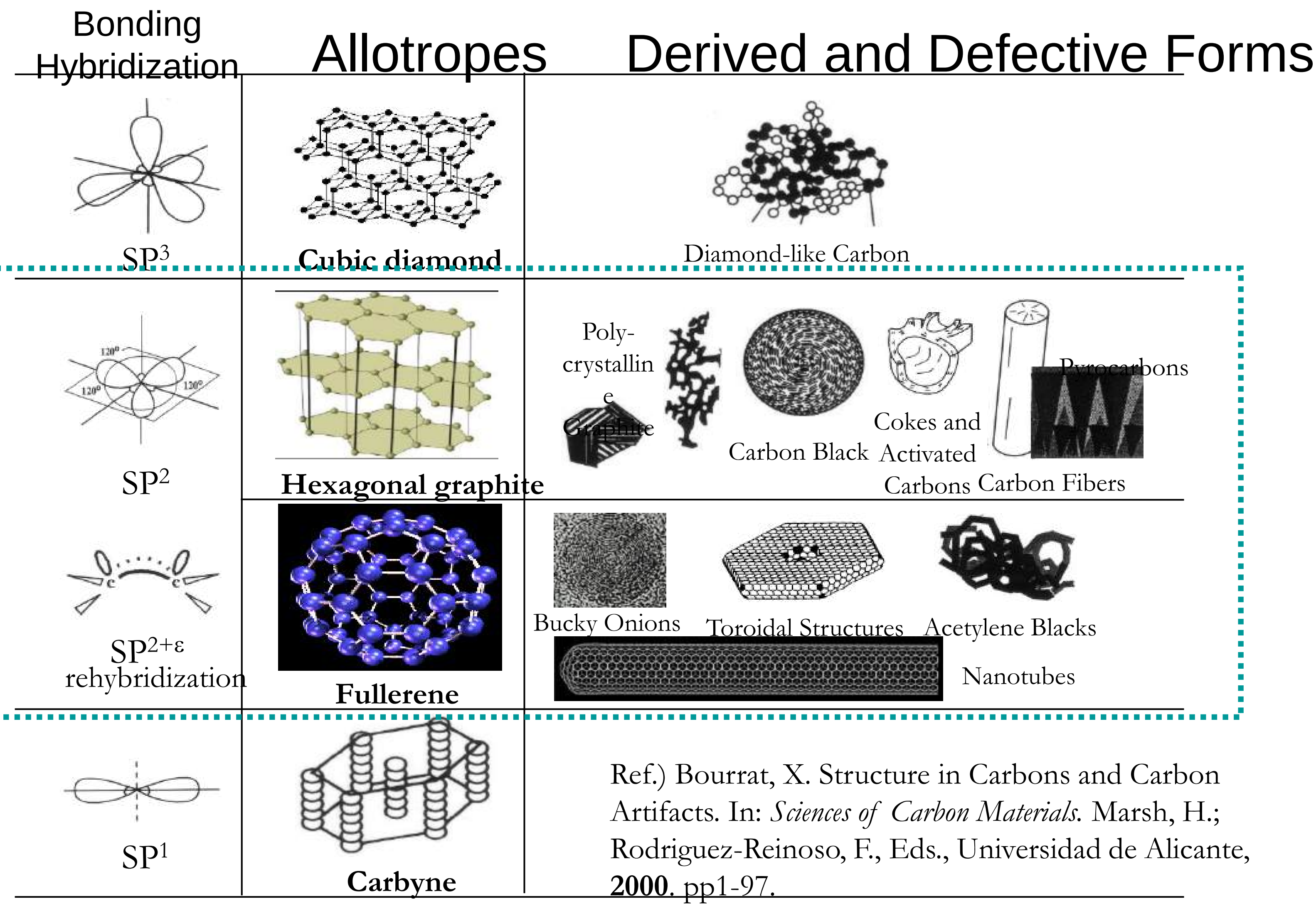
Methane
- Methane storage

Environmental Protections

Water
- Purification
- Water conversion
- NO_3^-, PO_4^{-3} removal

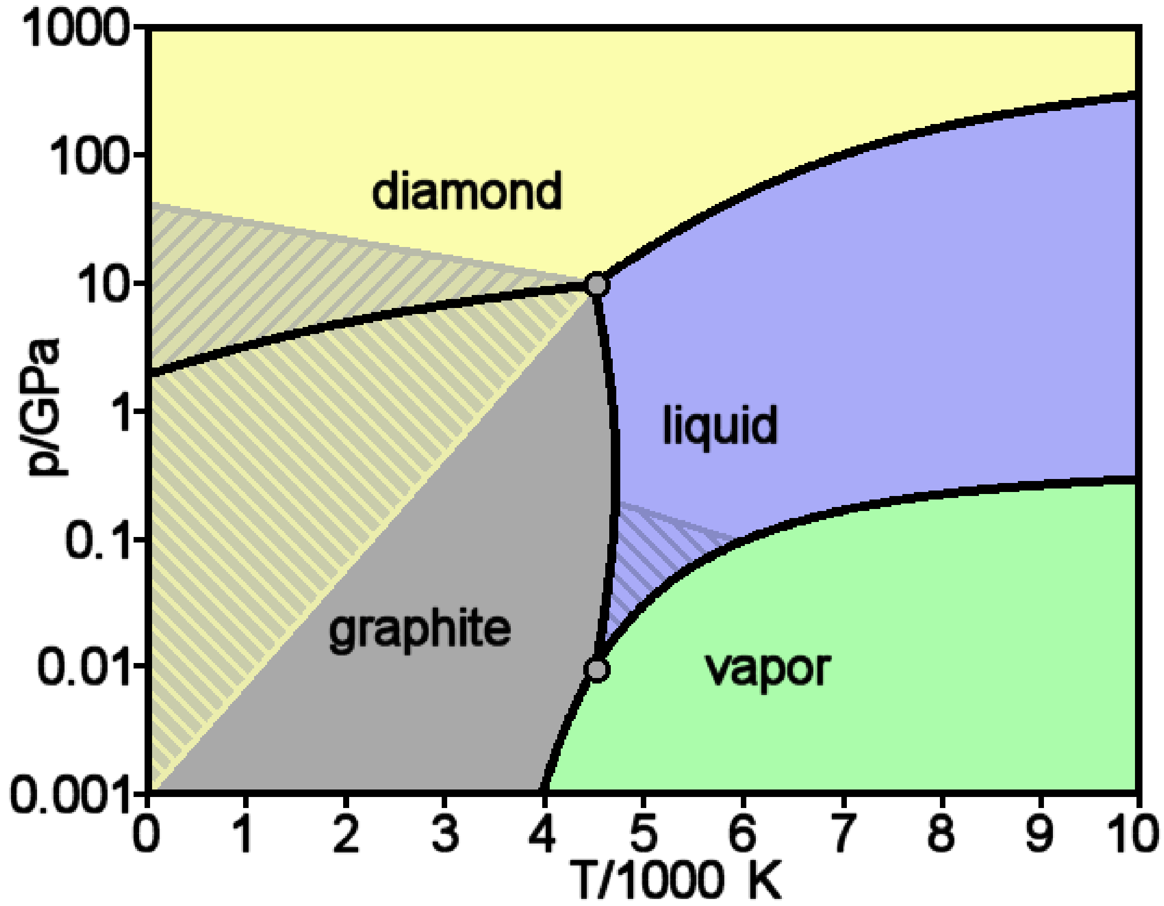
Atmosphere
- AC, ACF for DeSOx, DeNOx, deVOCs
- AC, ACF for Sick-house gases
- CO_2 separation & Concentration

Carbon Isotopes



Ref.) Bourrat, X. Structure in Carbons and Carbon Artifacts. In: *Sciences of Carbon Materials.* Marsh, H.; Rodriguez-Reinoso, F., Eds., Universidad de Alicante, **2000**. pp1-97.

炭素の状態図



0.001GPは10気圧に相当する

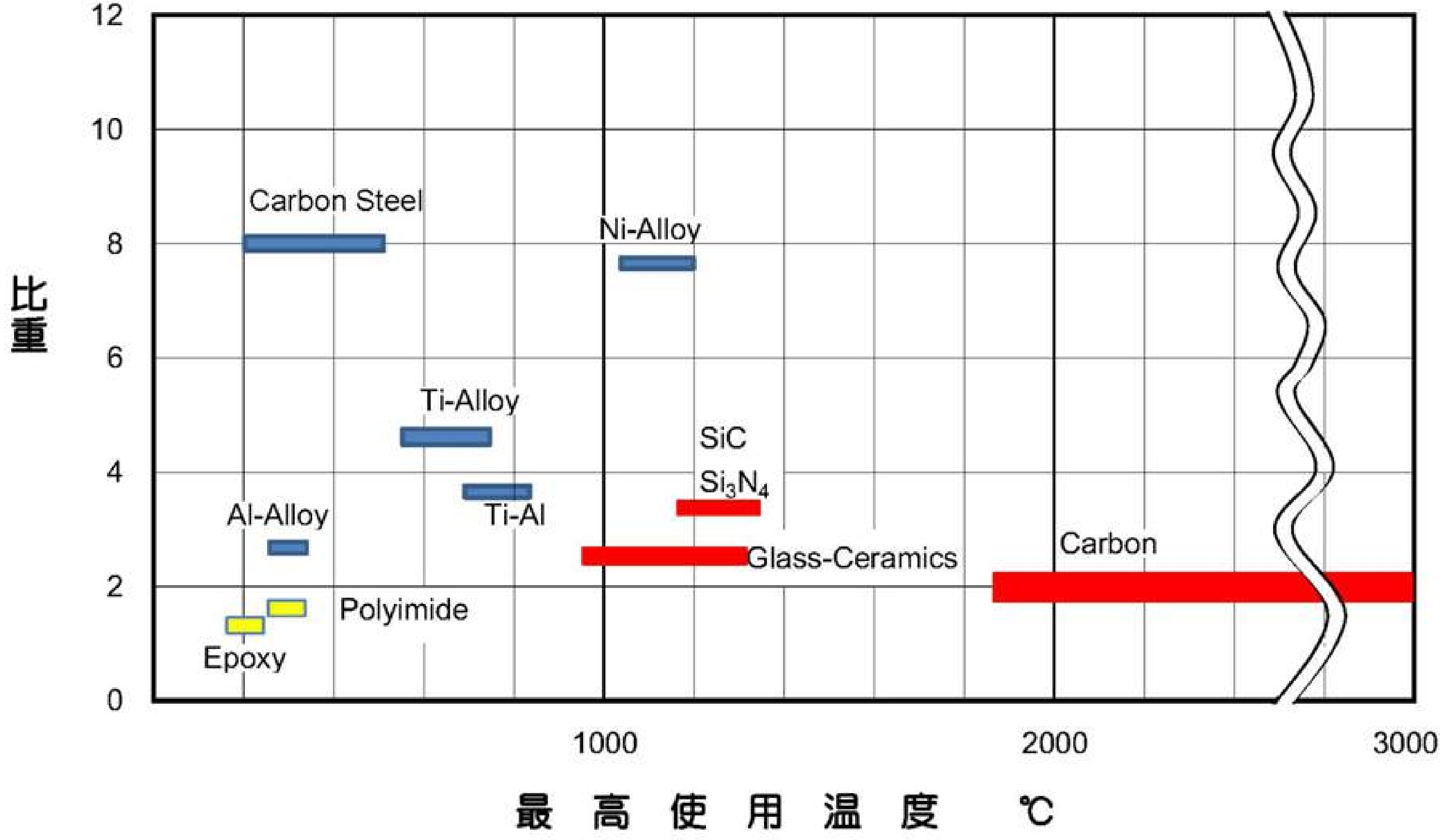
炭素の物理特性

相	固体
融点	3823 K (3550 ℃)
沸点	5073　K (4800 °　C,)
気化熱	355.8 kJ ·mol^{-1}
音の伝わる速さ	18350 m ·s^{-1} (293.15 K)

黒鉛の化学反応性

雰囲気又は反応対象物	反応温度（℃）	反応生成物
大気中	400	酸化
水蒸気中	700	酸化
水素ガス中	1,100	CH_4ガス
真空中	2,200	気化
窒素ガス中	2,500	C_2N_2
Al	800	Al_4C_3
B	1,600	B_4C
Fe	600-800	Fe_3C
W	1,400	W_2C，WC（水素中）

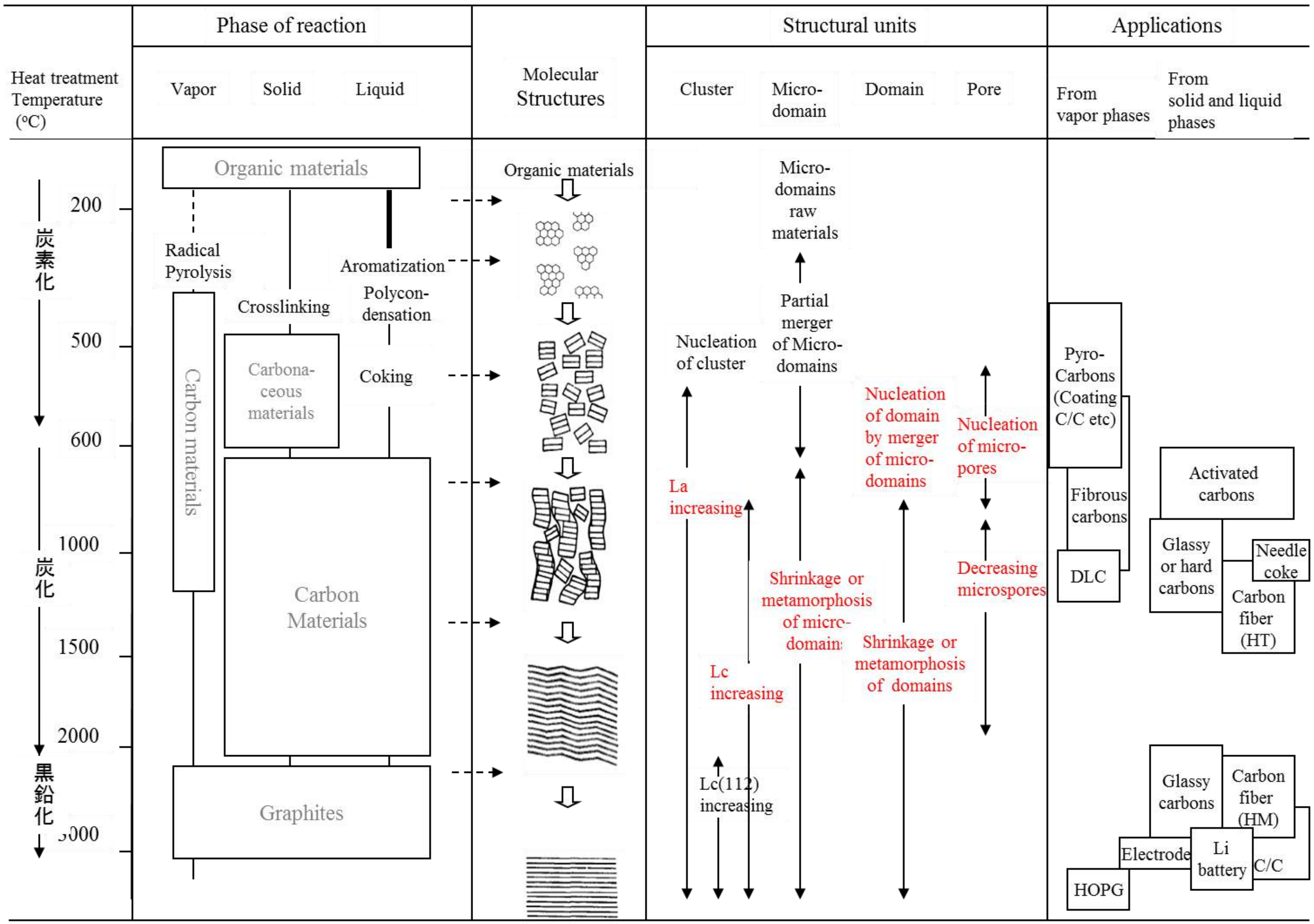
各種材料の耐熱性と比重



炭素化反応

炭素の生成反応

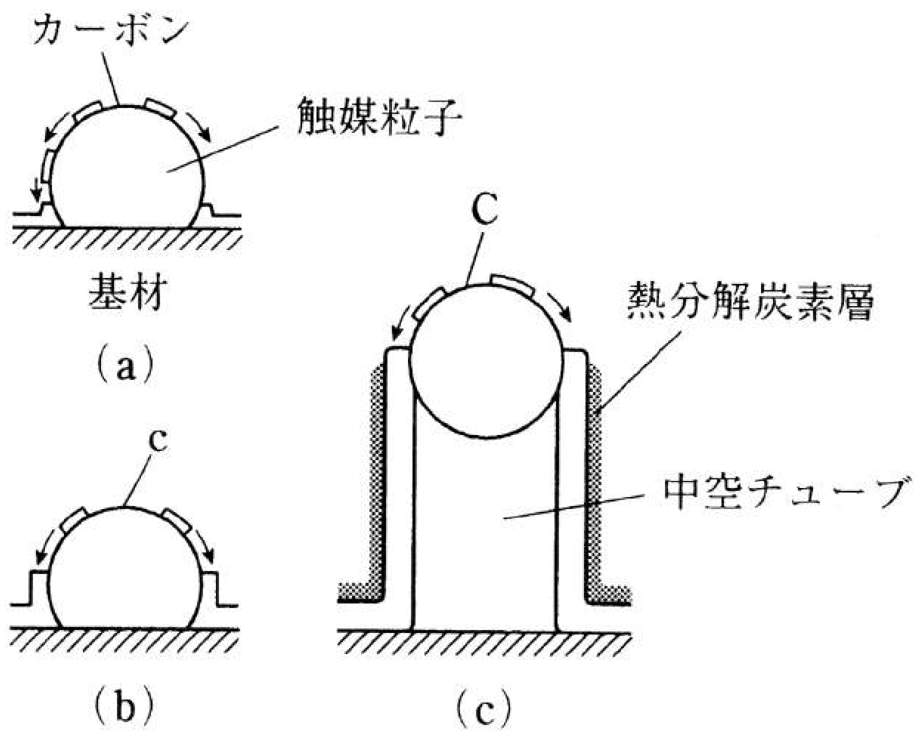
炭素の生成（固・液相）


Phase of reaction
Structural units
Applications
Heat treatment Temperature (°C)
Vapor
Solid
Liquid
Molecular Structures
Cluster
Micro-domain
Domain
Pore
From vapor phases
From solid and liquid phases
炭素化
炭化
黒鉛化
200
500
600
1000
1500
2000
Organic materials
Radical Pyrolysis
Crosslinking
Aromatization
Polycon-densation
Coking
Carbon materials
Carbona-ceous materials
Carbon Materials
Graphites
Organic materials
Micro-domains raw materials
Partial merger of Micro-domains
Nucleation of cluster
La increasing
Lc increasing
Lc(112) increasing
Shrinkage or metamorphosis of micro-domains
Nucleation of domain by merger of micro-domains
Shrinkage or metamorphosis of domains
Nucleation of micro-pores
Decreasing microspores
Pyro-Carbons (Coating C/C etc)
Fibrous carbons
DLC
Activated carbons
Glassy or hard carbons
Needle coke
Carbon fiber (HT)
Glassy carbons
Carbon fiber (HM)
Electrode
Li battery
C/C
HOPG

炭素化プロセスと特徴

プロセス	原　　　料	炭　素　材　料	特　　　徴
気相炭化	揮発性有機物	カーボンブラック 熱分解炭素 カーボンホイスカー	超微粒 高配向性 高強度、高電導性、高弾性
液相炭化	溶融溶解性有機物、溶融性石炭	コークス 人造黒鉛 高密度等方性黒鉛	高異方性 高異方性、高電導性 等方性、高密度
固相炭化	不融性繊維状有機物 熱硬化性高分子 木材、非溶融性石炭	炭素繊維 ガラス状炭素 活性炭 モレキュラーシーブカーボン	高強度、高弾性 高強度、ガス不適過 多孔性、吸着 分子ふるい

VGCF、CNTの成長モデル

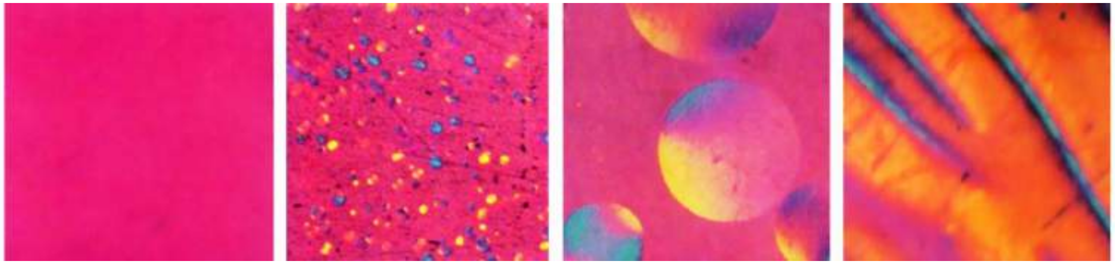


T. Bairdモデル； (a)→(b)→(c)の順に成長

典型的な液相炭化反応の様相

低　熱処理温度　高

短　熱処理時間　長

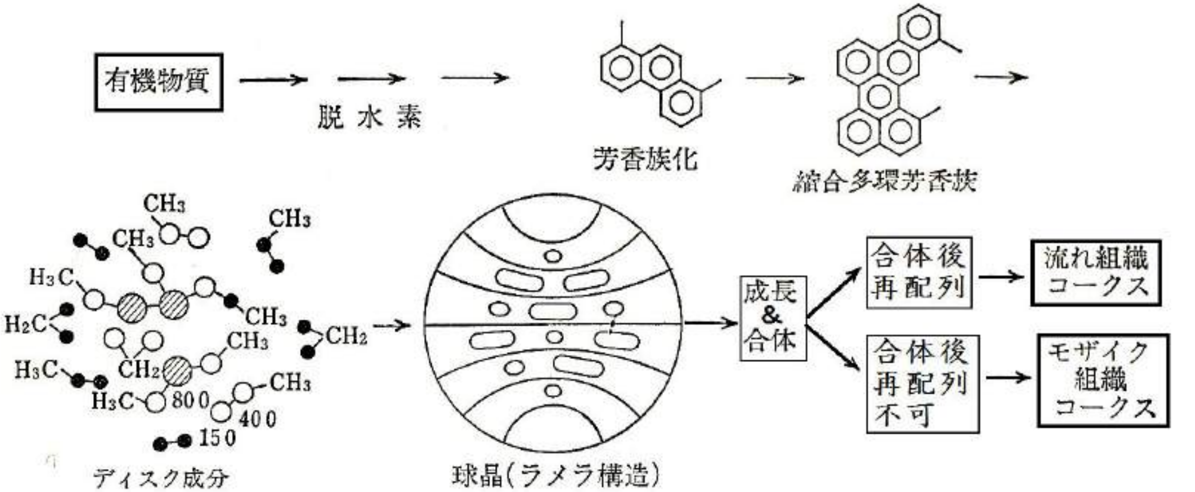


原料ピッチ

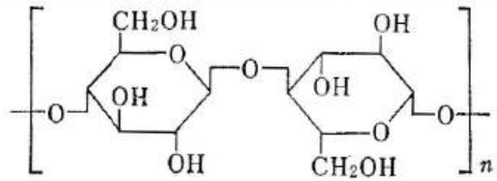
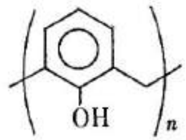
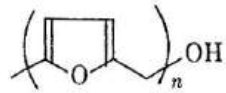
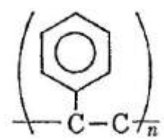
メソフェーズ
球晶発生

メソフェーズ
球晶成長

球晶成長・合体
バルクメソフェーズ

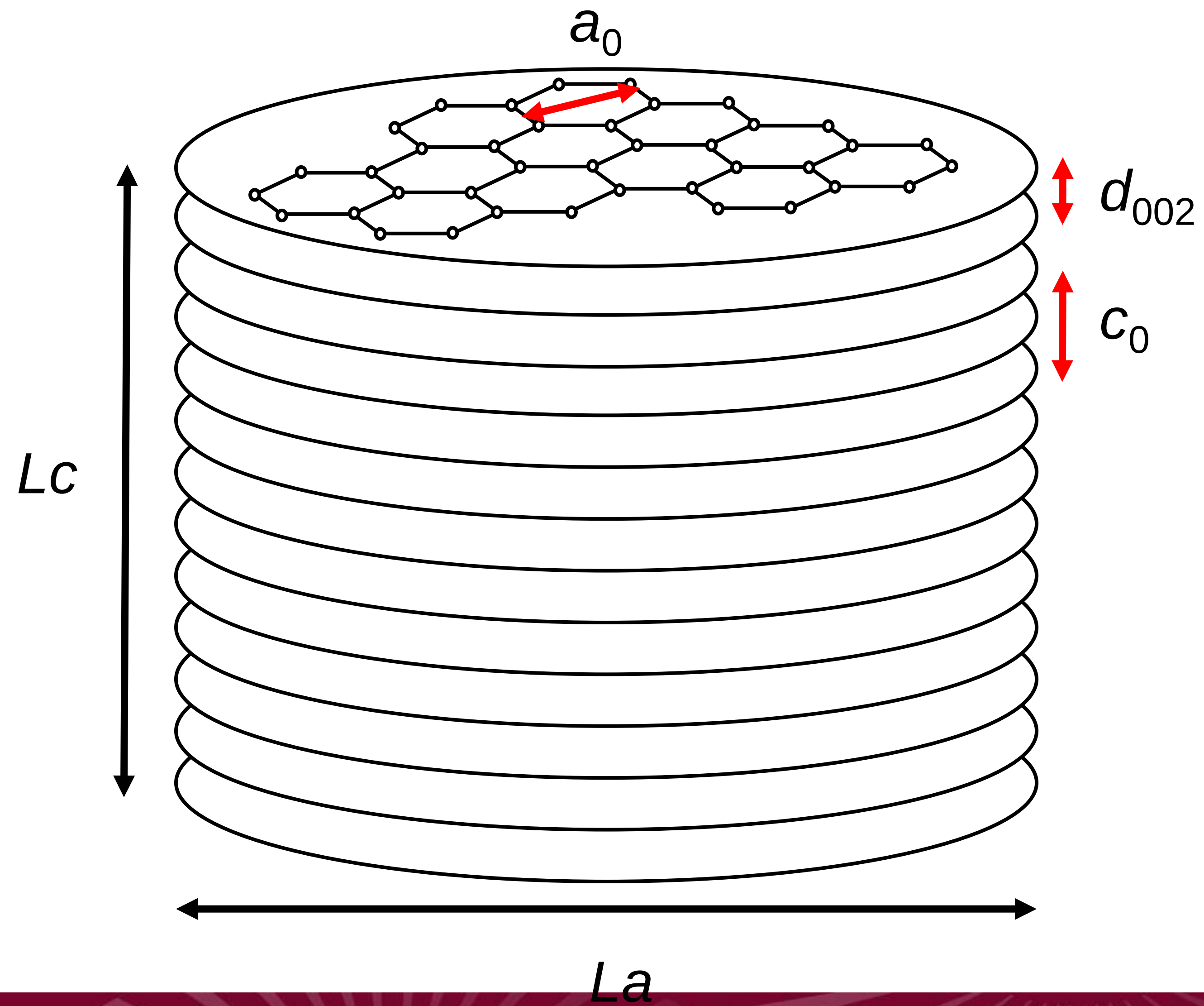


固相炭化の原料となる高分子

分類		高分子		通常の炭化相	用途
天然	不融	セルロース		固相	ガラス状炭素 炭素繊維 モレキュラーシーブカーボン
合成	熱硬化性	フェノール-ホルムアルデヒド樹脂		固相	ガラス状炭素
		フルフリルアルコール樹脂 フェノール-フラン系樹脂		固相	ガラス状炭素 ガラス状炭素繊維
		架橋状ポリスチレン		固相	微小球粉体
	熱可塑性	ポリスチレン		分解	
		ポリアミド	$(-(CH_2)_n-CONH-)_n$	固相	炭素繊維
		ポリアクリロニトリル (PAN)	$(-C-C\cdot CN-)_n$	固相（耐炎処理）	炭素繊維
		ポリ塩化ビニリデン (PVDC)	$(-C-C\cdot Cl_2-)_n$	固相	モレキュラーシーブカーボン
		ポリ塩化ビニル (PVC)	$(-C-C\cdot Cl-)_n$	液相	炭素繊維
		ポリビニルアルコール (PVA)	$(-C-C\cdot OH-)_n$	HClガス下ピッチ化	炭素繊維
ピッチ	可融	ピッチ		不融化処理後固相	炭素繊維

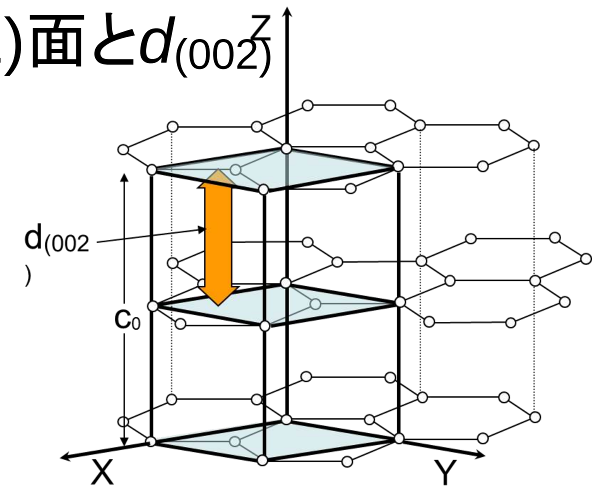
炭素の構造

炭素の結晶構造パラメータ

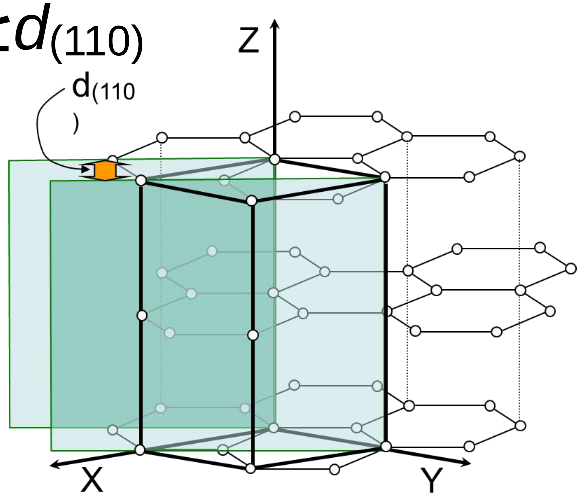


結晶面と面間隔の関係

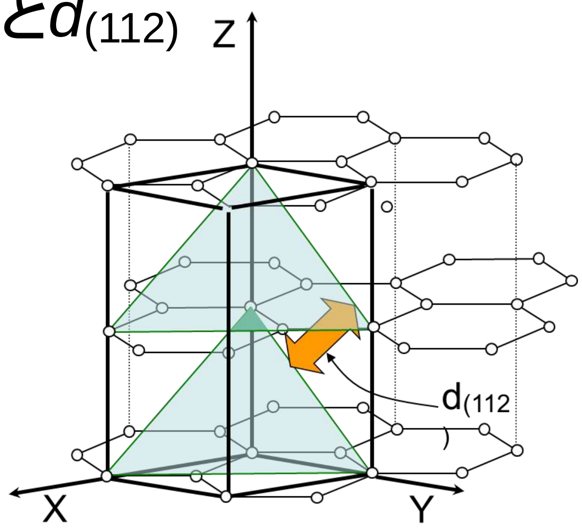
(002)面と$d_{(002)}$



(110)面と$d_{(110)}$



(112)面と$d_{(112)}$



有機物の加熱による変化

前駆体生成過程

炭素化過程

黒鉛化過程

前期

後期

低分子
生成物　H_2O, CO_2, CH_4, H_2

500℃

1000℃

1500℃

3000℃

分解
芳香族化
重縮合

前駆体

共役系
拡大

炭素

組織の
緻密化

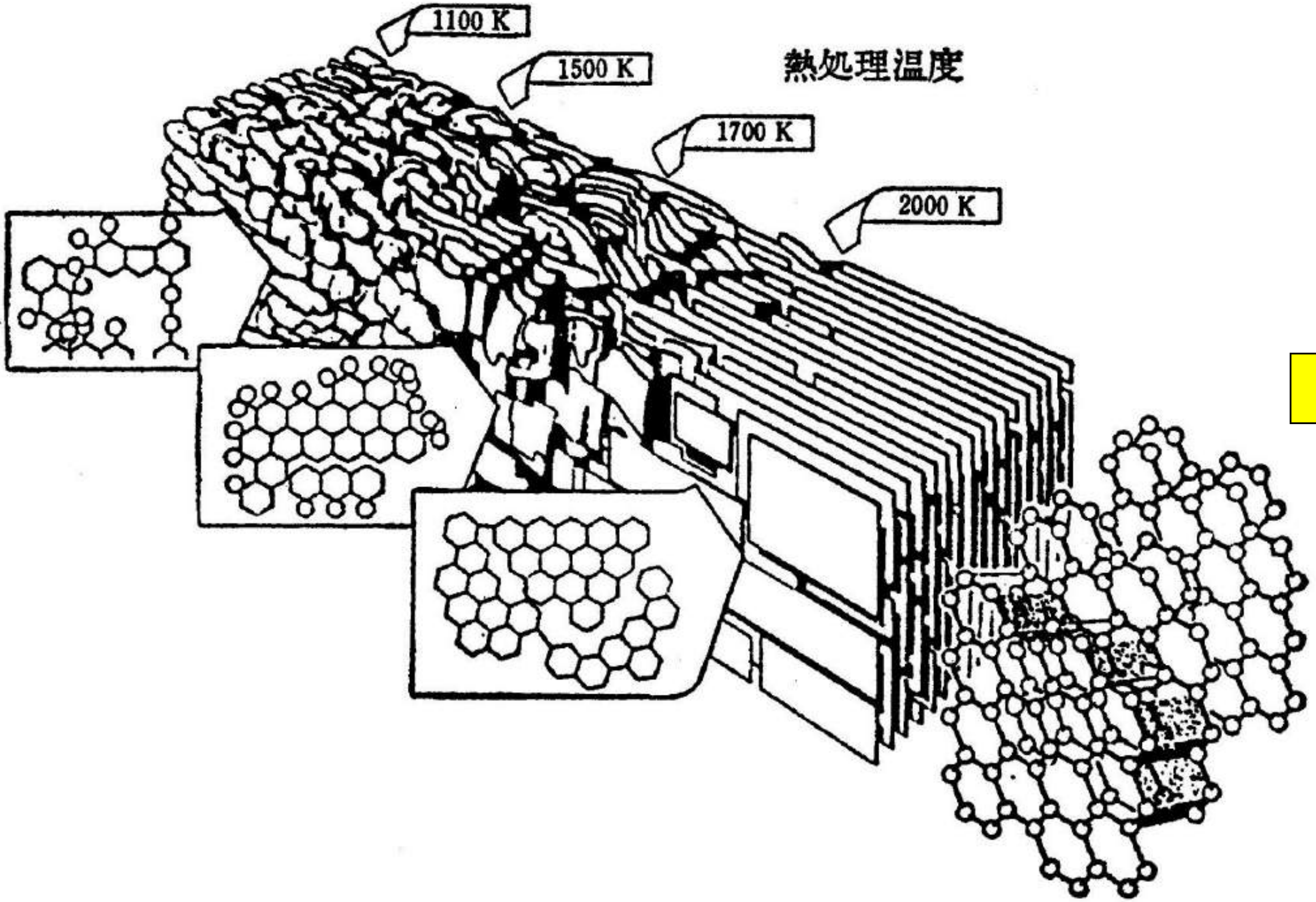
構造再編
黒鉛構造発達

黒鉛

焼成工程

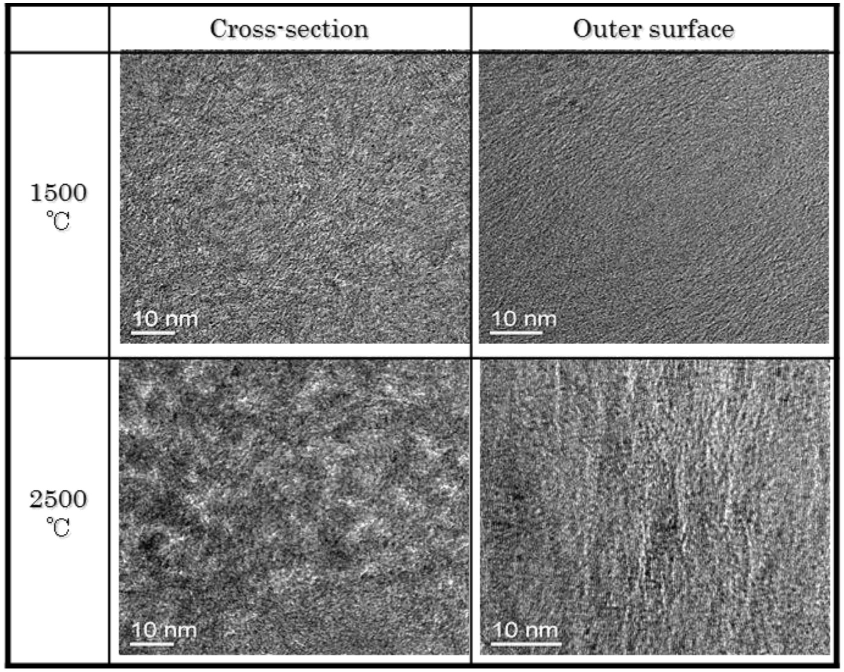
黒鉛化工程

熱処理温度による結晶構造変化



黒鉛

Nanoscopic Structure of PAN Based CF



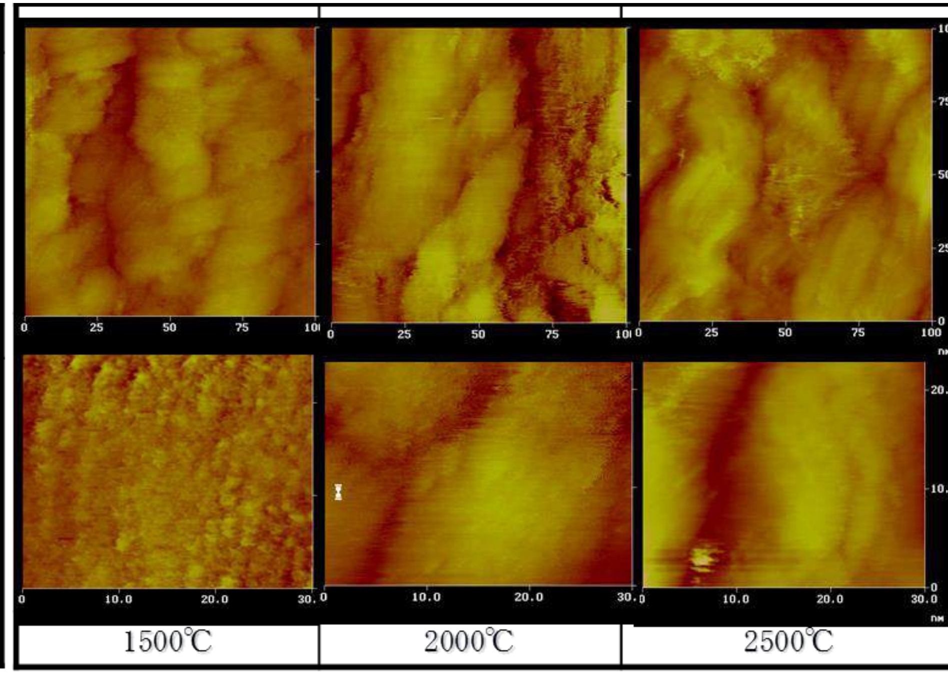
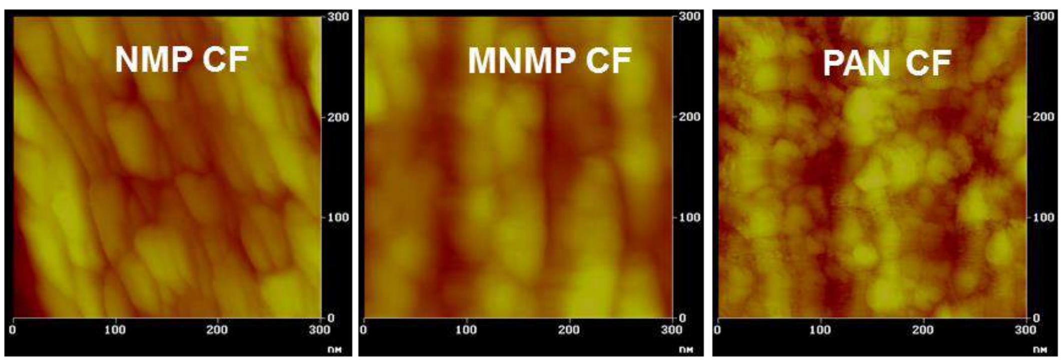
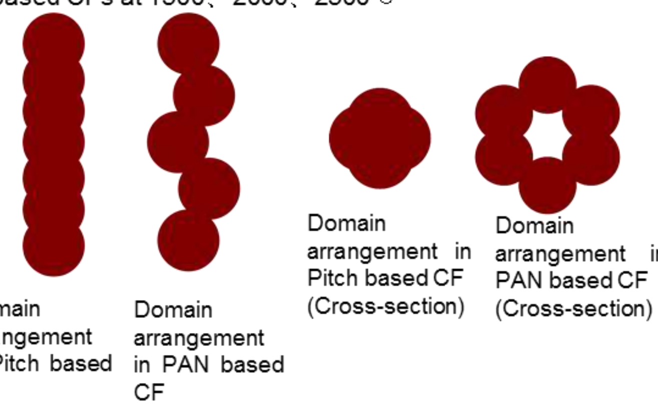


Figure SEM & STM images of heat treated PAN based CFs at 1500、2000、2500℃



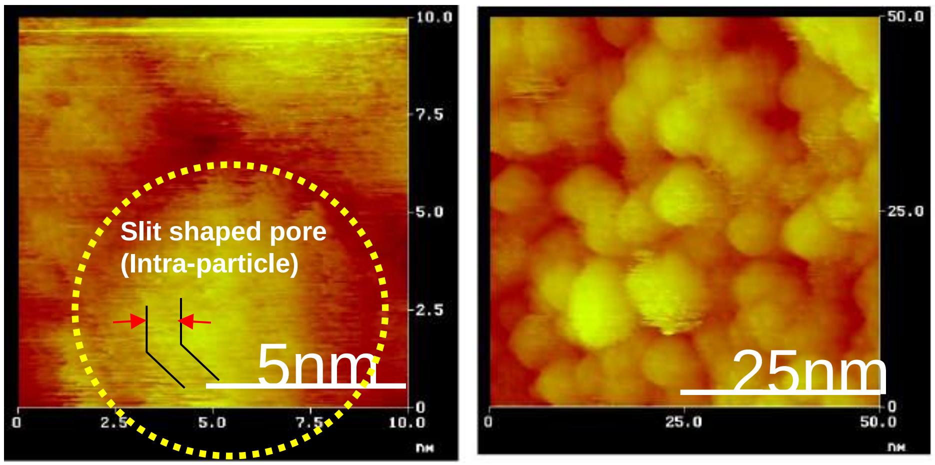


“Structural comparison of mesophase and PAN based carbon fibers”
S.H. Hong, S. H. Yoon, I. Mochida J. Material Sci., in press (2011)

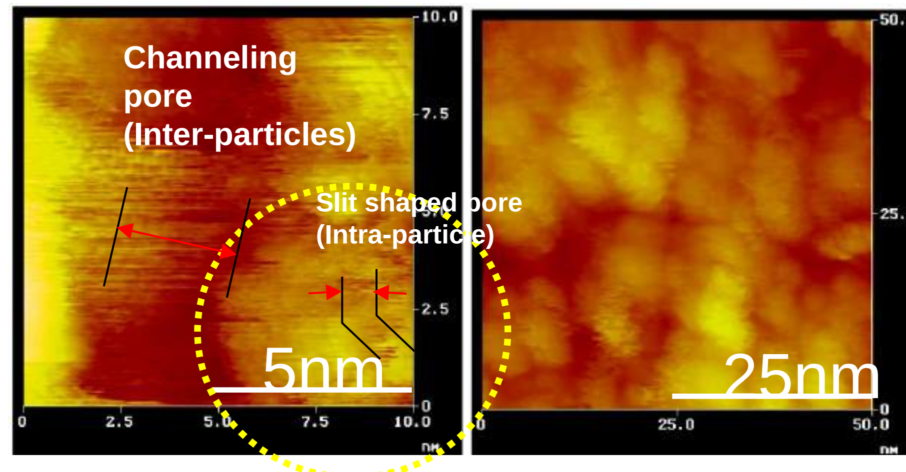
STM images of ACFs

In order to remove oxygen containing functional groups for removing the heterogeneous effect of STM, OG7A and OG20A were heat-treated at 800^{O}C in a hydrogen atmosphere (H_2 / He =1/4).

OG7A-800H



OG20A-800H



♣**Vacant spaces between the two domains of OG20A are larger than that of OG7A.**

♣**Domain size of OG20A is a little smaller than that of OG7A.**

♣**Slit type pores were observed in domains of OG7A and OG20A.**

♣**It can be presumed that almost pores larger than 2nm nucleated by the inter-particle mechanism.**

What is the synthetic carbon!

Origin of Structural Units And Crystalline Defects

Organic materials → (Heat treatment) → Carbon

Basic structural units → Micro domain (4 ~ 6 nm)

2 ~ 10 nm

Micro domain ↓ Domain

Orientation
Rearrangement

Coagulation
Partial melt fusion

Domain — Modified Structures

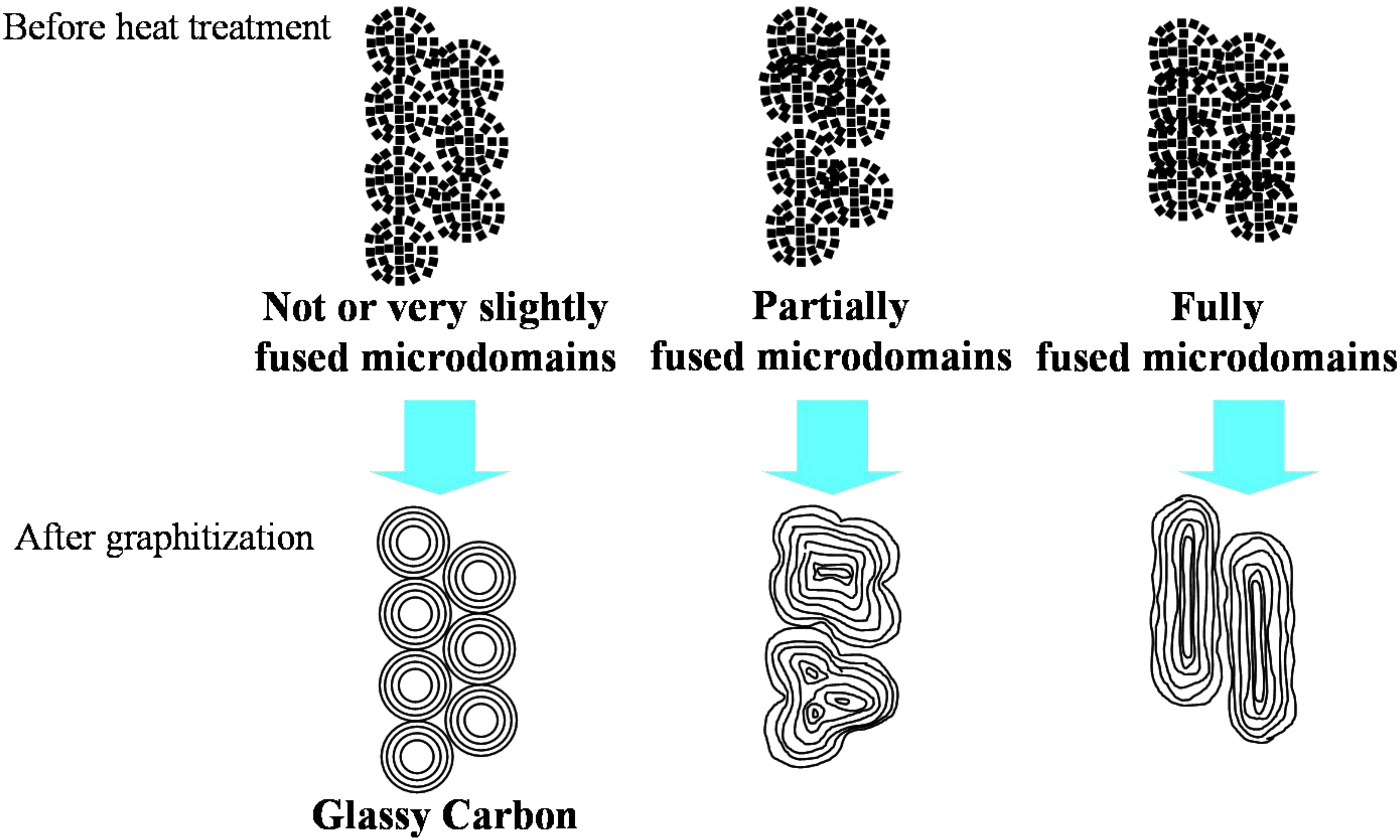
Gas, Liquid → Carbon or carbonaceous materials

Solid → Varieties of structural unit

↓

Heat treatment

Basic structure and structural control of carbon



“Axial nano-scale microstructure in the graphitized fiber inherited from liquid crystal mesophase pitch”
Carbon, 34, 83-88 (1996) S. H. Yoon, Y. Korai, K.Yokogawa, S. Fukuyama, M. Yoshimura, I. Mochida

Understanding carbon structures：Carbon nano-world

Nano

Structures
- Structural units
- Nano-phased units

Spaces
- Pore size and homogeneity
- Pore amounts

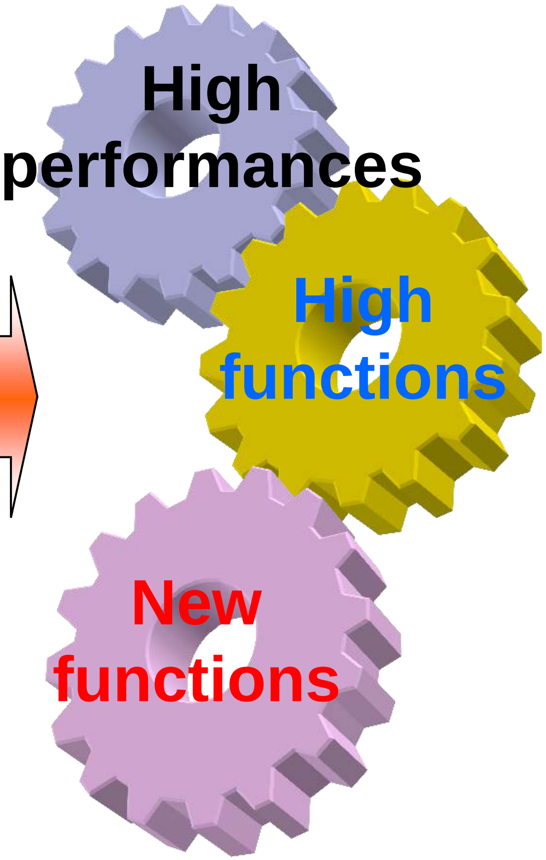
+

Surfaces
- Edges (Kinds and amounts)
- Basals (Perfectness and Orientation)

Productions

Hybridization
→
Improving Performances and Functions
→
Creating New Functions

Applications



炭素の応用

Electric and Heat Conductions
- **Conductor and Semi-conductor**

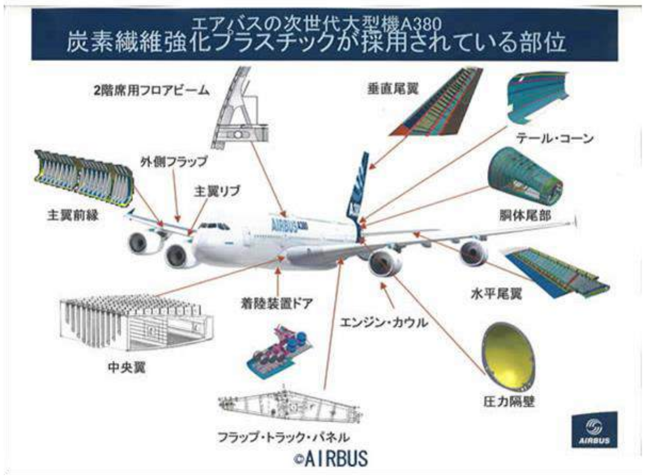
Energy Storage
- **Battery anode**
- **Super capacitor**
- **Gas storage**

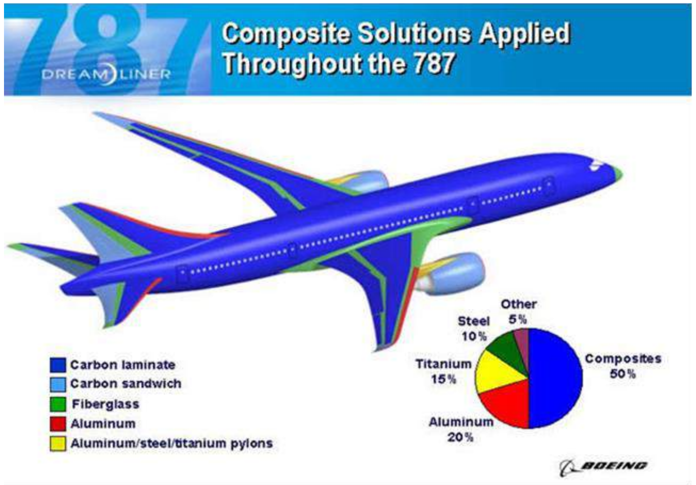
Environmental Protection
- **Activated surface**

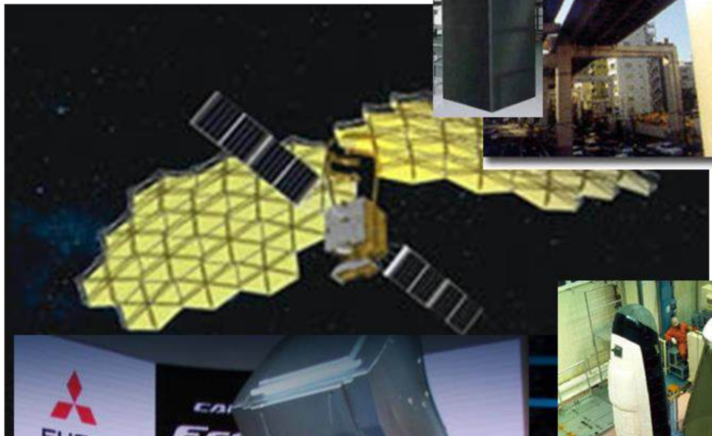
Mechanical Reinforcement

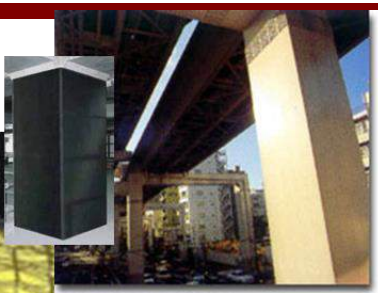
High Temperature Materials

Carbon Fiber





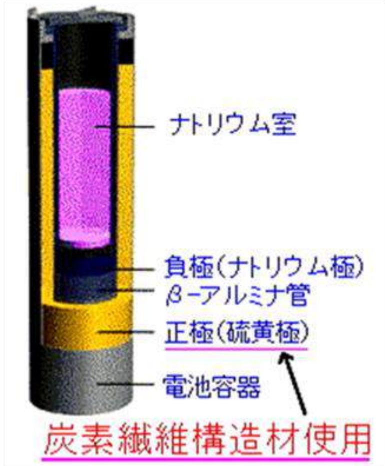


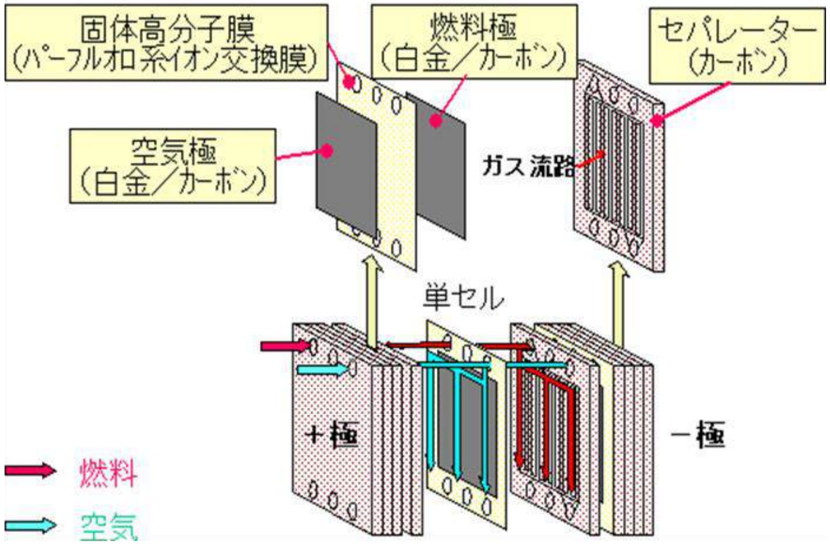


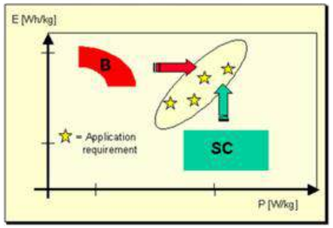

宇宙航空研究開発機構 提供

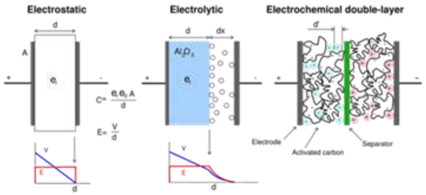

宇宙航空研究開発機構 提供

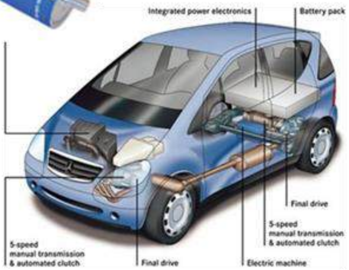
Battery, Capacitor, Atomic and Coal Power Plants

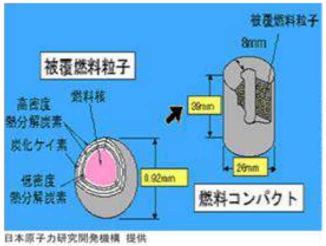






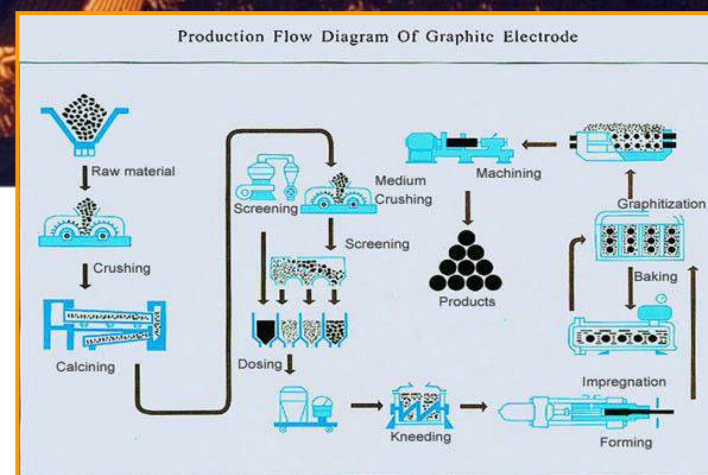




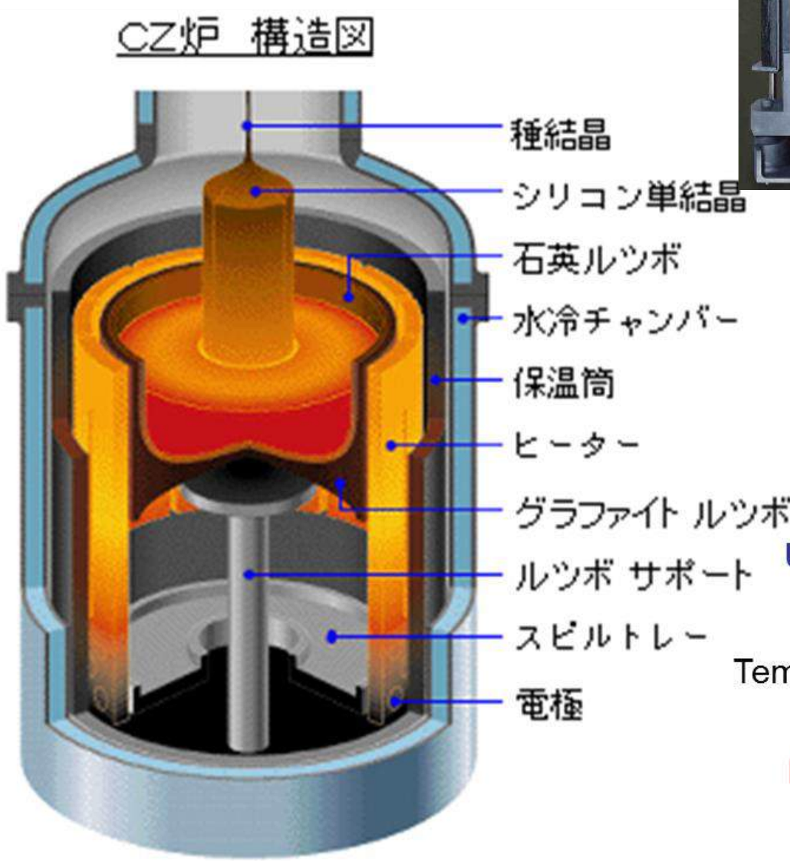


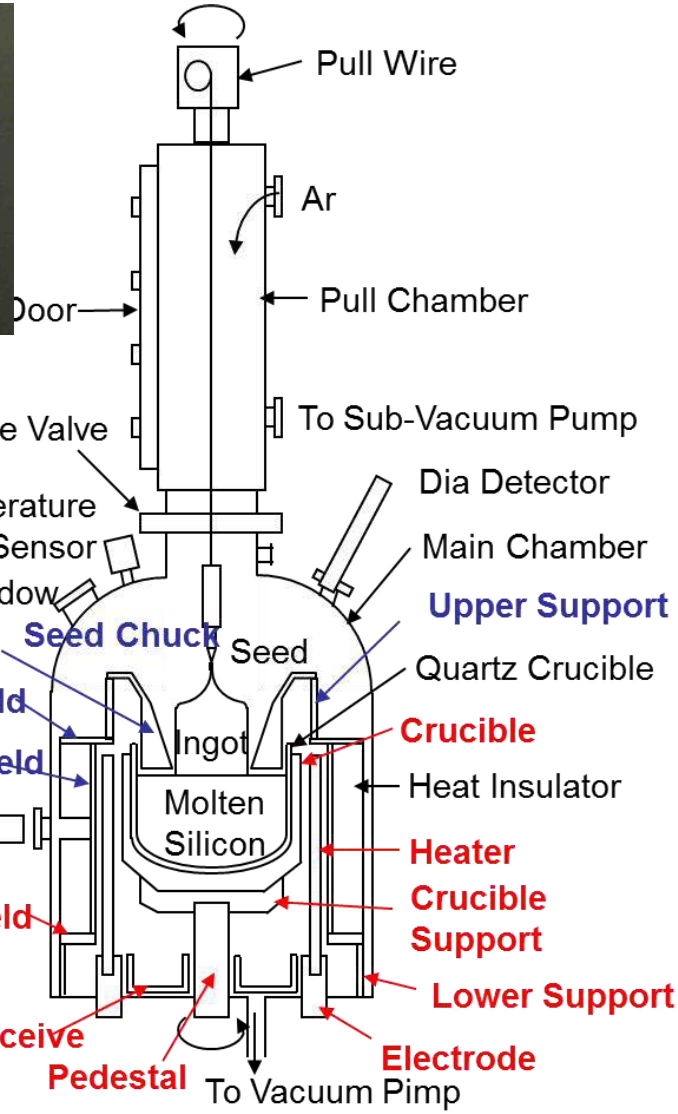
5トン/日バイオマス/廃棄物炭化ガス化実験設備

Graphite Electrode

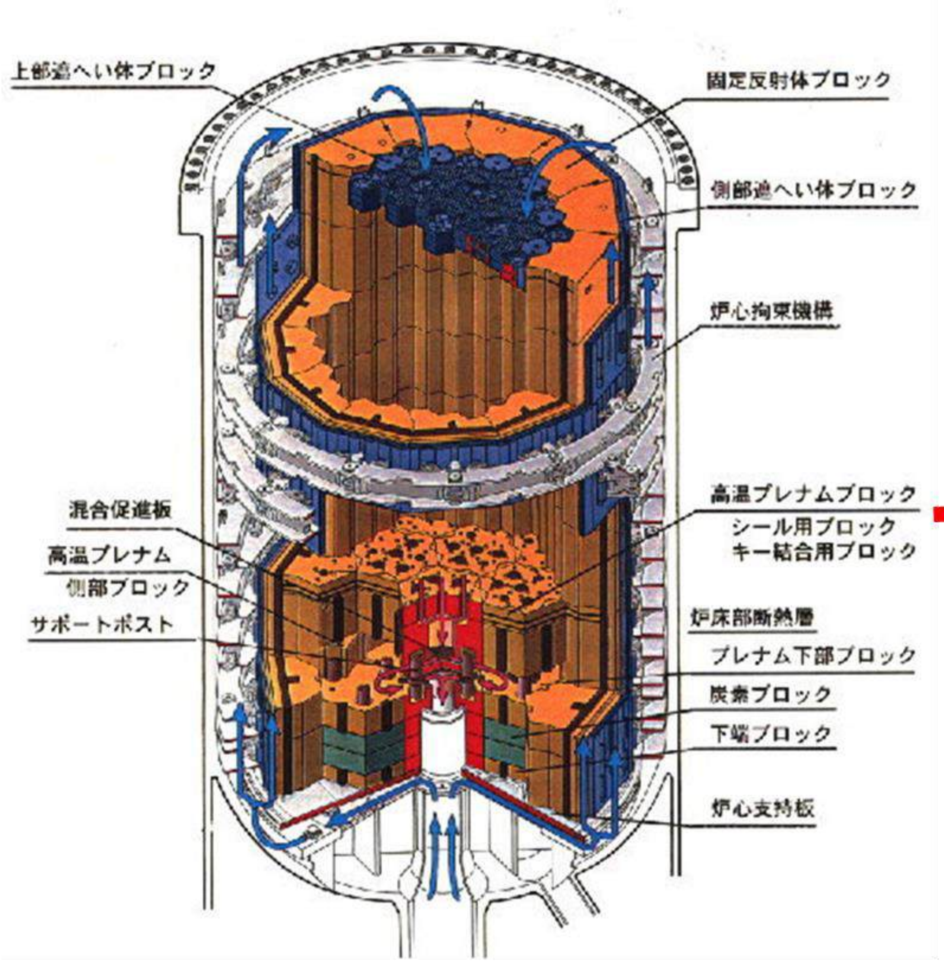


単結晶シリコン引上げ用CZ炉

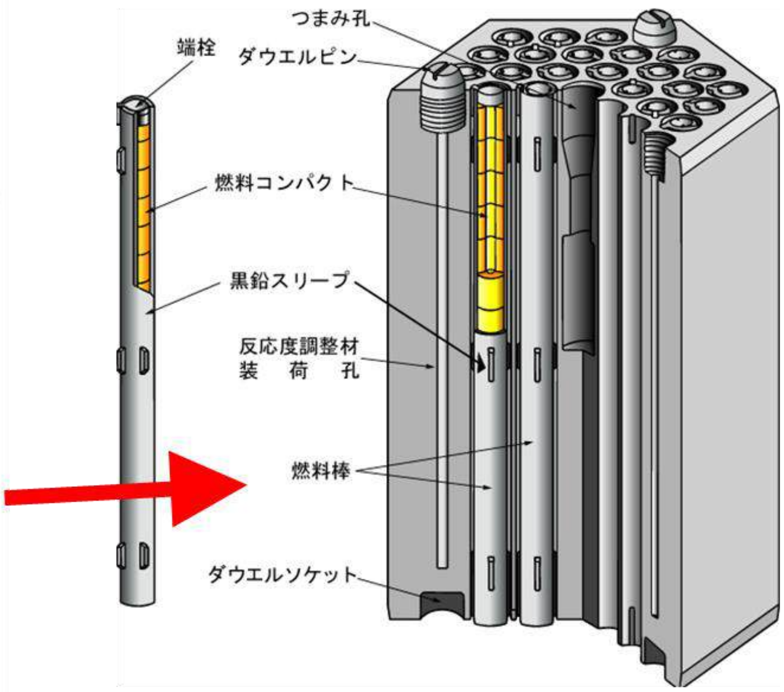




高温工学試験研究炉（HTTR）



炉心構造体

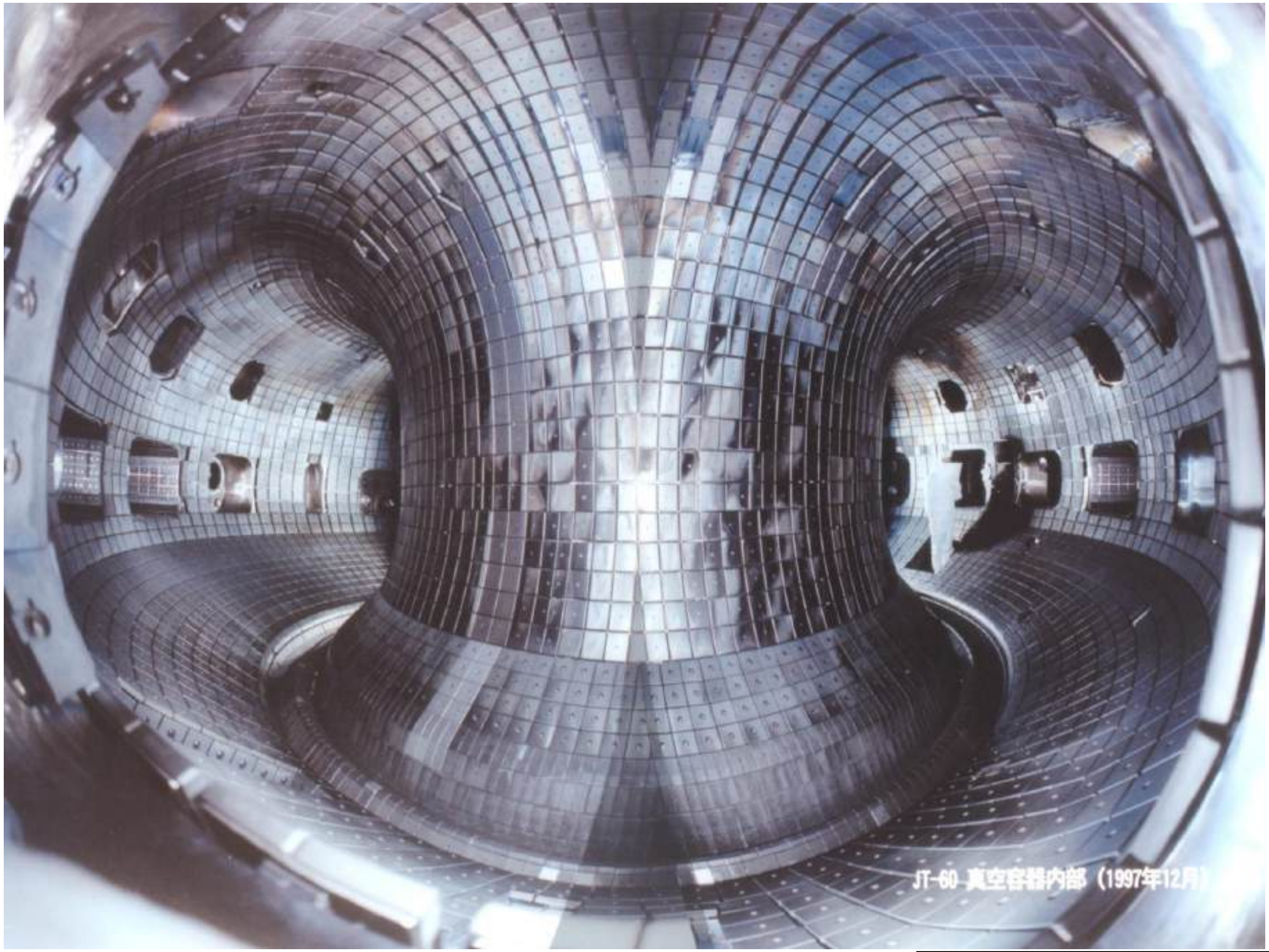


黒鉛プレナムブロック

燃料棒が収納される

出典：日本原子力研究開発機構 HP

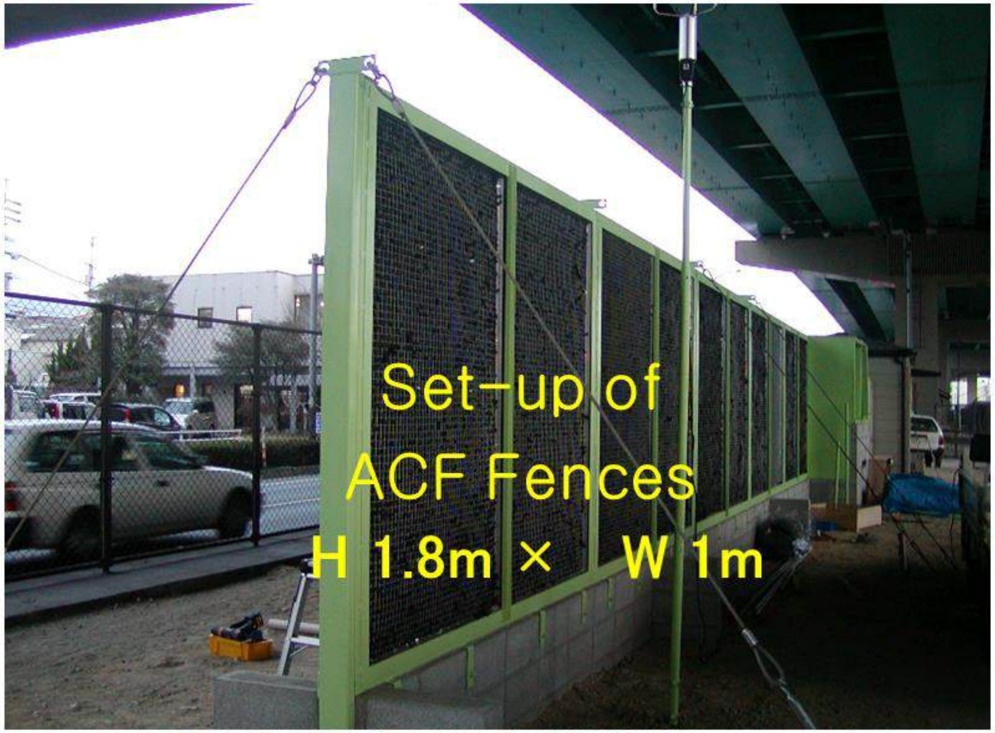
臨界プラズマ(核融合)試験装置JT-60



提供: 日本原子力研究開発機構

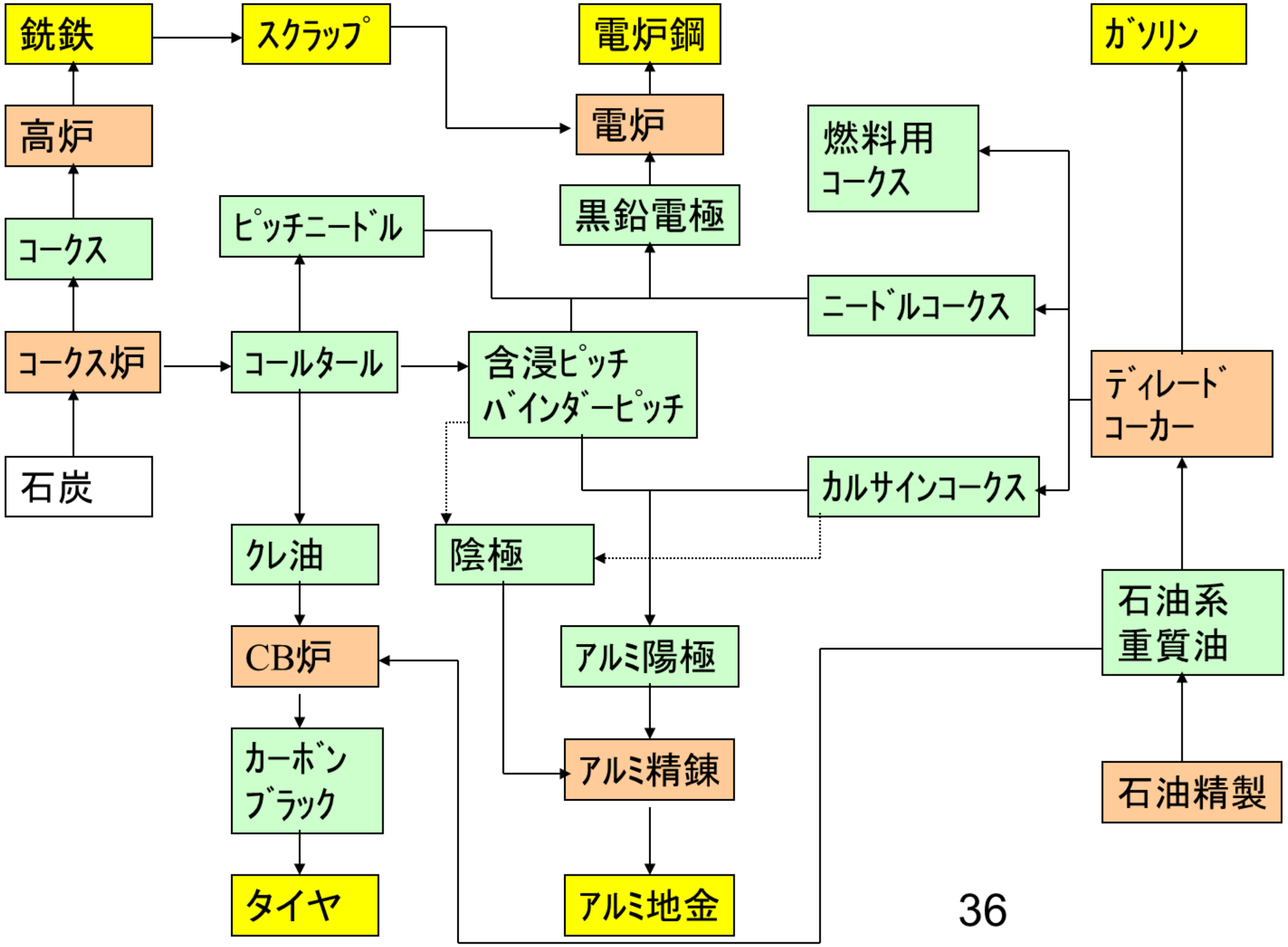
医療用　X線CTスキャナ

Air Purification Using ACF (Remote Watching System)

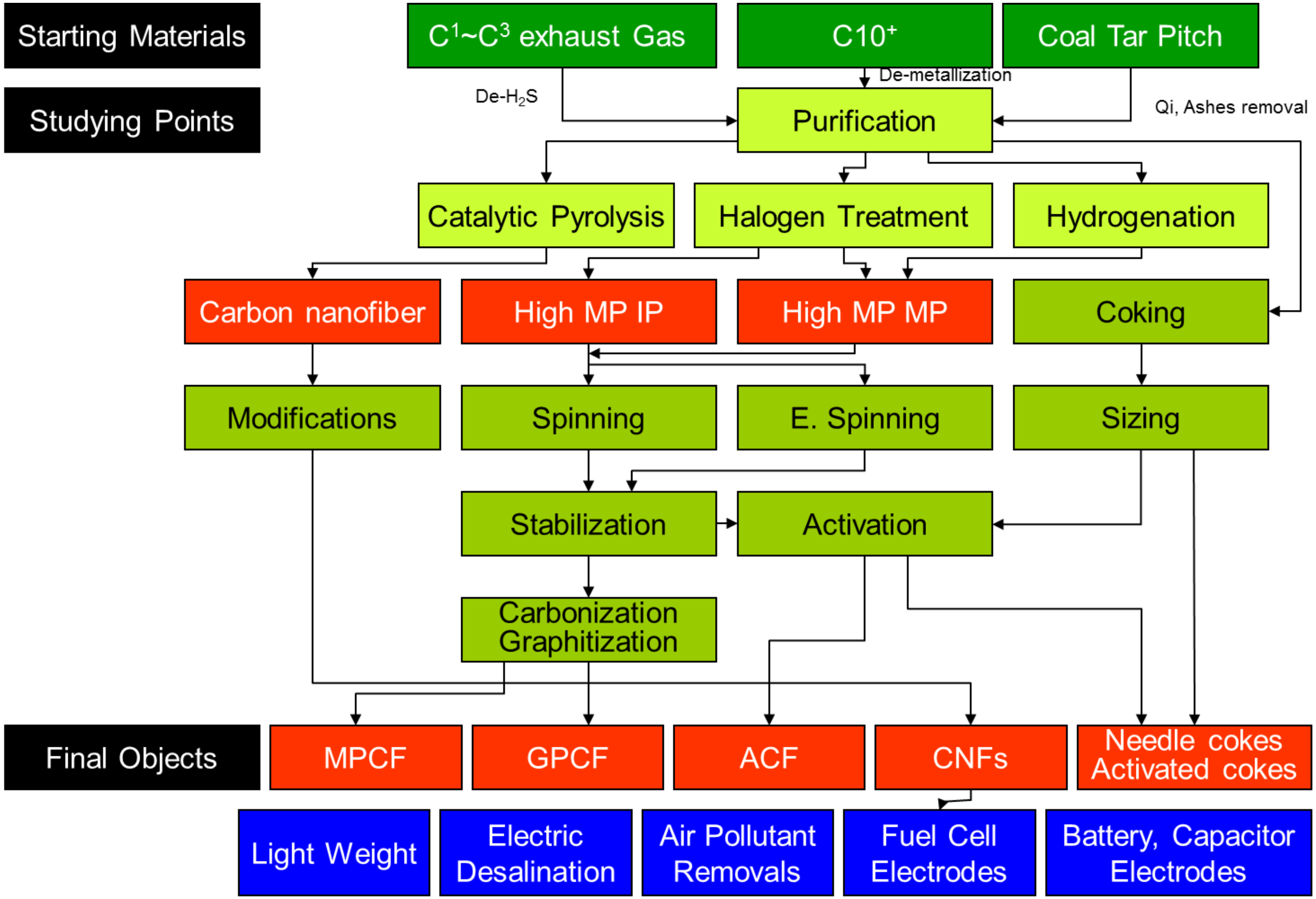


炭素材の製造

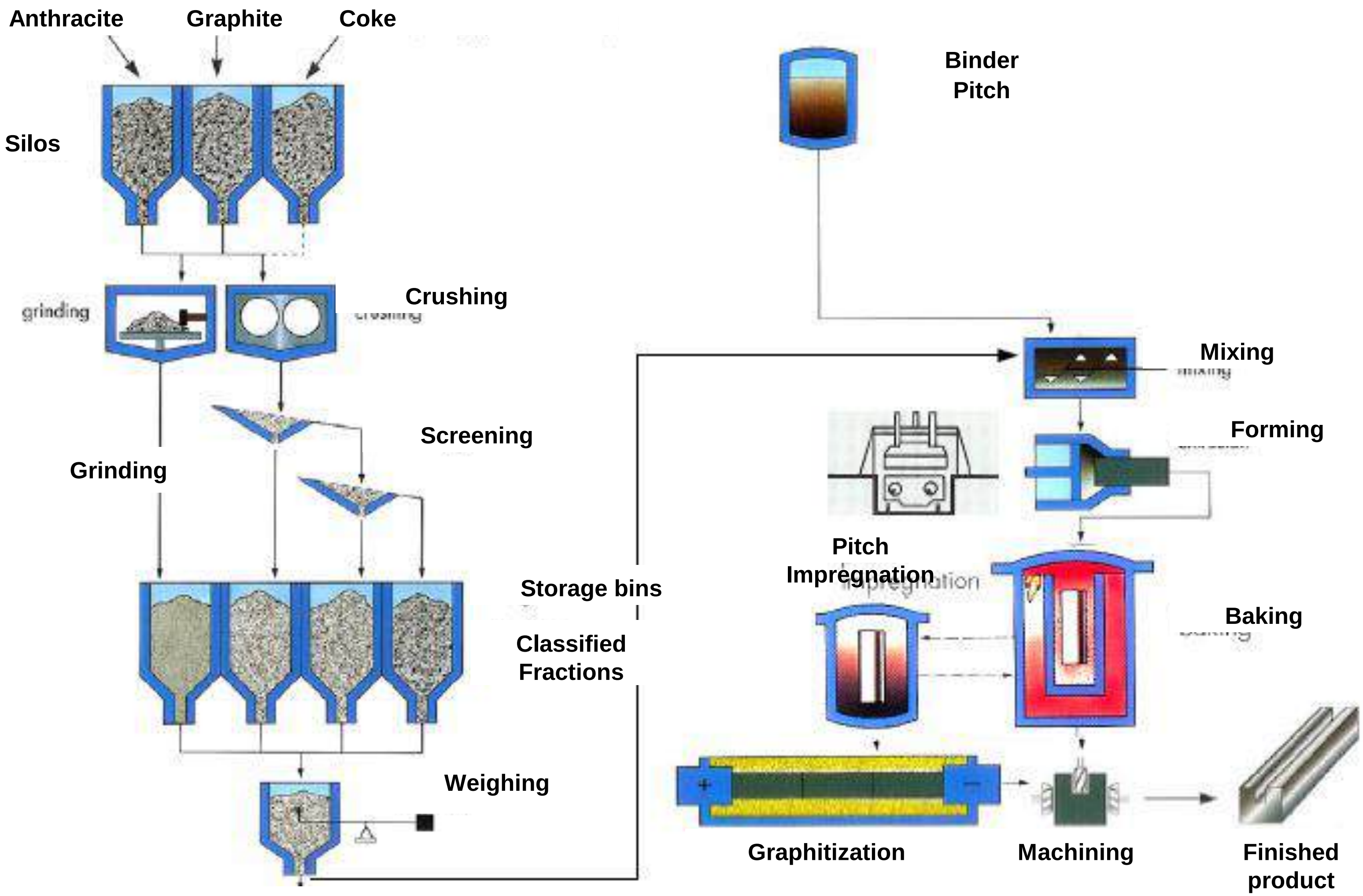
重質油を用いたカーボンサークル



重質油又は石炭残渣を用いた炭素材の製造模式図

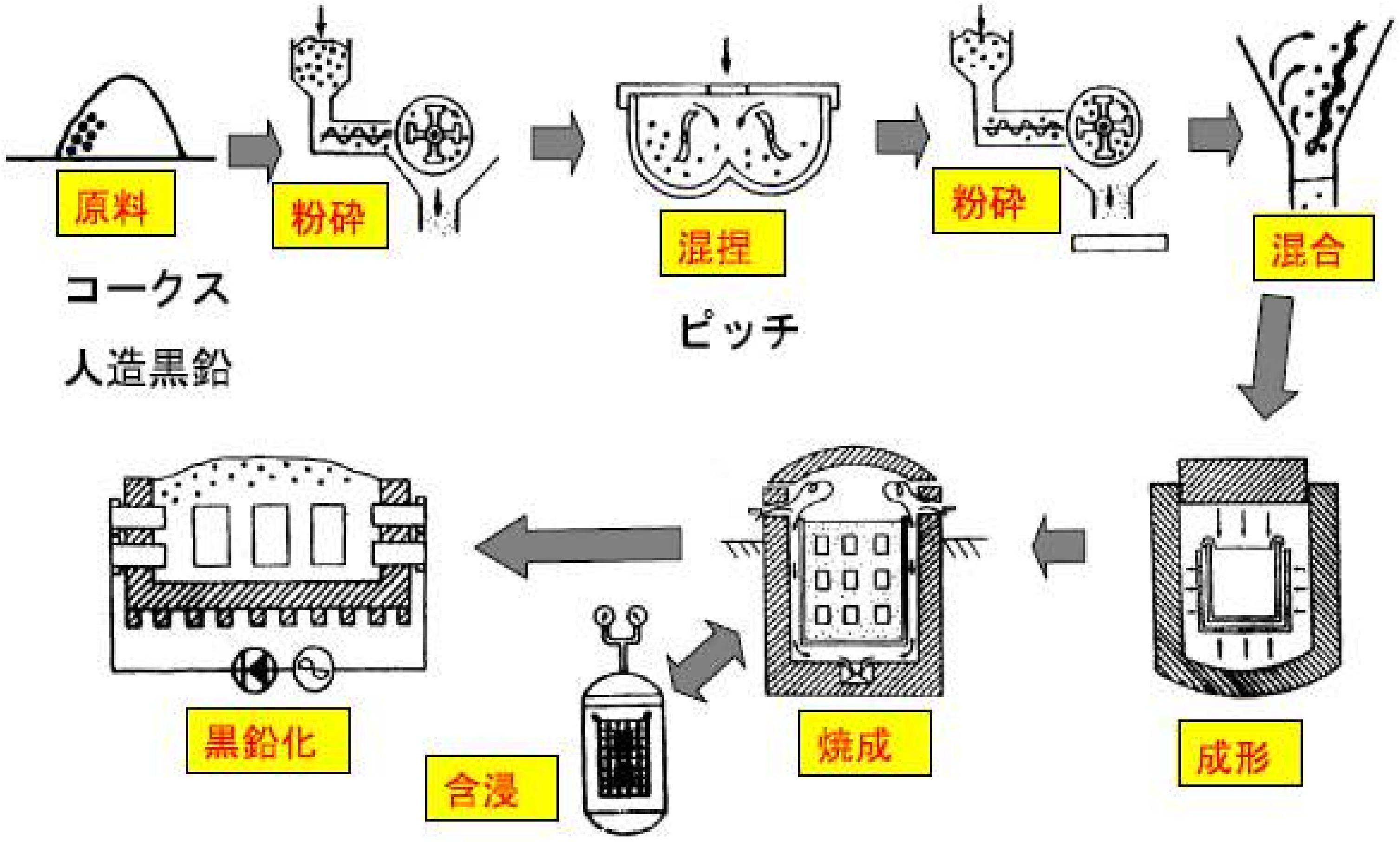


黒鉛電極の製造



Anthracite
Graphite
Coke
Silos
Binder
Pitch
grinding
Crushing
Mixing
Screening
Forming
Grinding
Pitch
Impregnation
Storage bins
Baking
Classified
Fractions
Weighing
Graphitization
Machining
Finished
product

等方性黒鉛の製造工程(二元系原料)



先端炭素材の製造におけるポイント

High performance pitch based carbon fibers: less than 50 ppm

Capacitor : less than 500 ppm

High performance needle coke : 500 ppm

Carbon medicines: less than 300 ppm?

Carbon anode for LIB: less than 100 ppm

…

コールタールピッチのQI 除去

Method	Principle	Advantage	Disadvantage
① Filtering (Heat, Solvent)	Decreasing viscosity by heating or solution Mesh filtering of QI	Only QI Removal No heavy fraction removal	Large equipment X
② Centrifuging (Heat, Solvent)	Decreasing viscosity by heating or solution Centrifugal condensing of QI	Only QI Removal No heavy fraction removal	Large equipment X
③ Solvent - Precipitation	Mixing of miscible solvents Precipitation removal of QI		Low productivity
④ Non-solvent Precipitation	Mixing of non-miscible solvents Precipitation removal of QI	Large equipment OK	Heavy fraction removal

- It is relatively easy to remove QI in lab scale.
- QI removal in the industrial scale
  - Very difficult to remove finely dispersed QI from large amount of viscous liquid
  - Only success in Japan
    Japan several ten thousands ~ hundreds tons/year scale

ピッチ系炭素繊維

Needs and Seeds of Carbon Fiber

- High Performance Carbon Fiber(HPCF) : CF with TS over 3500MPa
  - CFRP for lightening :
    - Transportation: Aerospace (B787, A380,…), Military, EV (EV, HEV, FEV: Parts need special properties/performances)
    - Sports, Robotics, …
    - Energy Devices: Windmill, …
    - Construction: CFRC, Supplement
- Middle Performance Carbon Fiber(MPCF) : CF with TS of 1500~3500MPa
  - CFRP Application: CF with TS of 1500~3500MPa, Long Fiber
    - Transportation: Main Body for EV (EV, HEV, FEV)
    - Construction (Short Fiber ⇨ CFRC)
- Low Performance Carbon Fiber(LPCF) : CF with TS Less Than 1200 MPa
  - Refractory Materials for High Temperature Devices (Short Fiber)
  - ACF for Environmental Protections

⇨**Strong demand of MPCF with appropriate mechanical properties and production cost for broadening novel market;**
Pitch Based Carbon Fiber Can Meet of the Carbon Fiber.

Production Capacity of PAN CF in the world

Company	T/Y
Toray	17,600
Toho TENAX	13,900
Mitsubishi Rayon	7,400
etc.	16,400
Total	55,300

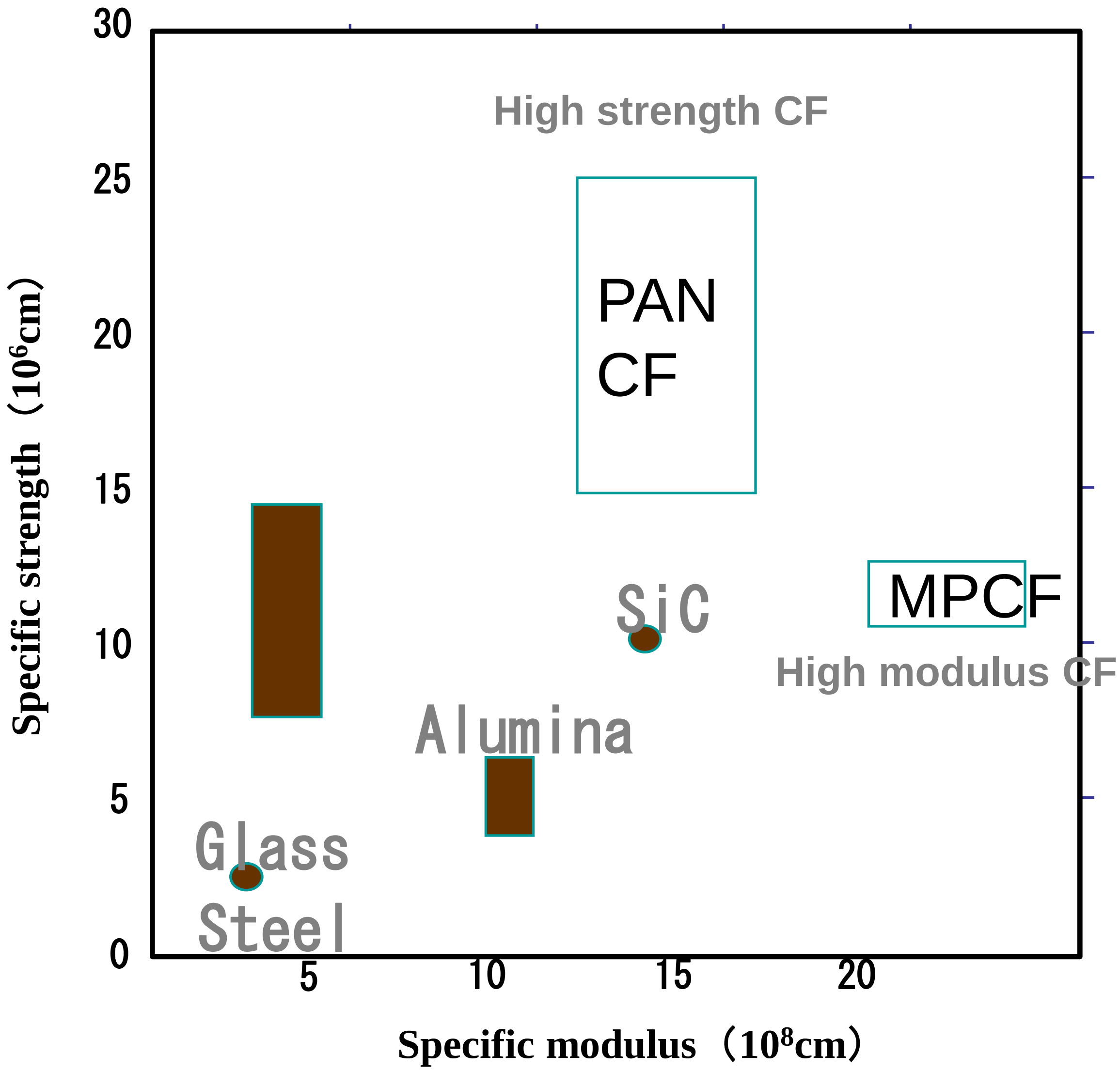
* Capacity for less than 24K, 2010

Current State Production Capacity of Pitch Based CF

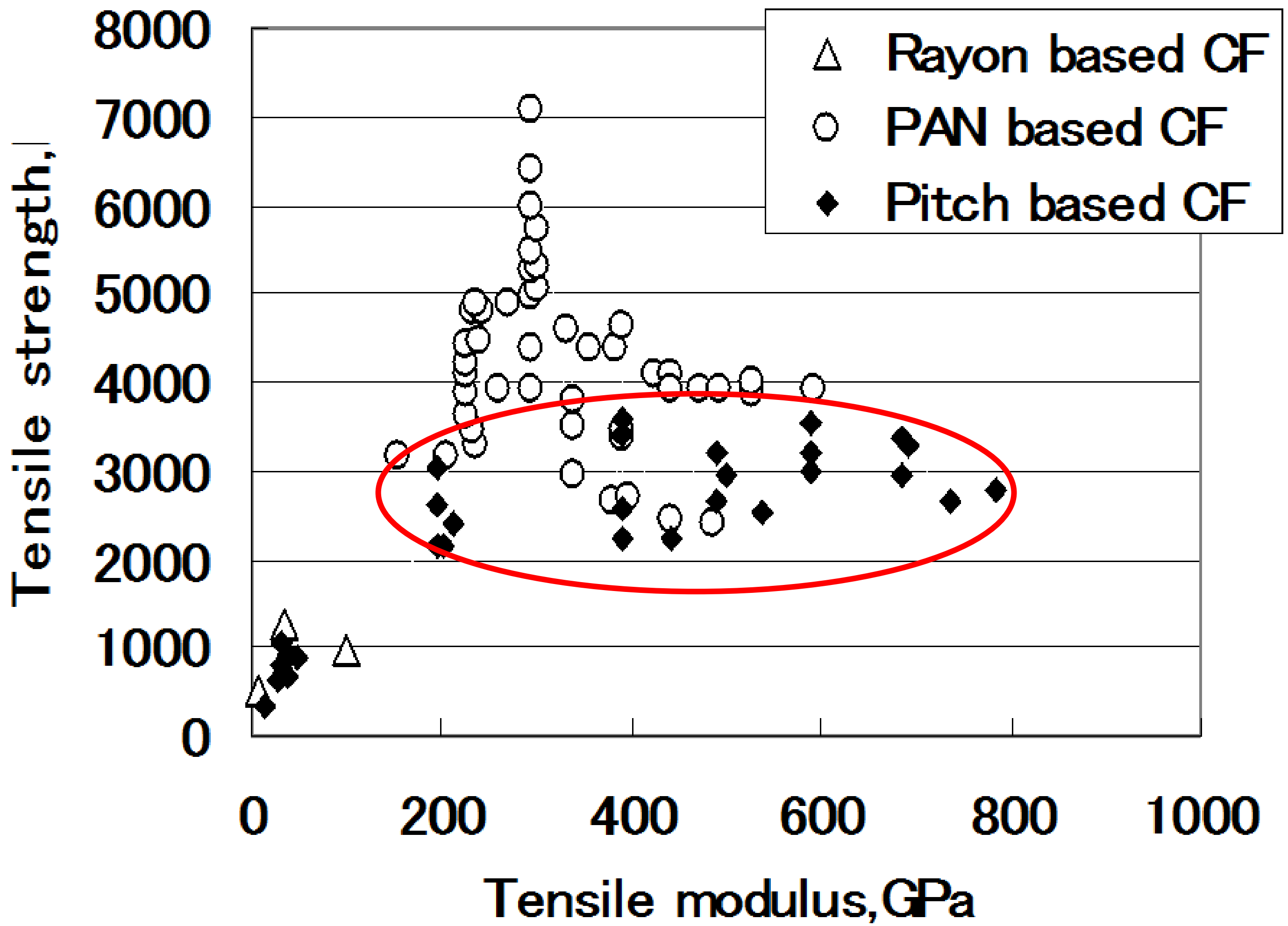
Company	T/Y	Type	Precursor Pitch
Kureha	1450	Short	Isotropic
Osaka Gas Chemical	600	Short	Isotropic
Mitsubishi Chemical	1000	Long	Mesophase
Japan Graphite Fiber	180	Long	Mesophase
CYTEC	230	Long	Mesophase
Total	3460		

* 2010, (From HP Information, China: 200T/Y, Isotropic)

Specific tensile strength and modulus of various reinforcing fibers

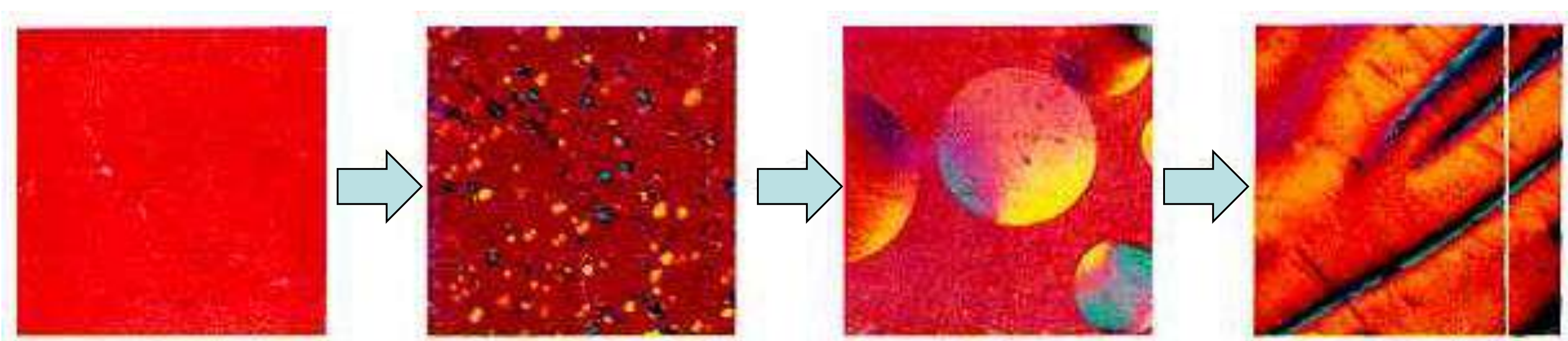


Relationship between TS & YM before Improving



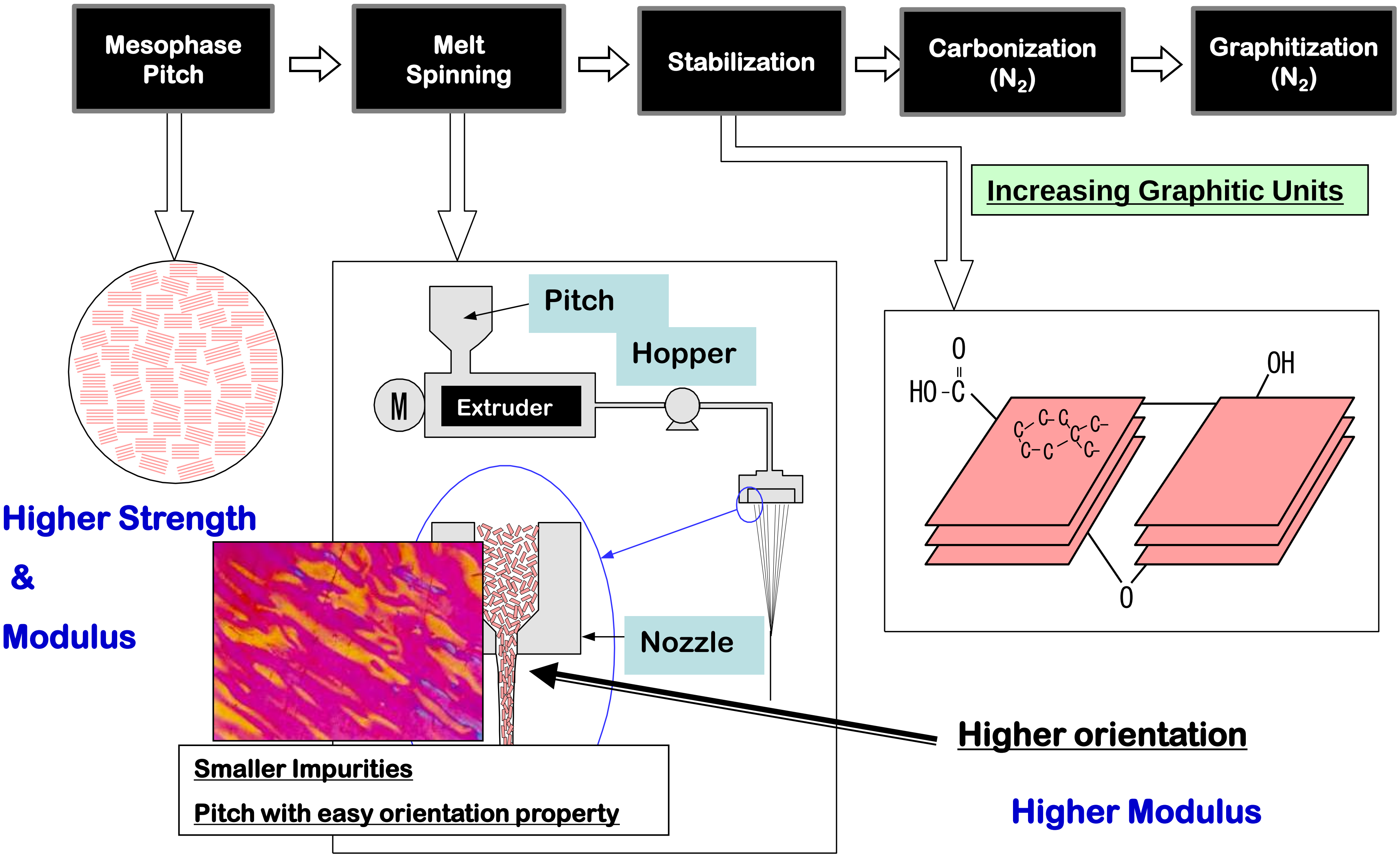
Preparation of Mesophase Pitch

Raw Material	Before treatment and transferring to mesophase
DO	De-ash → Thermal Polycondensation → Thermal Transferring to Mesophase → Mesophase pitch
Coal tar	De-ash → Hydrogenation → Thermal Polycondensation (Mesophase) → Mesophase Pitch
Naphthalene	Polycondensation (HF/BF_3) → Removal of light Matters → Mesophase Pitch



Isotropic pitch | Formation of mesophase | Growth of mesophase | Bulky mesophase

MPCF Production Processes



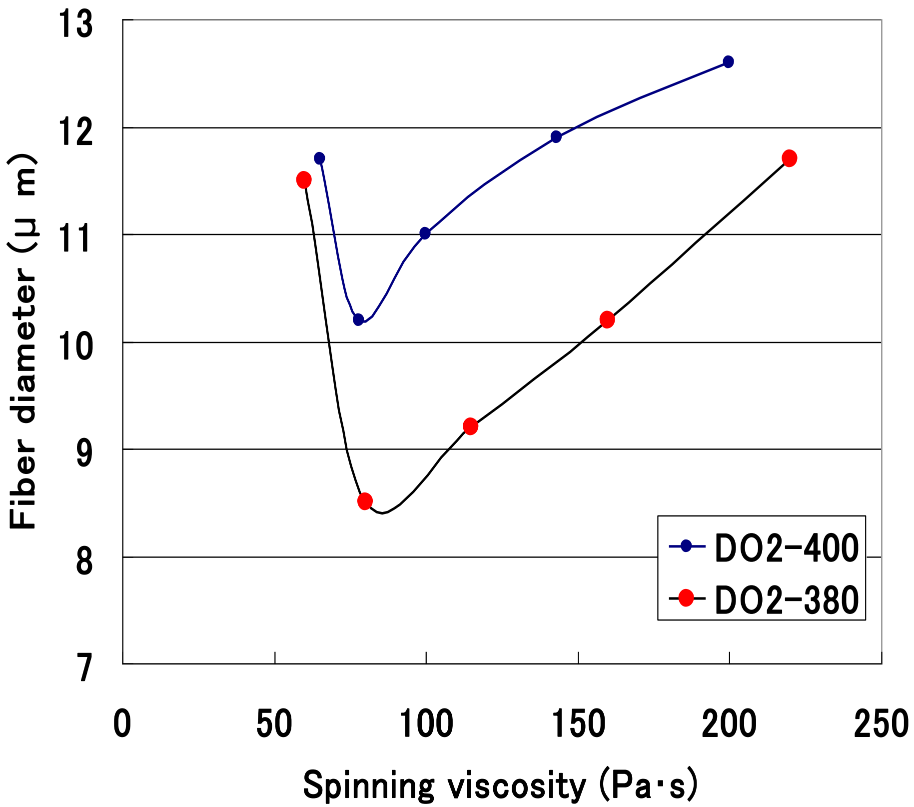


Fig. Correlation between fiber diameter and spinning viscosity

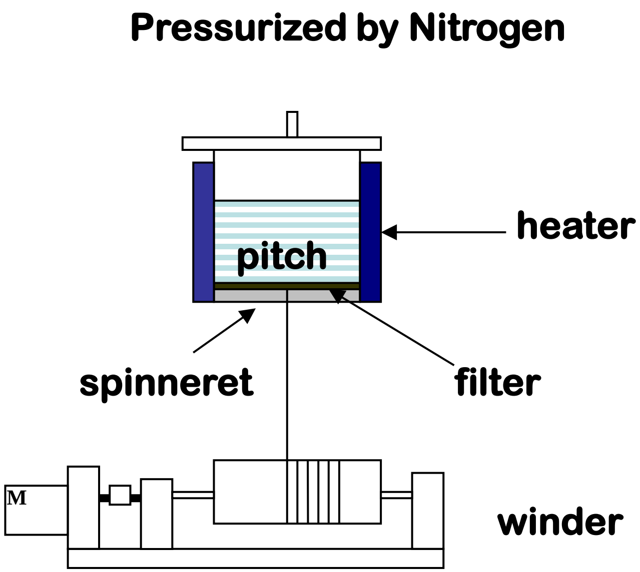
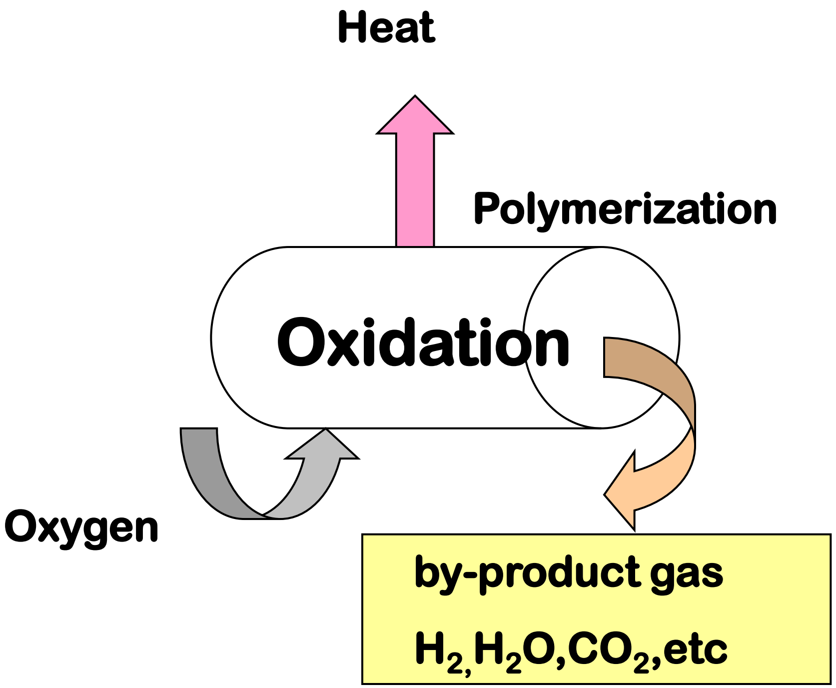


Fig. Spinning apparatus

Stabilization of Pitch Fibers



Increasing Tensile Strength by Removal of Inorganic Impurities

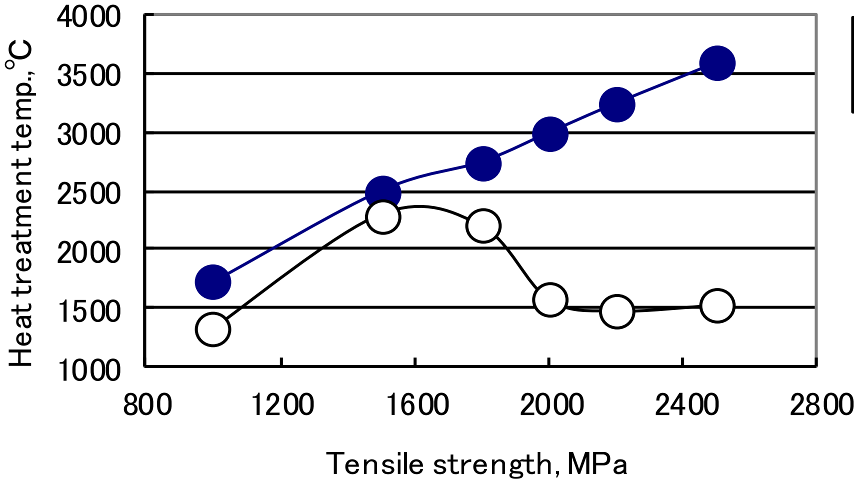
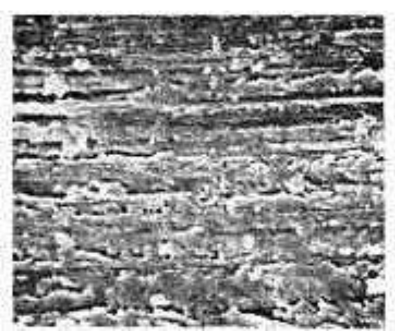
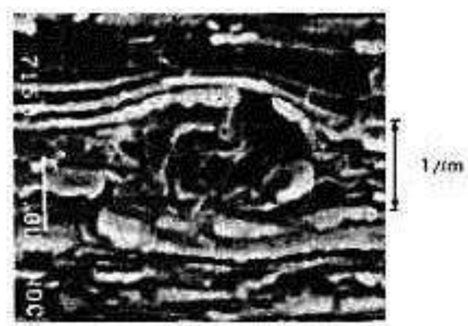


Fig. Relationship between the tensile strength and heat treatment temperature

$SiO_2 + C \rightarrow SiC + CO_2$
Over 1250 °C
$SiC \rightarrow Si + C$
Nucleation of voids
Over 1800 °C



30ppm



270ppm

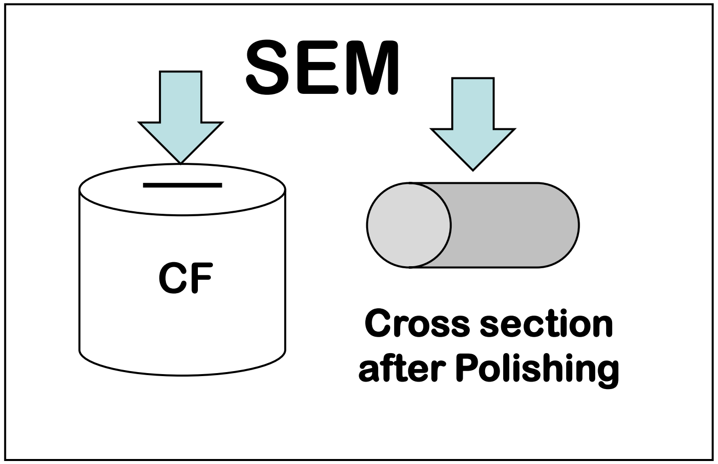
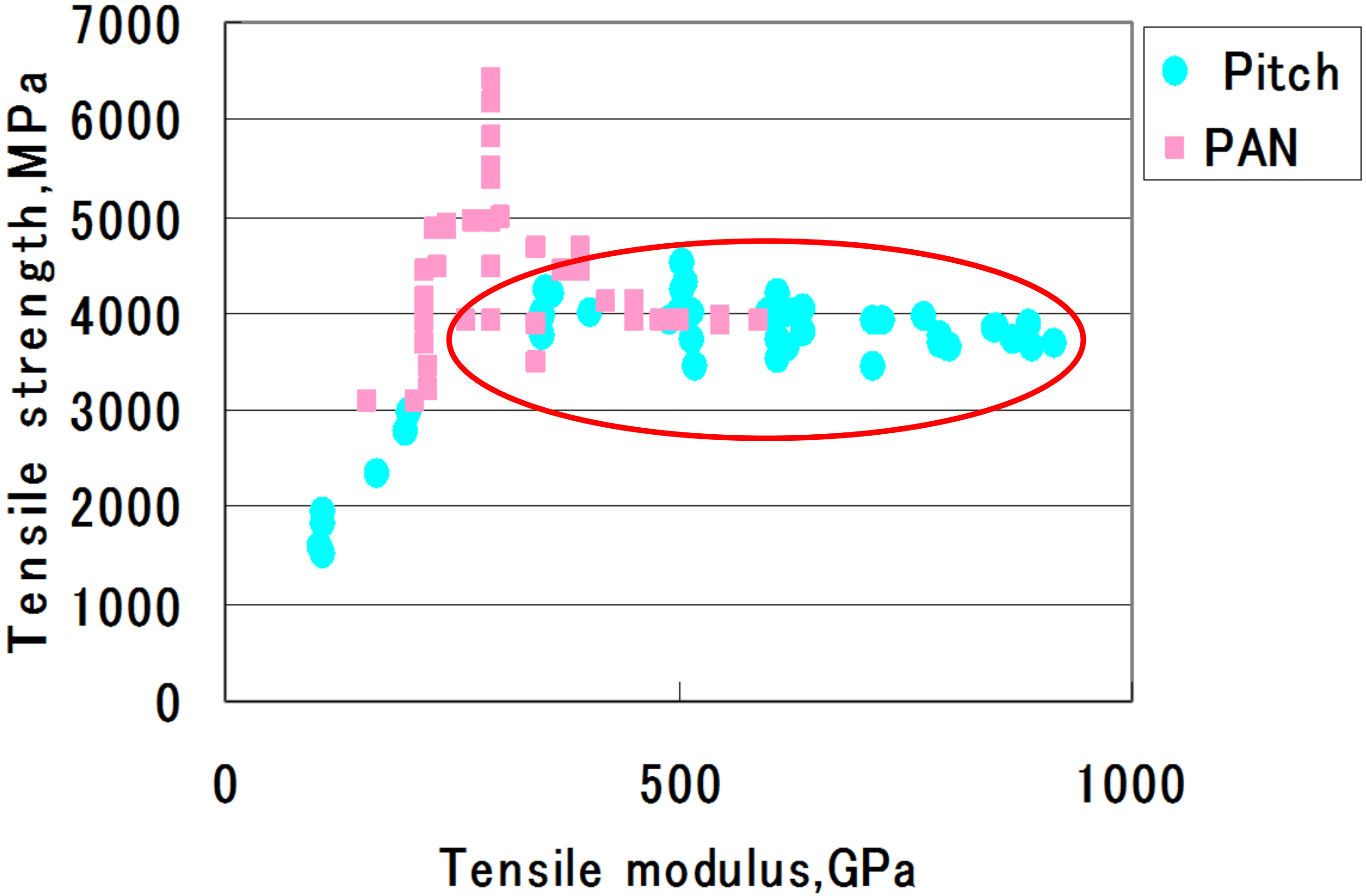
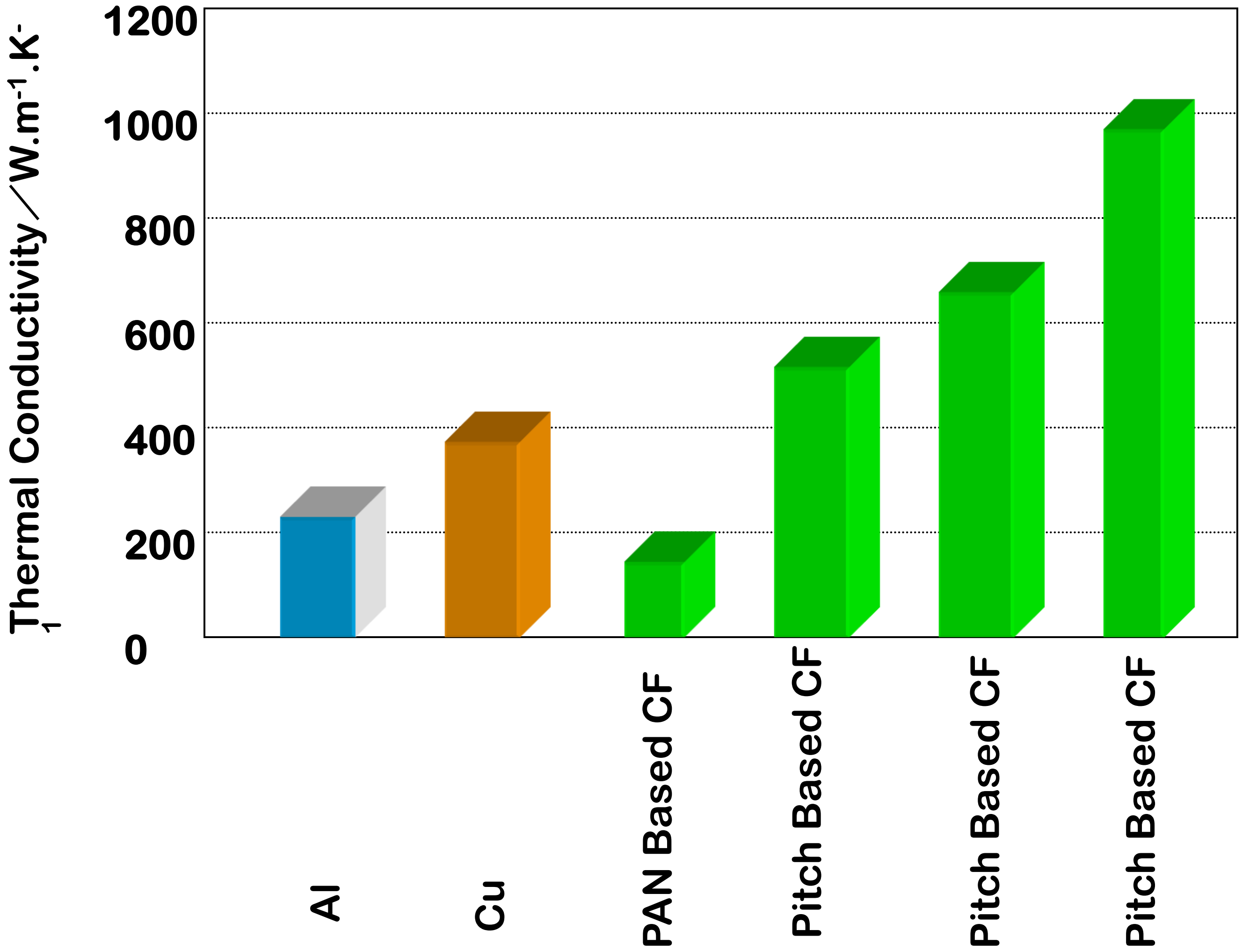


Fig. Observation of void defect

Relationship between TS & YM of Recent CFs



Thermal Conductivity of CF



How to Achieve Pitch Based MPCF

- Cost : Yields of Pitch and Fiber, High Productivity Fiber
- Required Characteristics

Tensile Strength	800~1100 MPa ⇒ 1500~3500 MPa
Elongation Property	1.5 % ⇒ 2.0~2.5%
Fiber Shape	Diameter: Less than 10 μm, Long Fiber

- How to Achieve?

Precursor	Low Cost, Linear, high MW highly polymeric molecular compositions ⇒ Introduction of Molecular Orientation, High Purity
Spinning	Less than 10 μm and Control of microstructure
Stabilization	Low Defect (Low Heat Value), Homogeneous Oxidation
Carbonization	High Carbonization Yield, Low Defects

電池材料

Carbon is key element for Batteries !!

①Li-ion

[High capacity]

(+) : $LiCoO_2$
(-) : Carbon(Graphite)
Conductor : Carbon

②Dry Battery

[Cheap]
[Easy Available]

(+) : MnO_2
(-) : Zn
Conductor : Carbon

③Ni-MH

[High power]
[Total balance]

(+) : $(Ni\text{-}Co)(OH)_2$
(-) : $Mm(Ni\text{-}Mn\text{-}Al\text{-}Co)_5$
substrate: Nickel and Carbon

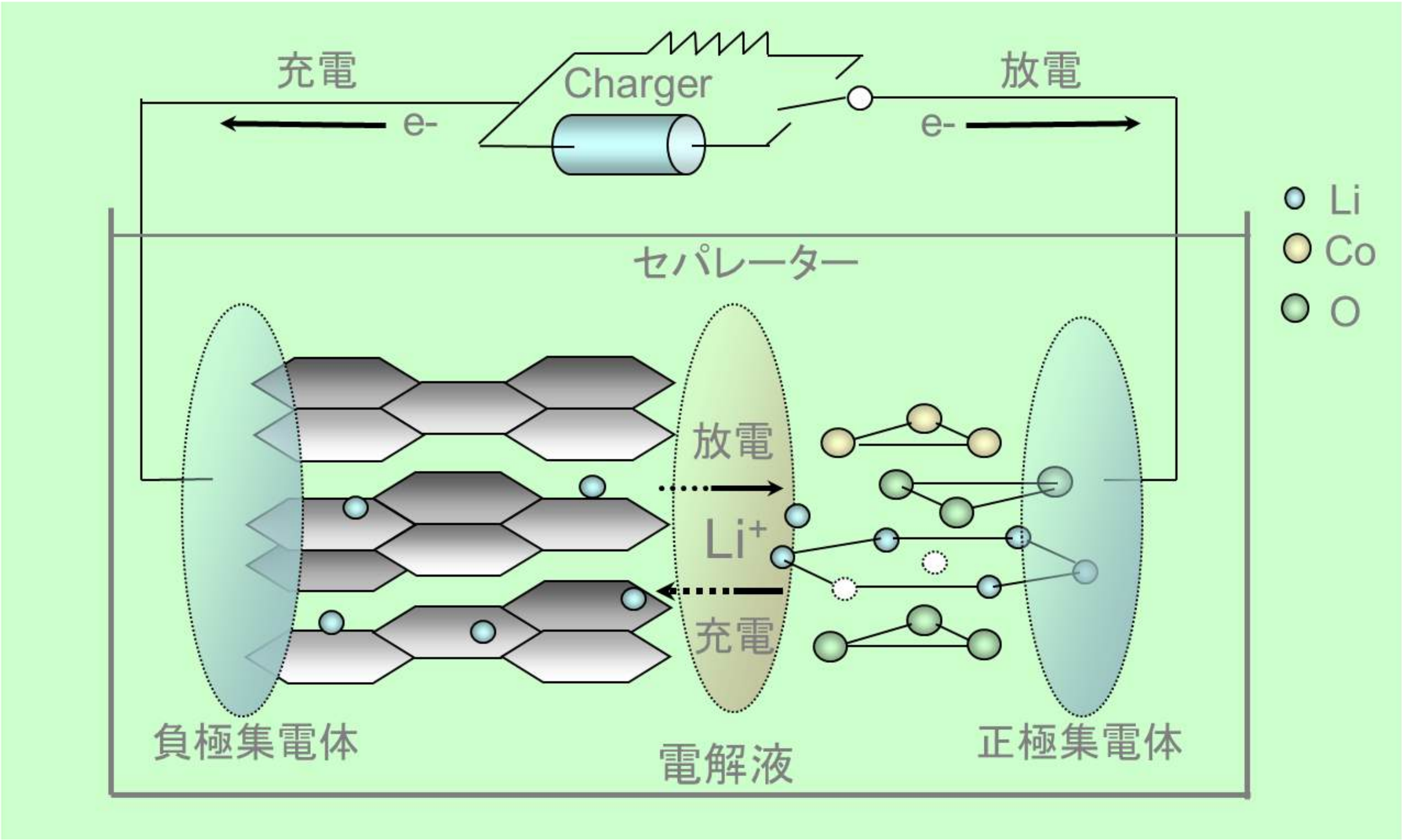
リチウムイオン二次電池の動作原理

負極

$$C_6Li \underset{充電}{\overset{放電}{\rightleftarrows}} Li^{+}+C_6+e^{-}$$

正極

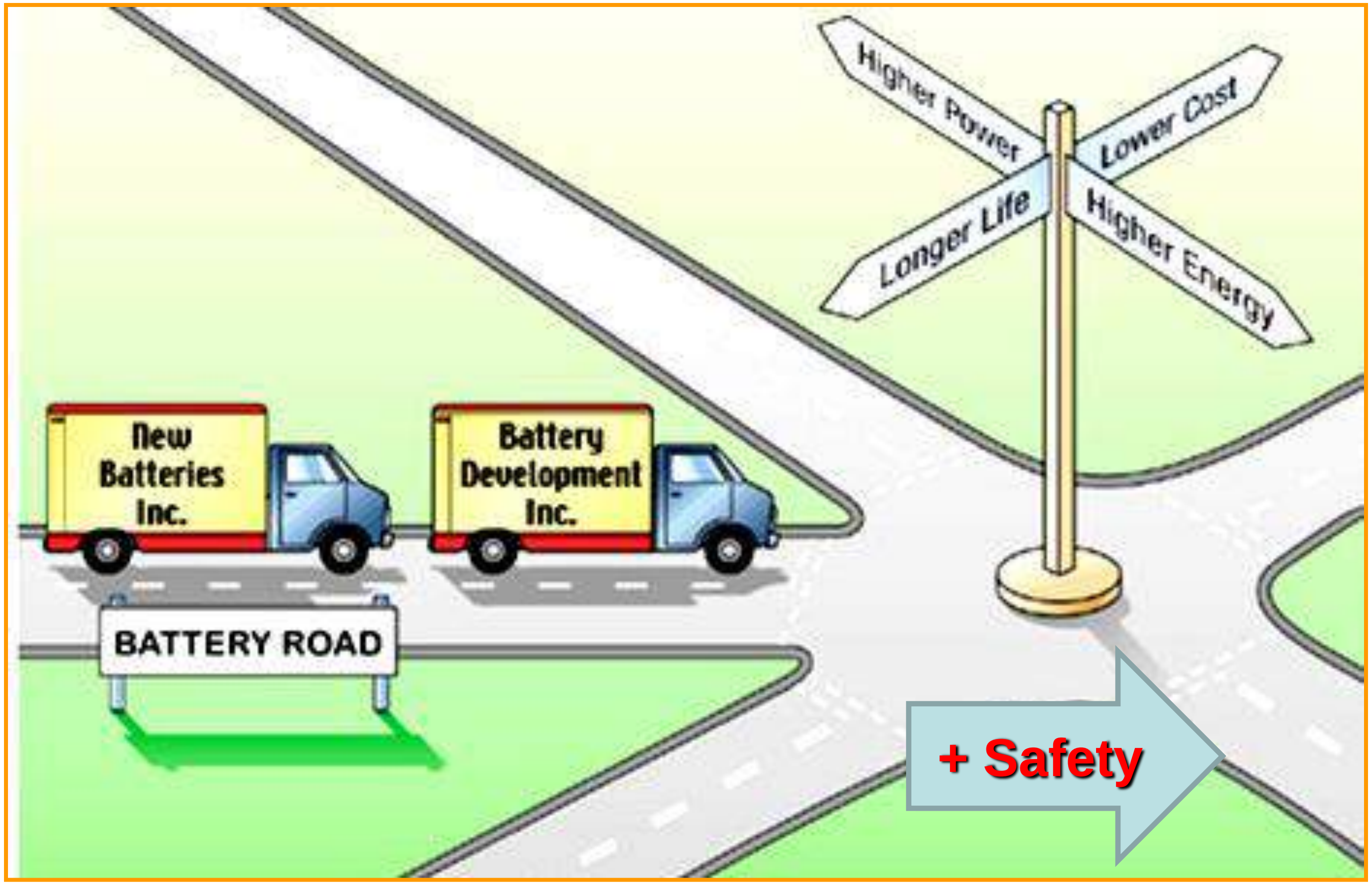
$$CoO_2+Li^{+}+e^{-} \underset{充電}{\overset{放電}{\rightleftarrows}} LiCoO_2$$



Electrode Materials for Lithium Secondary Battery

Different materials for different applications

A spectacularly reactive cathode
Nature Materials **2,** 705–706 (2003)



炭素負極材

Anodic Electrode to Hold Reduced Li-ion

Intercalation → Graphite

Surface Electron Transfer into Sealed Void
→ Hard or Low Temperature
Calcined Carbon

Electron Conductive Material

Anodic Carbon and Cathode Material

Expansion Moderator

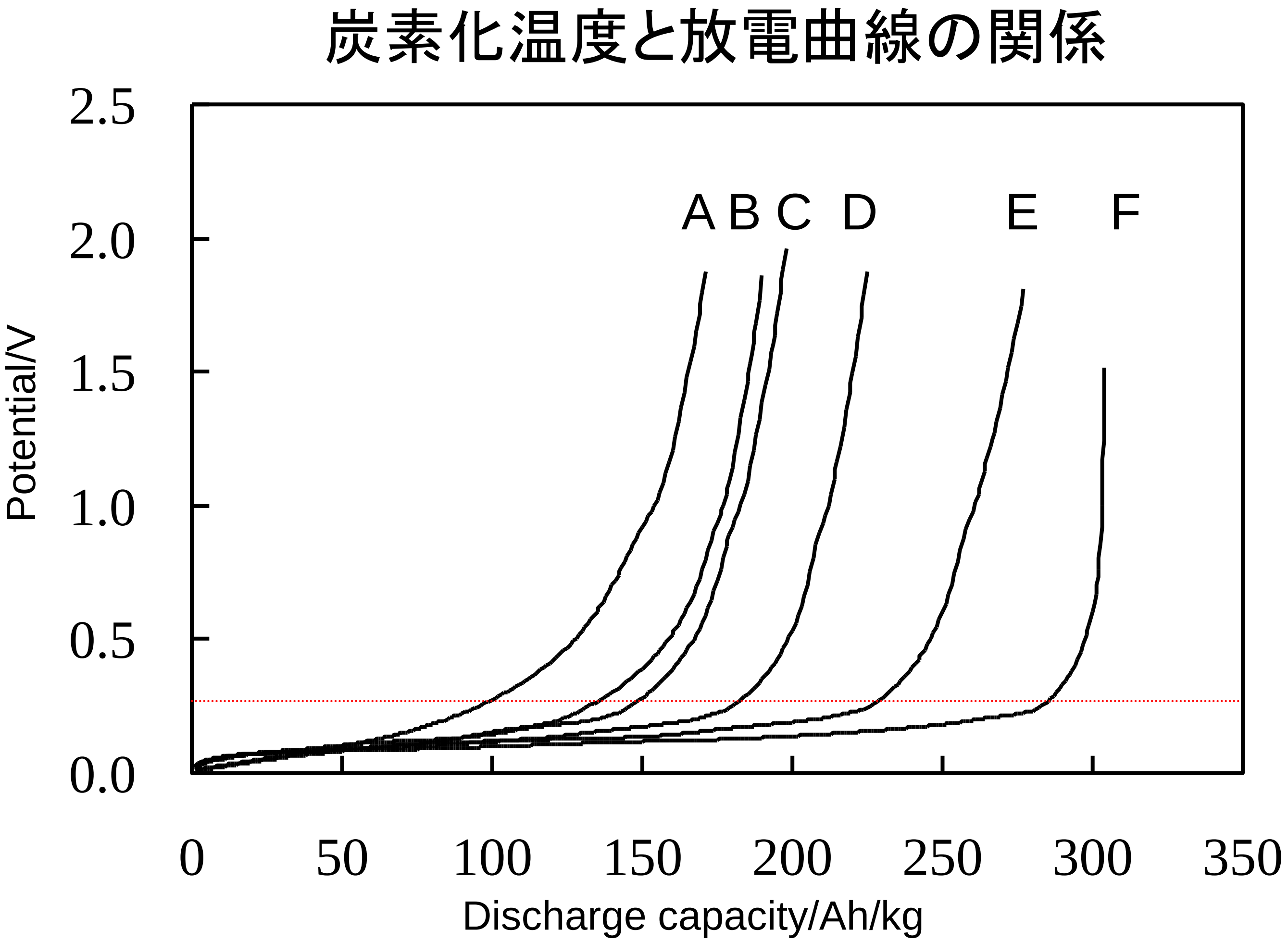
Holding and Release of Ion Is Accompanied with Volumetric Charge

Larger Capacity per Volume → Larger Expansion

Moderation and Control of SEI

Irreversible Charge → Surface Coating, Composite Structure

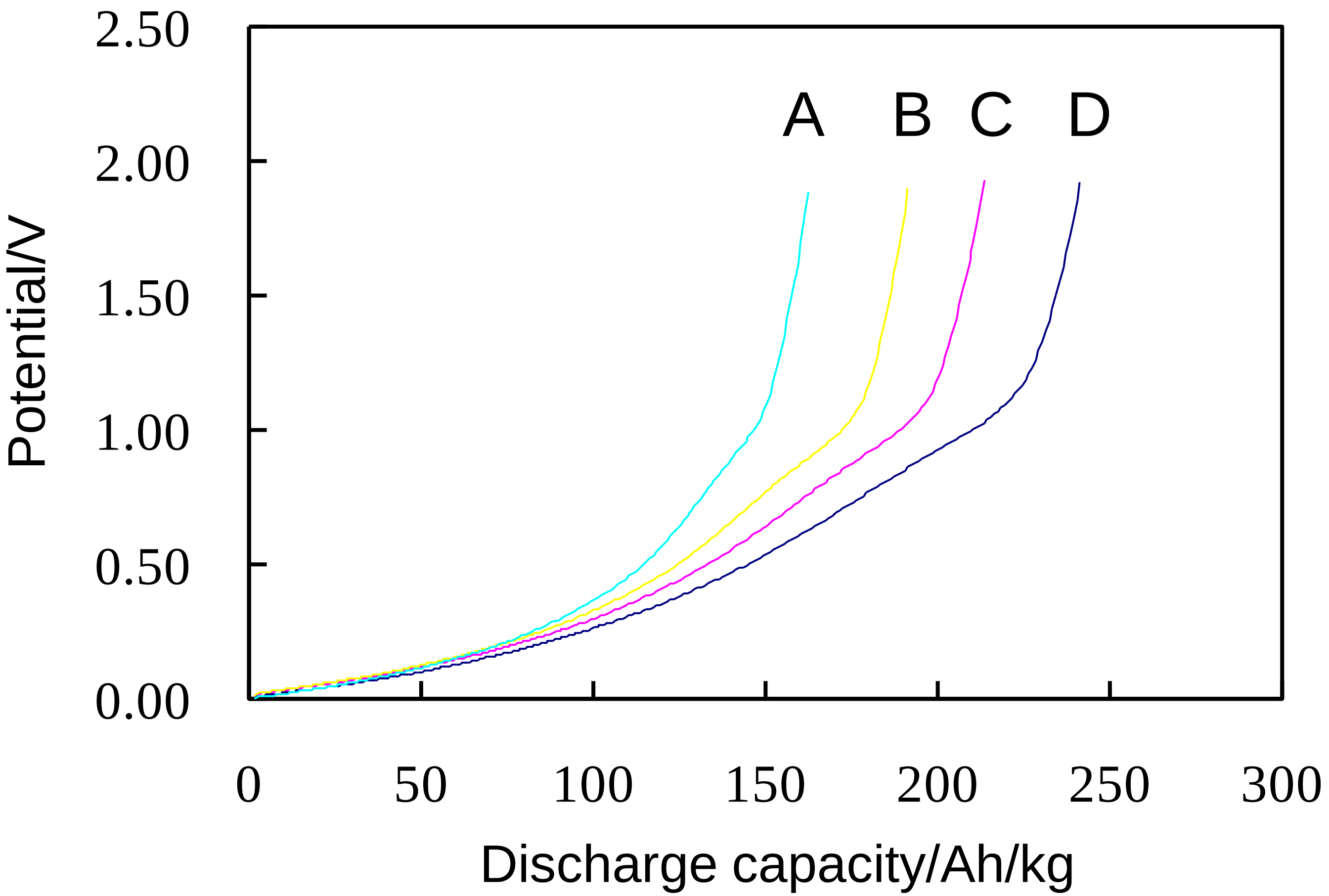
黒鉛系材料



A:2000°C B:2200°C C:2400°C D:2600°C
E:2800°C F:3000°C

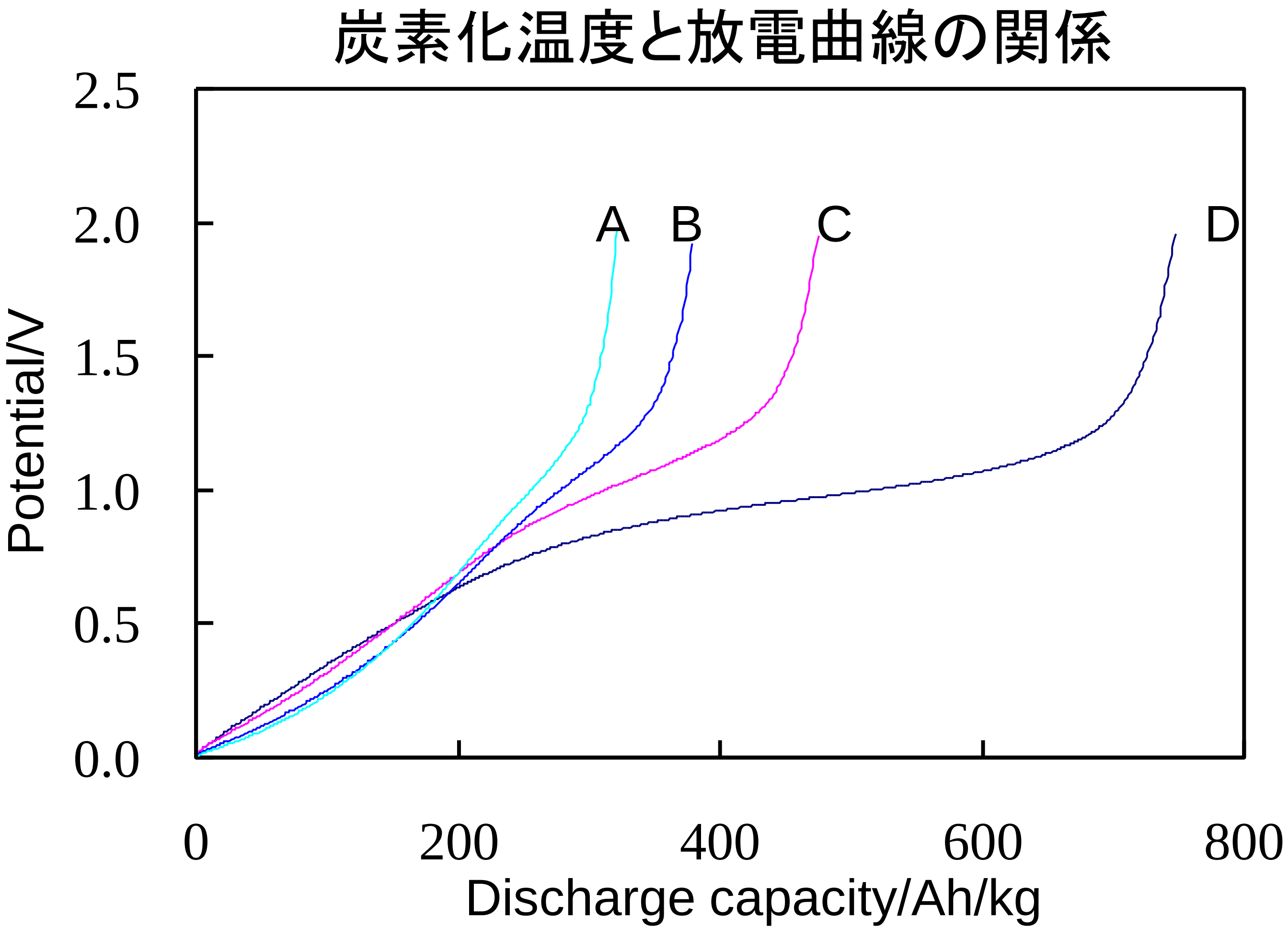
コークス系材料

炭素化温度と放電曲線の関係



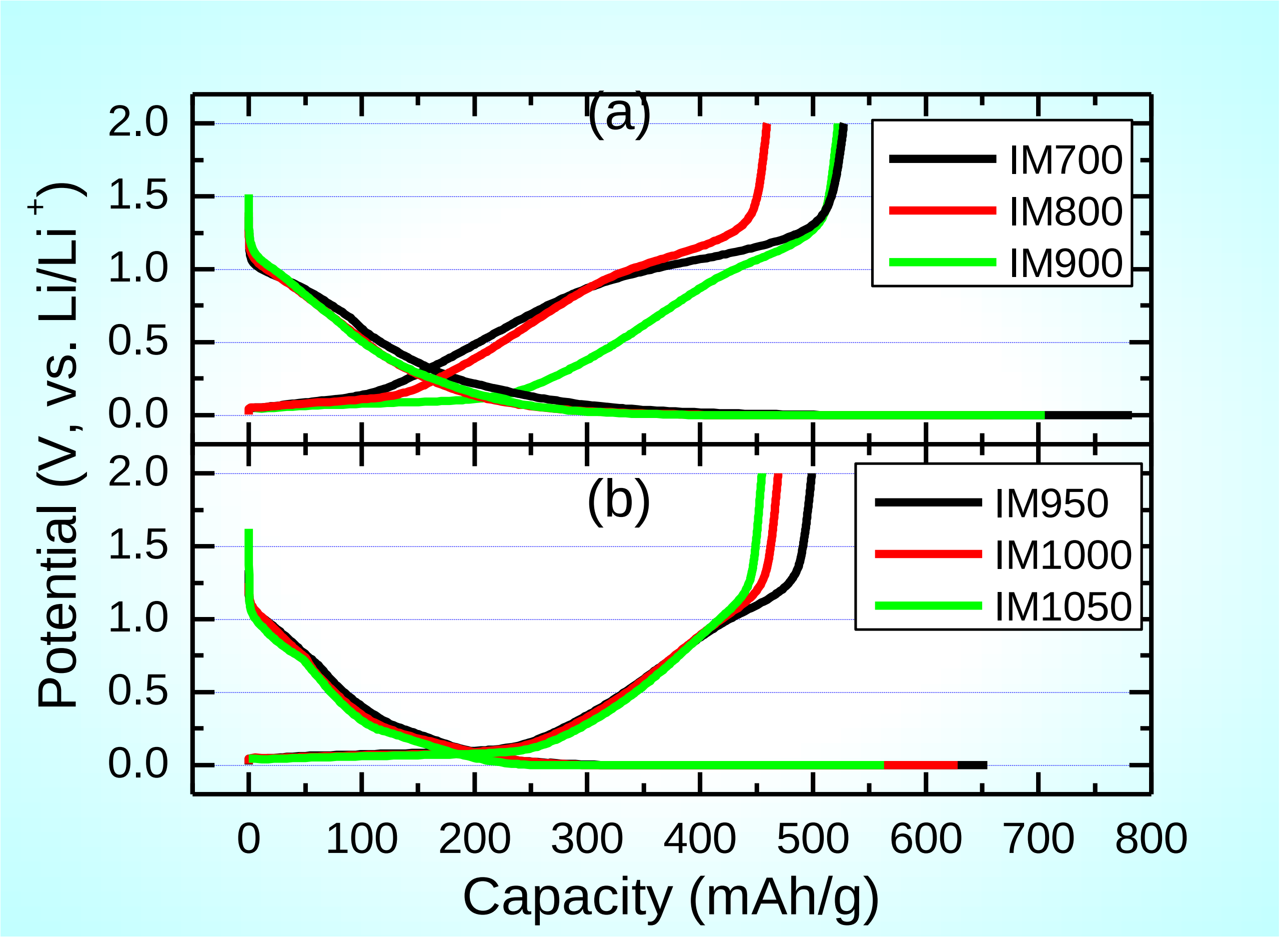
A:1800°C　B:1600°C　C:1400°C　D:1200°C

低温焼成炭素系材料



A:1000°C　B:900°C　C:800°C　D:700°C

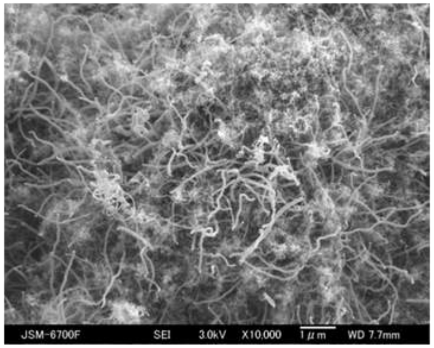
バイオ由来のハードカーボン



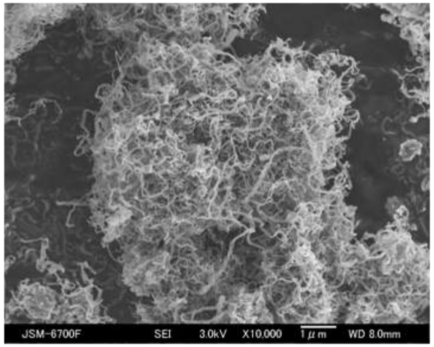
IM is heat treated under Ar atmosphere with the heating rate of 10°C/min

Preparation and Analysis of SiO-CNF Composites

SEM



Ni cat. (500℃, H-CNF)

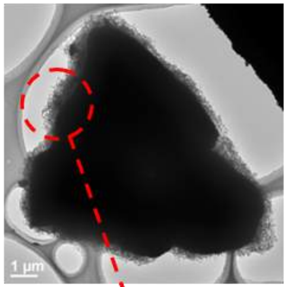


Fe cat. (600℃, P-CNF)

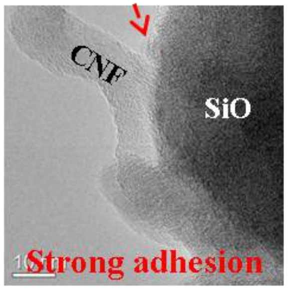
Ref: Yoon et al., Carbon 43 (9) (2005),1828-1838

TEM

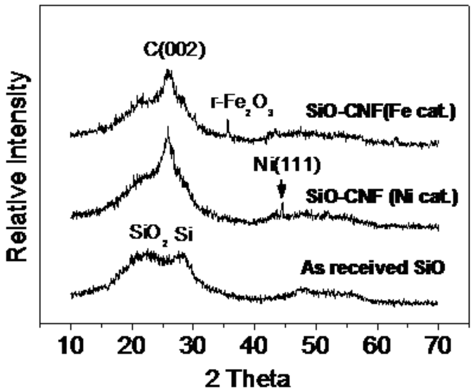
Reaction time (10s)



SiO-CNF composite



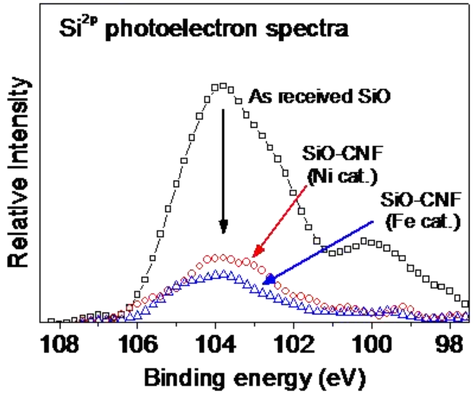
XRD



SiO showed amorphous structure

C(002) peak was observed by CNF growth

XPS

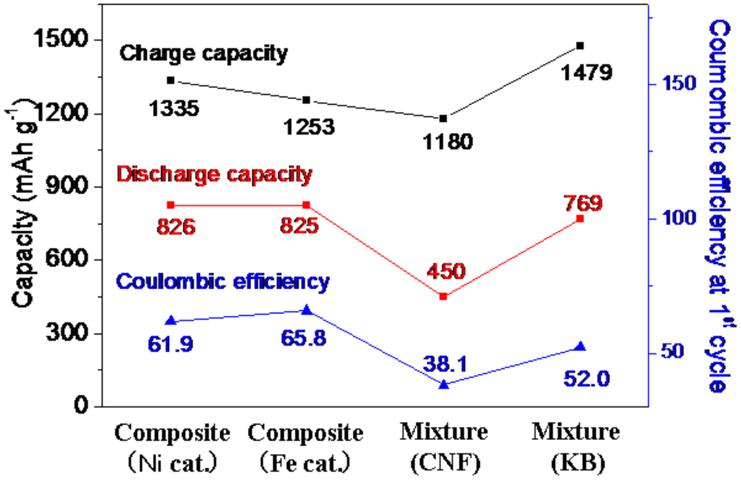


CNF growth decreases Si exposure.

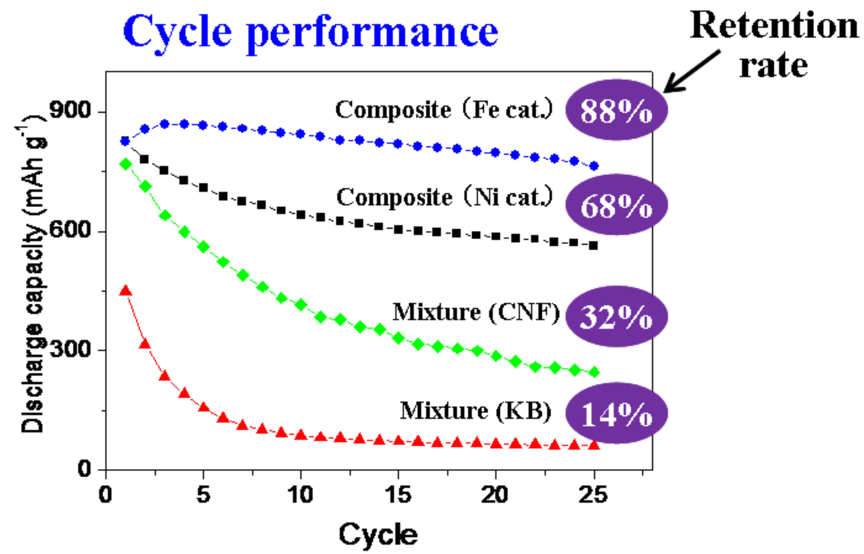
Electrochimica Acta, 55, 5519-5522 (2010)

Comparison *bet.* Composite *and* Mixture

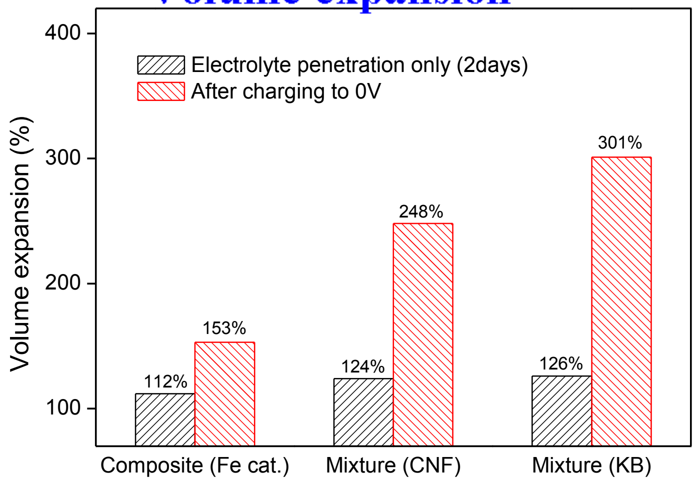
At 1st cycle



Cycle performance



Volume expansion

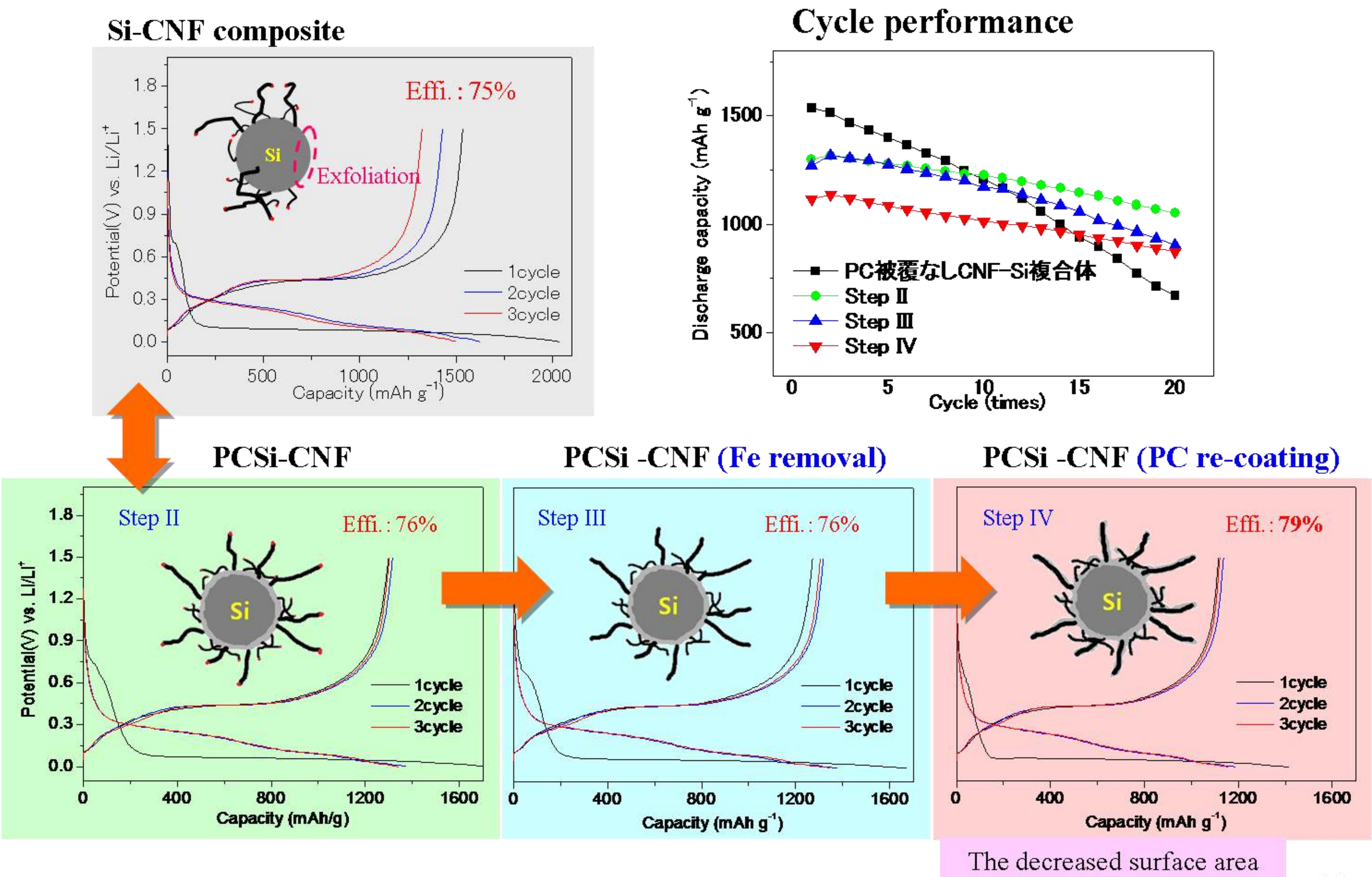


Superiority of the CNF composite

- High discharge capacity and coulombic efficiency at 1st cycle
- Excellent cycle performance
- Lower volume expansion

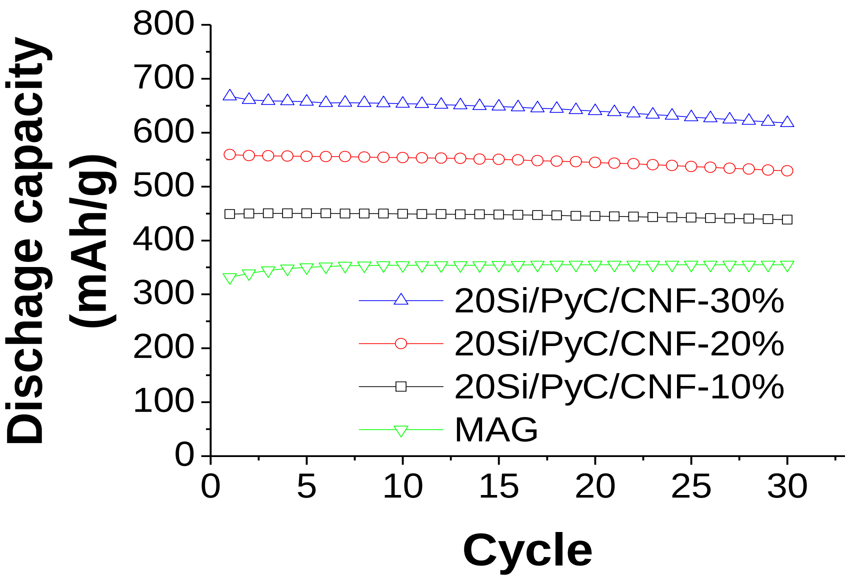
⇒ CNF growth provides spaces to relieve volume expansion and conductivities to improve performances

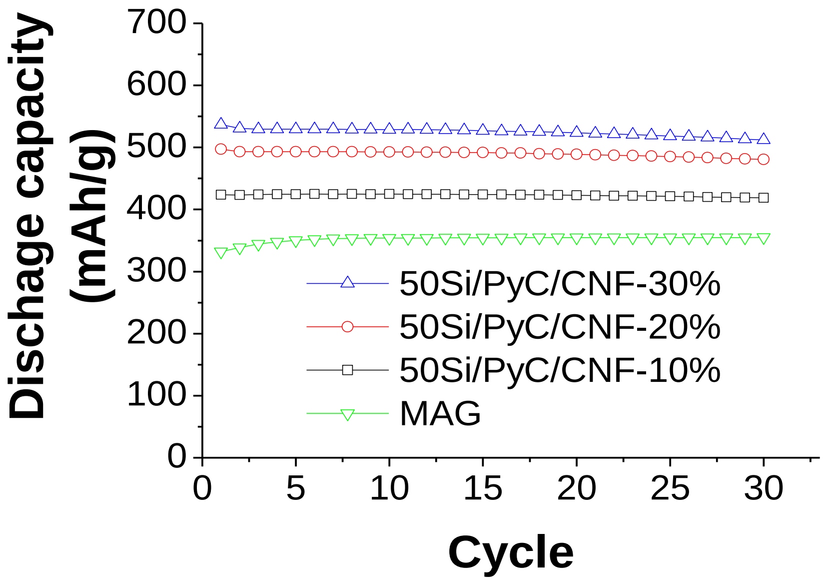
Cycle performances of PCSi-CNF composite



CARBON, 48, 3381-3391, 2009.

Si-CNF composite / Graphite Hybridization

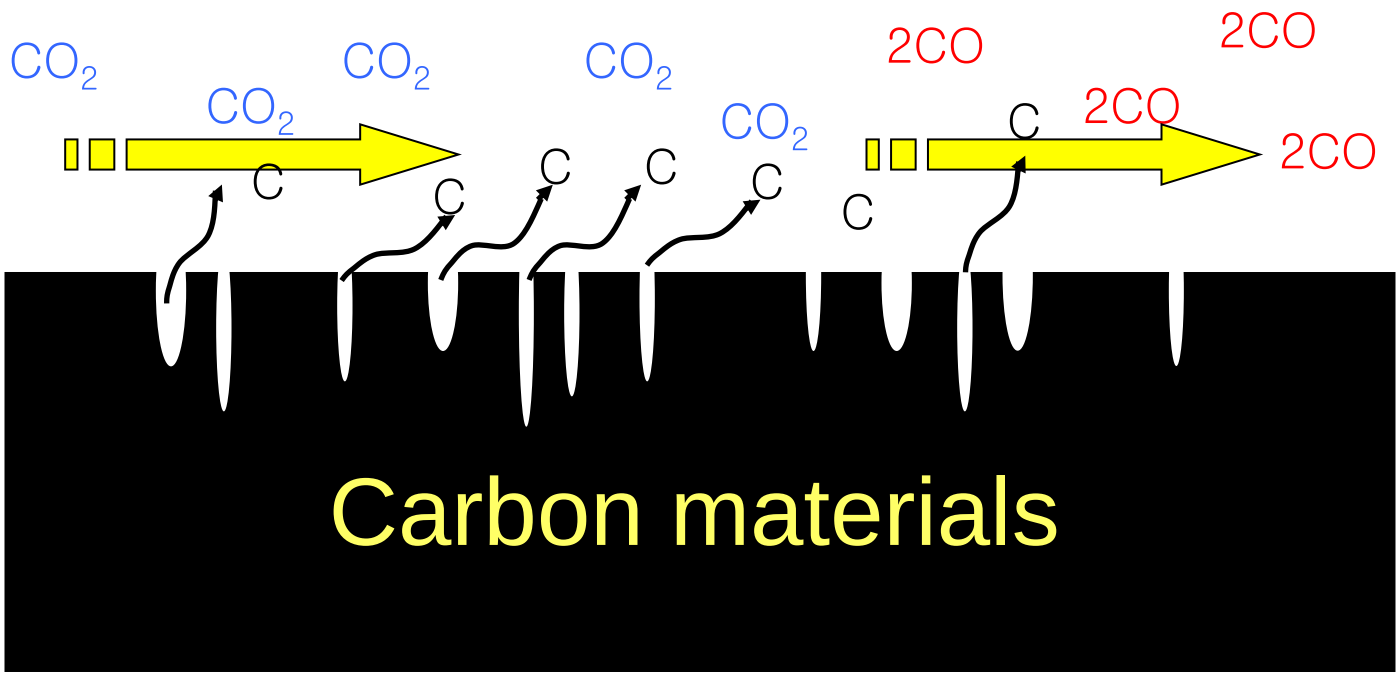




Activated Carbons for Energy and Environmental Devices

Activation（活性化）

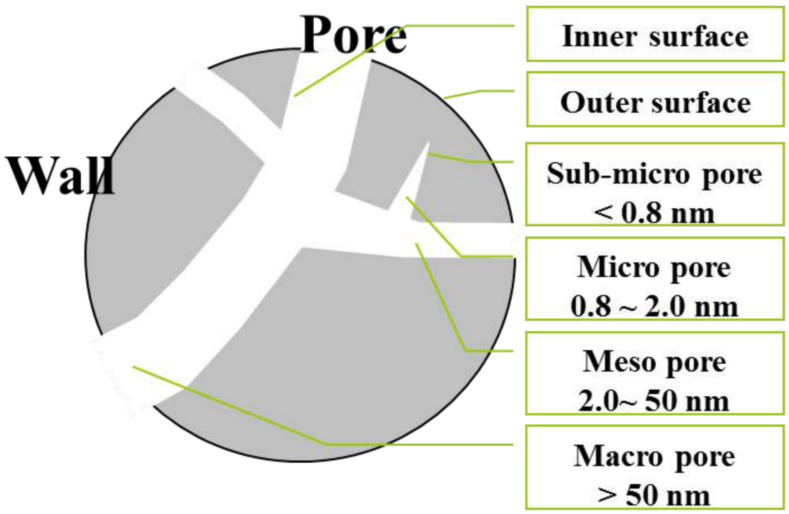
(Making small pores in the carbon materials)



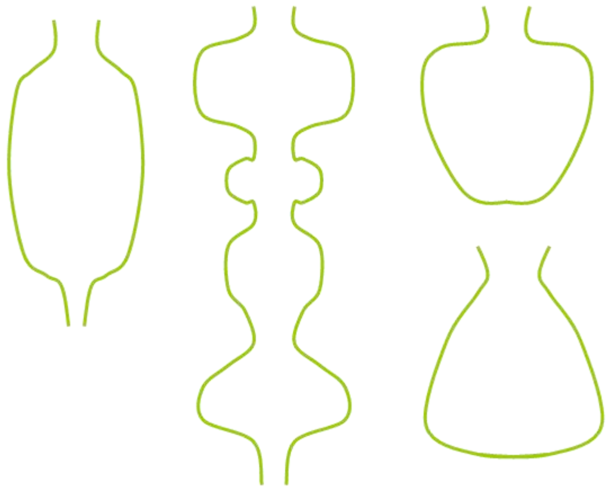
Activation reagents

- Air, CO_2, Steam
- KOH (NaOH), $ZnCl_2$

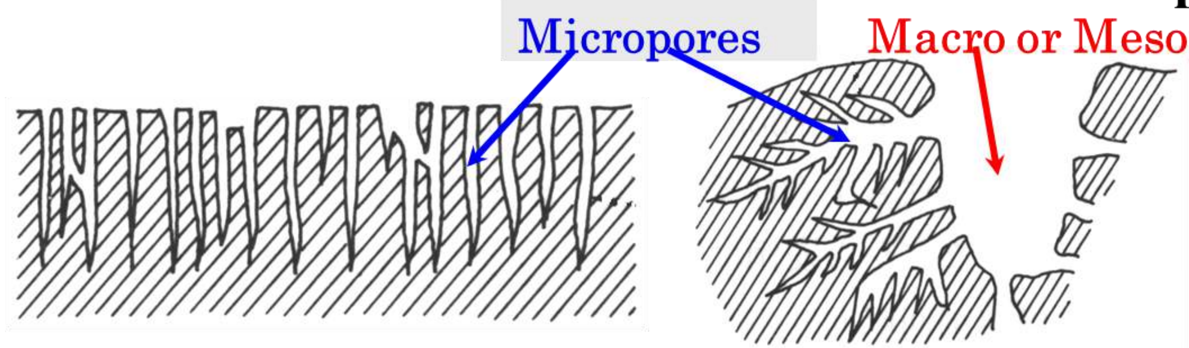
活性炭の構造モデル



Classification of surface and pores

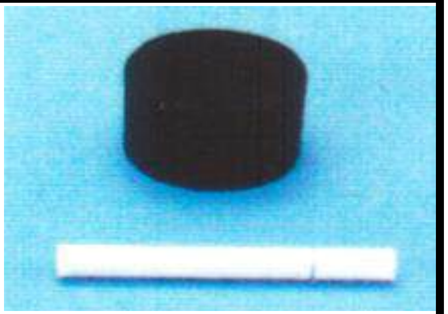
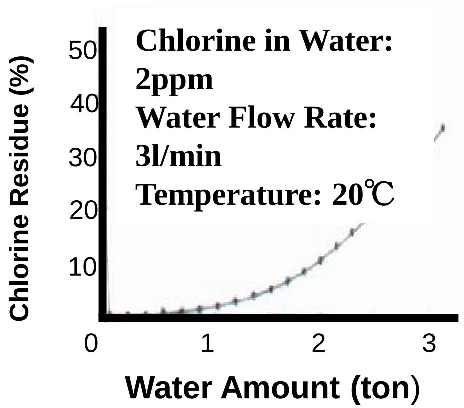


Schematic shapes of pores



Schematic pore images of activated carbon fiber and activated carbon

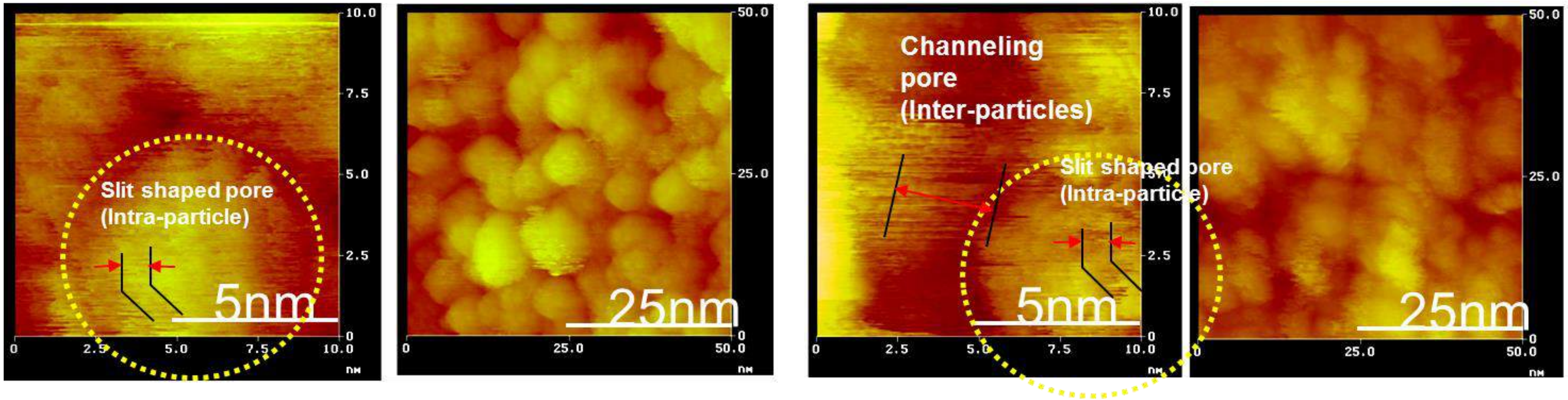
ACF Products in Particular Forms

Felt	Paper	Manufacturing Products
		 Water Filter  Small Water filte
• Thickness 1~8 mm ACF Coat 60~100% • Mixing organic fibers to improve the strength and dimension stability. • Needle punched felt (FN type) heat-processed felt (FH type). • Selection according to the concentration and amount of the contaminant.	• Thickness 0.2~0.8 mm ACF Coat 60~70% • Anti-water • Anti-chemicals • Easy formation into any shapes	• Columnar • Low resistivity • Chlorine removal 

STM images of ACFs

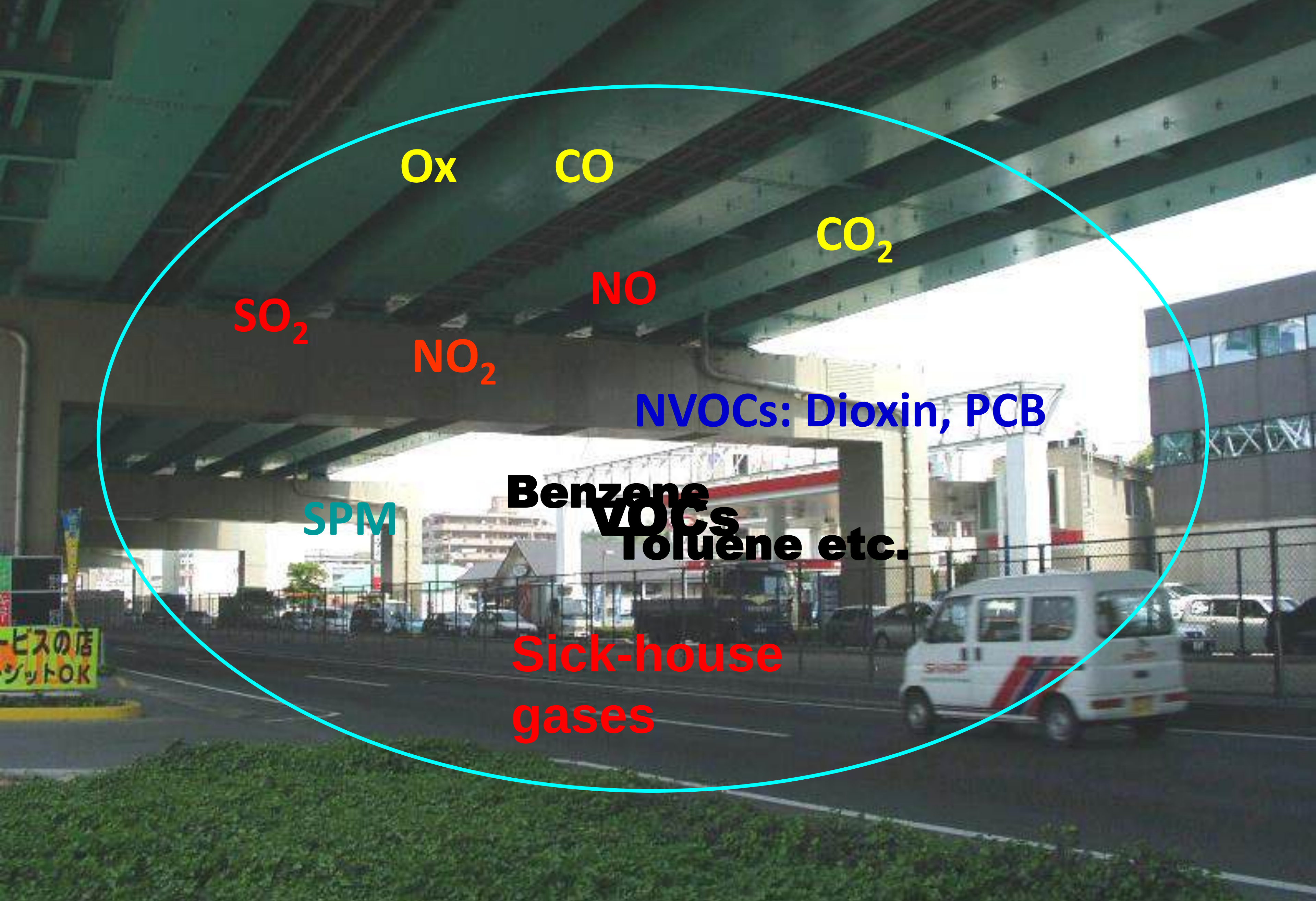
In order to remove oxygen containing functional groups for removing the heterogeneous effect of STM, OG7A and OG20A were heat-treated at 800^{O}C in a hydrogen atmosphere (H_2 / He =1/4).

OG7A-800H OG20A-800H



- ♣ **Vacant spaces between the two domains of OG20A are larger than that of OG7A.**
- ♣ **Domain size of OG20A is a little smaller than that of OG7A.**
- ♣ **Slit type pores were observed in domains of OG7A and OG20A.**
- ♣ **It can be presumed that almost pores larger than 2nm nucleated by the inter-particle mechanism.**

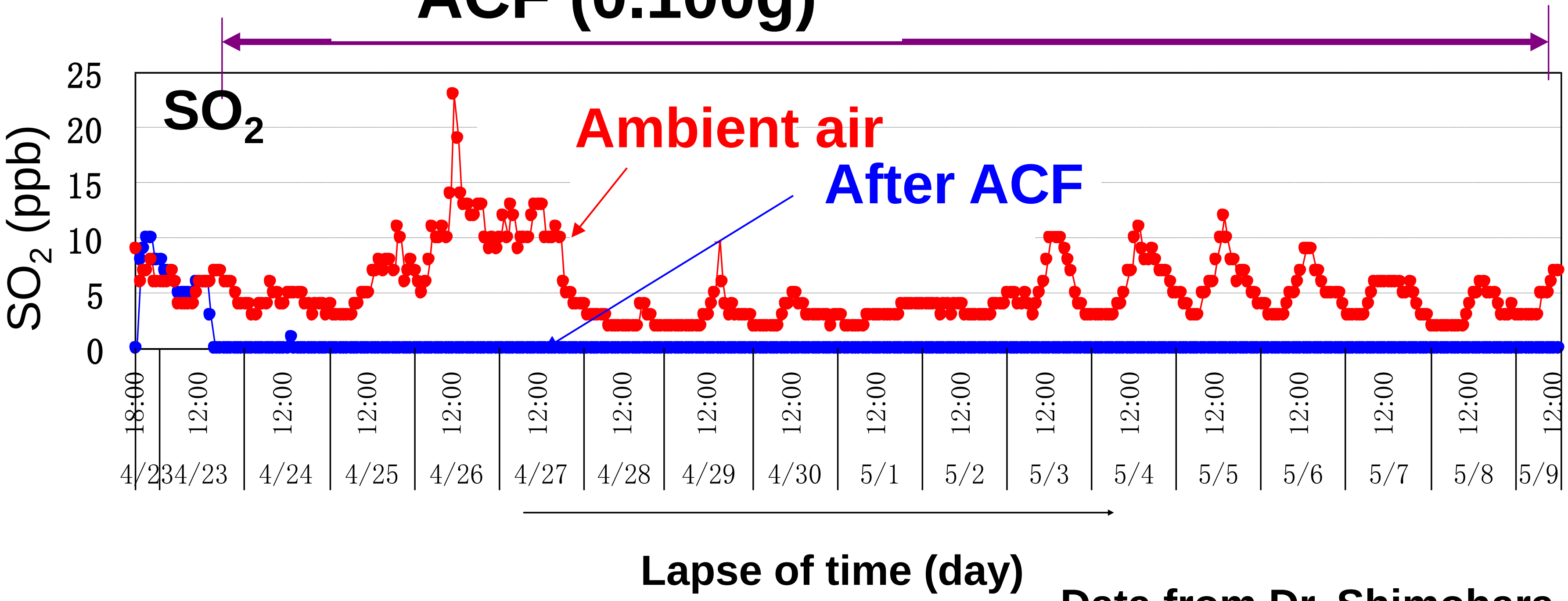
Typical Hazard Gases in the Atmosphere



活性炭素繊維を用いた道路辺のDeSOx

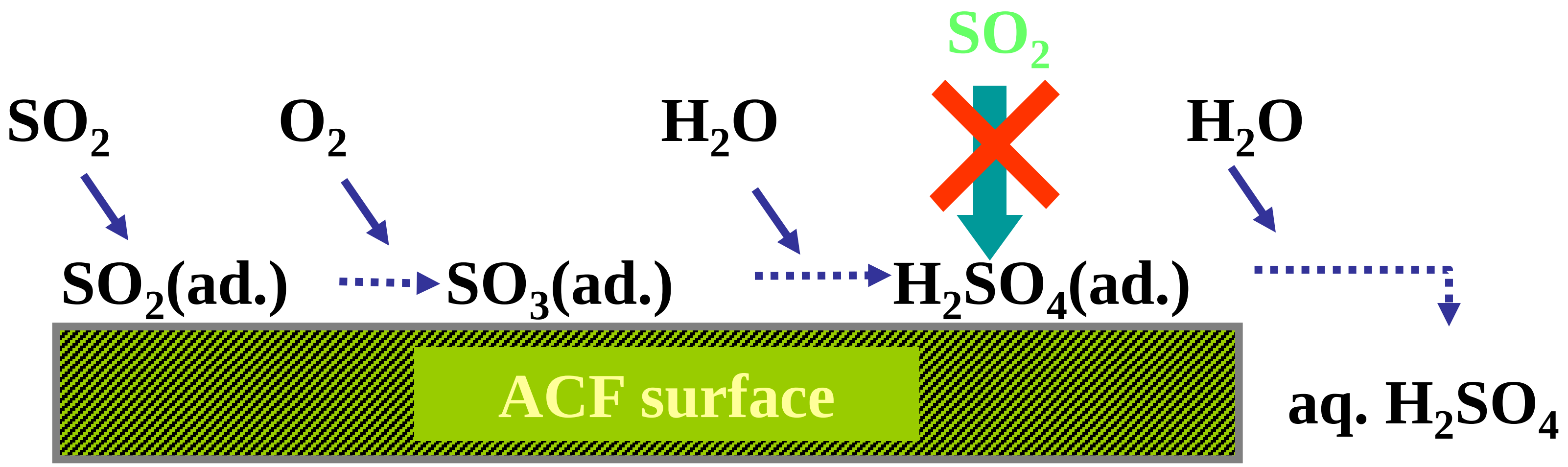
ACF

SO_2 → SO_4^{2-}



Data from Dr. Shimohara
Of Fukuoka H & E Institute

DeSOx mechanism using ACF



$$SO_2 + ad. \rightarrow SO_2 ad.$$

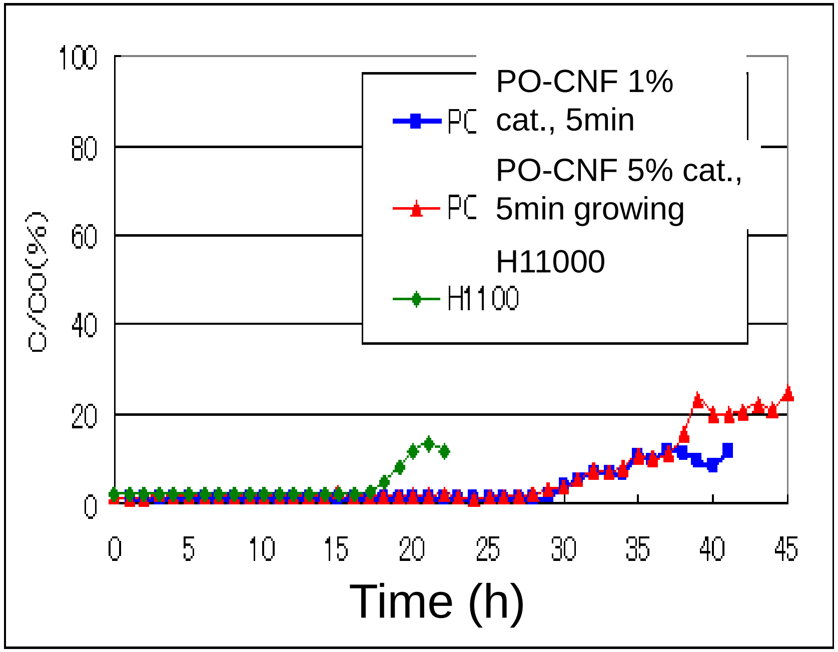
$$SO_2 ad. + 1/2 O_2 \rightarrow SO_3 ad.$$

$$SO_3 ad. + H_2O \rightarrow H_2SO_4 ad.$$

$$H_2SO_4 ad. + H_2O \rightarrow aq. H_2SO_4$$

DeSOx by ACF and CNF-ACF Composite

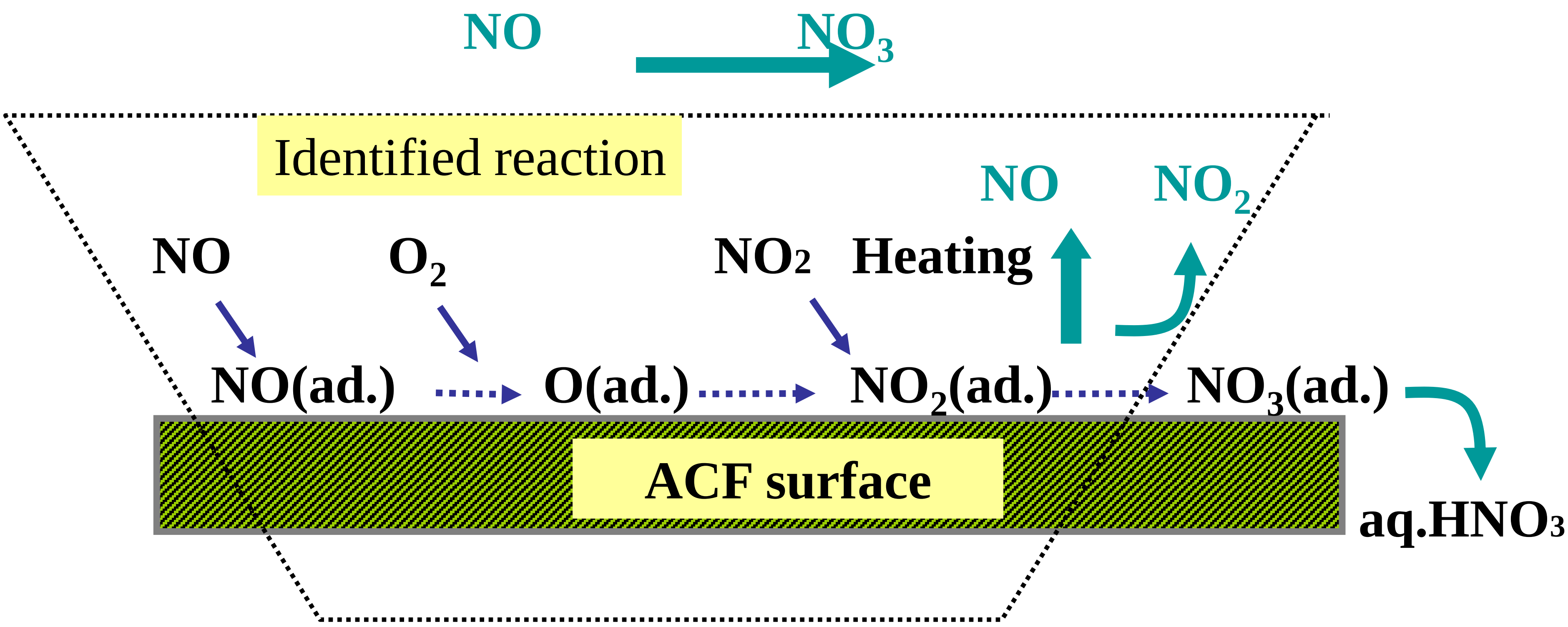
DeSOx Properties of ACF and ACF-CNF



DeSOx condition: SO_2 1000ppm, O_2 5vol%, H_2O 10vol%,
N_2 balance、Total flow rate: 100 ml/min
Reaction Temperature: 50 ℃

PDU for SOx Removal by ACF

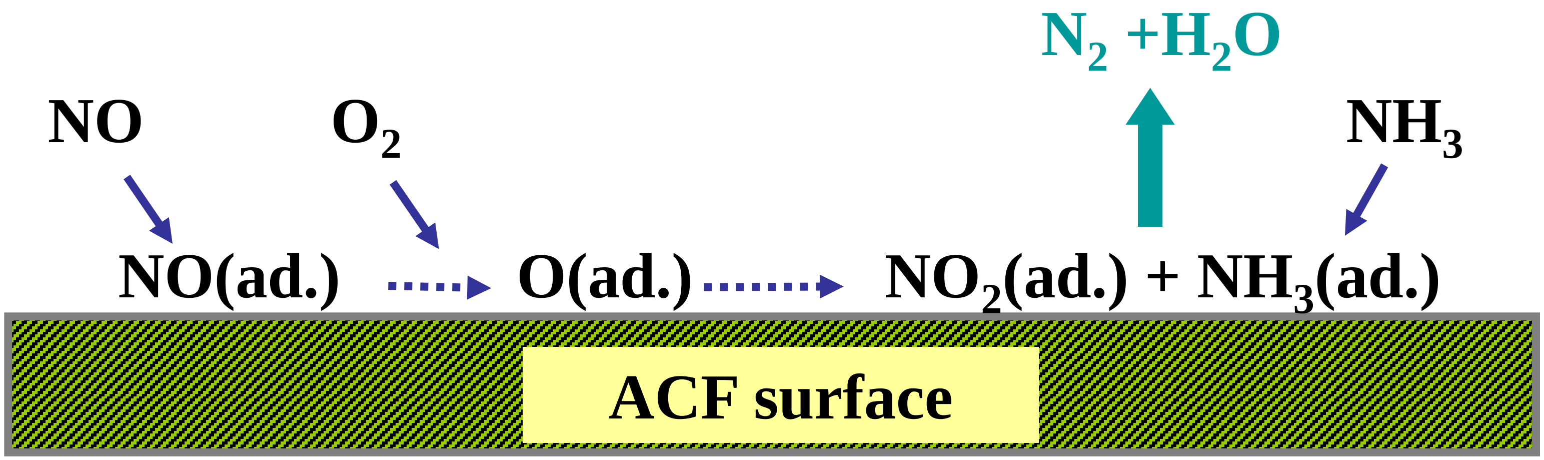
NO & NO_2 Oxidation over ACF



Strong Inhibition of H_2O

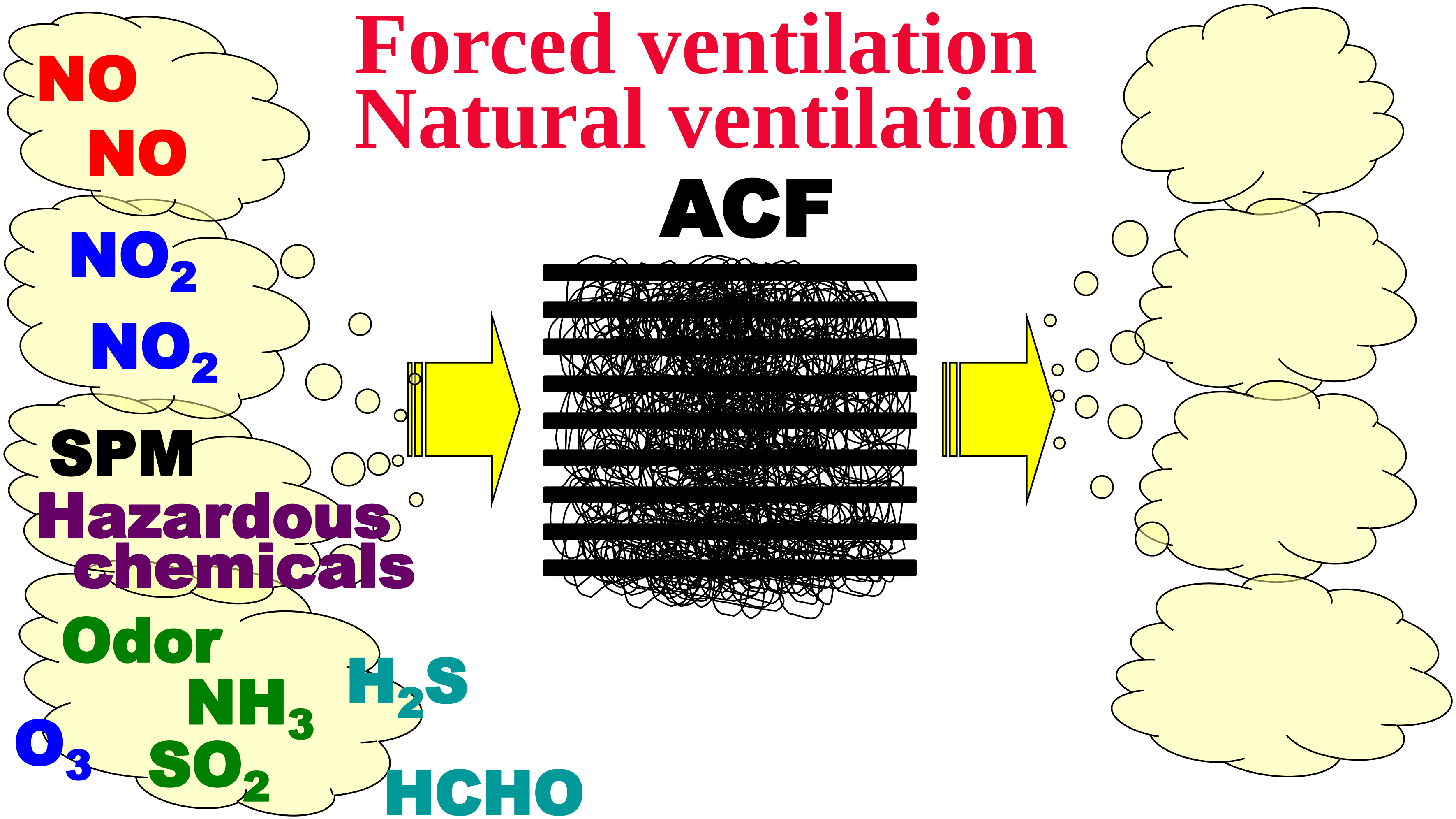
The oxidation of NO_2 always produces NO And NO_3^- through the disproportionation.

The Mechanism of NO Reductive Removal

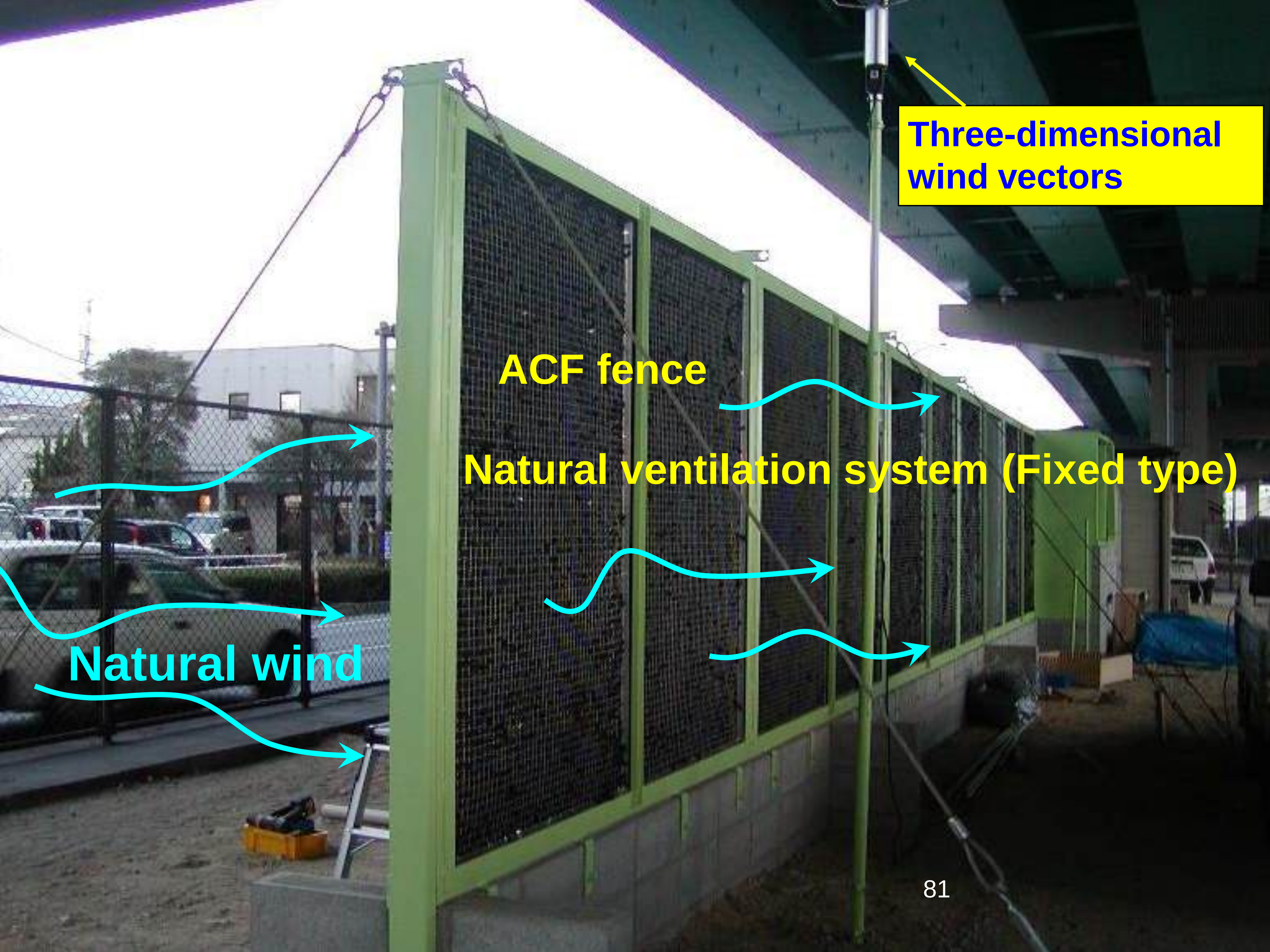


The mechanism of NO removal consists of adsorption and oxidation of NO into NO_2 which is reduced with NH_3

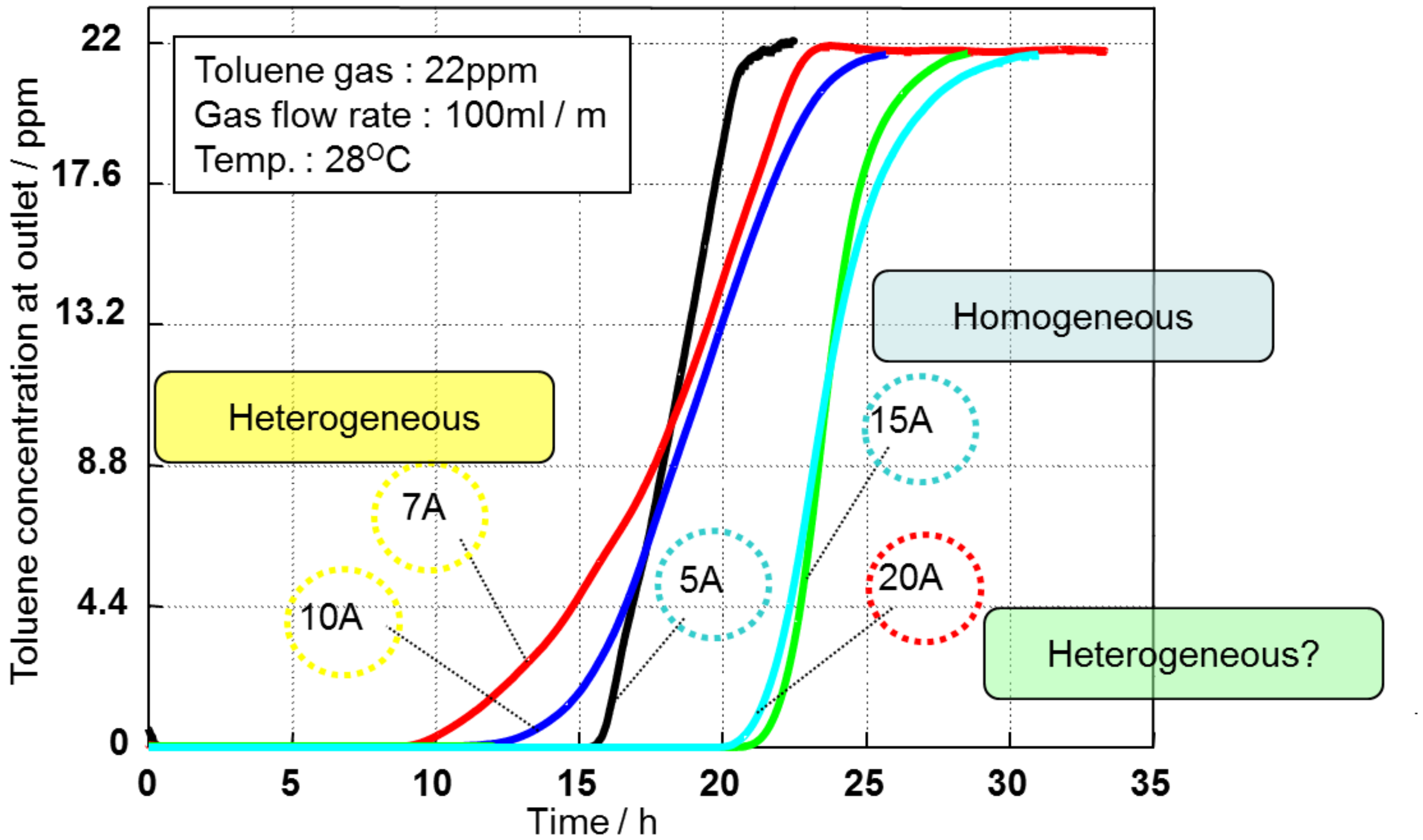
Characterization of ACF purification



Room temperature, ozonizer is no need, no light irradiation, compact design

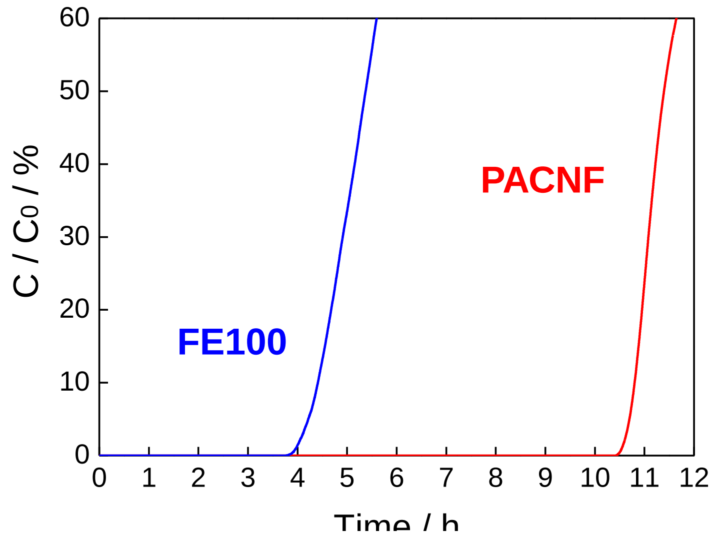

Three-dimensional wind vectors
ACF fence
Natural ventilation system (Fixed type)
Natural wind

Toluene adsorption characteristics of ACFs

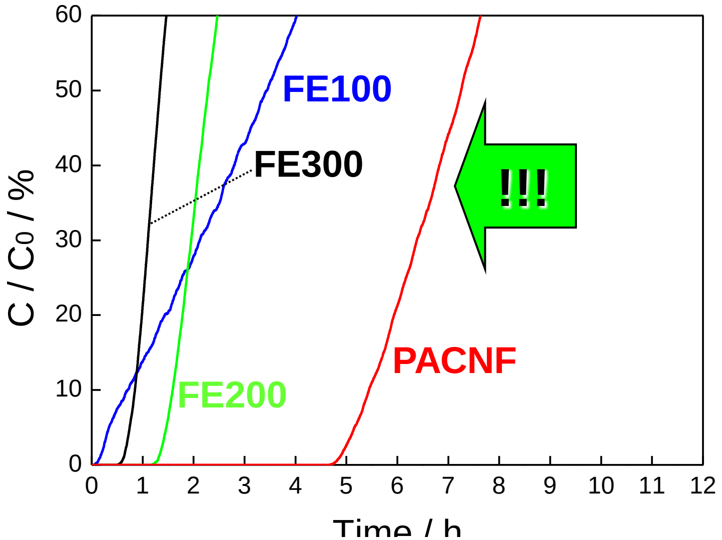


HCHO adsorption characteristics of PACNF in humidified atmosphere

RH	BET	Elemental analysis (wt%)						Microporous
	(m2 / g)	C	H	*N*	*Odiff*	ash	N / O	ratio (%)
90%	375	68.06	1.19	*18.02*	*11.41*	1.32	1.80	94.7%



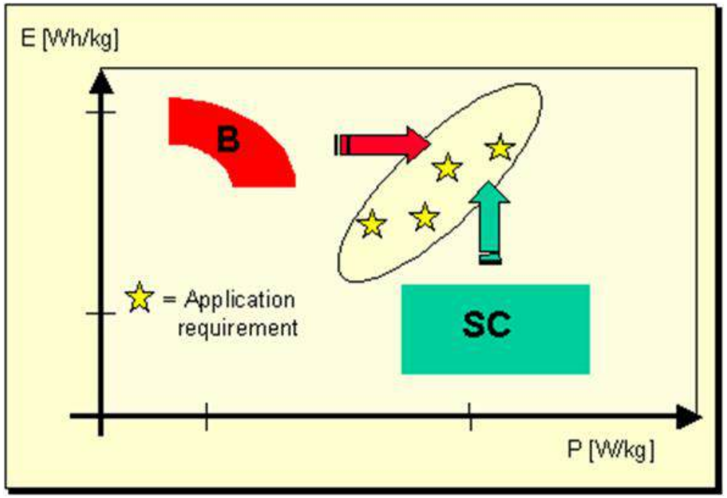
Experimental
HCHO : 11 ppm
Sample weight : 0.05g
Gas flow rate : 100ml / ml
Humidity of condition : 0%

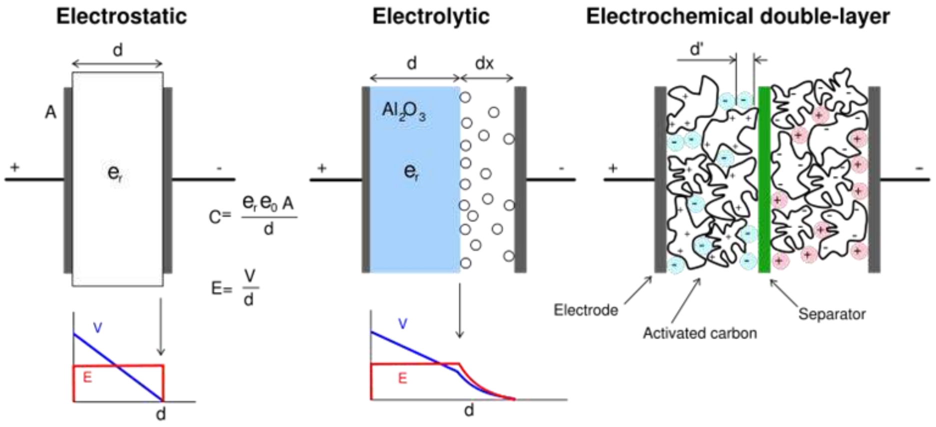


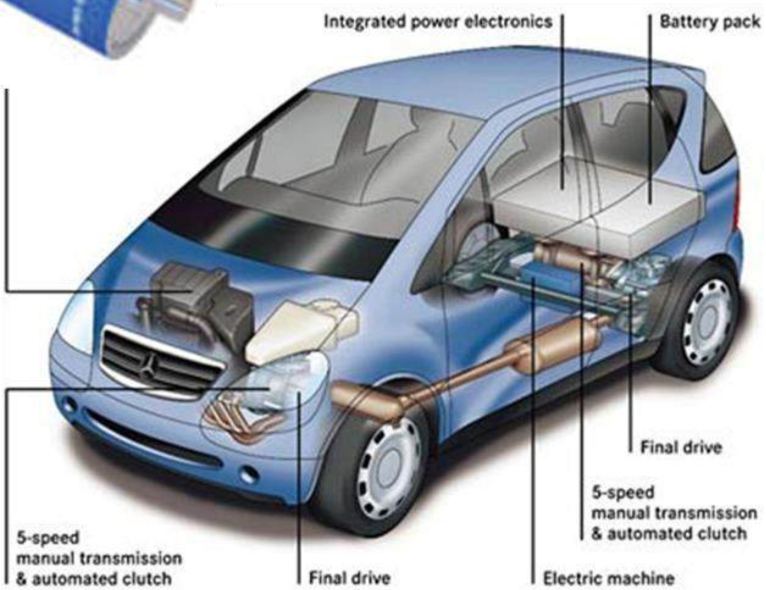
Experimental
HCHO : 11 ppm
Sample weight : 0.05g
Gas flow rate : 100ml / ml
Humidity of condition : 50%

Under the circumstances of humidity (RH=50%),
PACNF shows specific prominent adsorption characteristics for formaldehyde.

Carbons for Super Capacitor



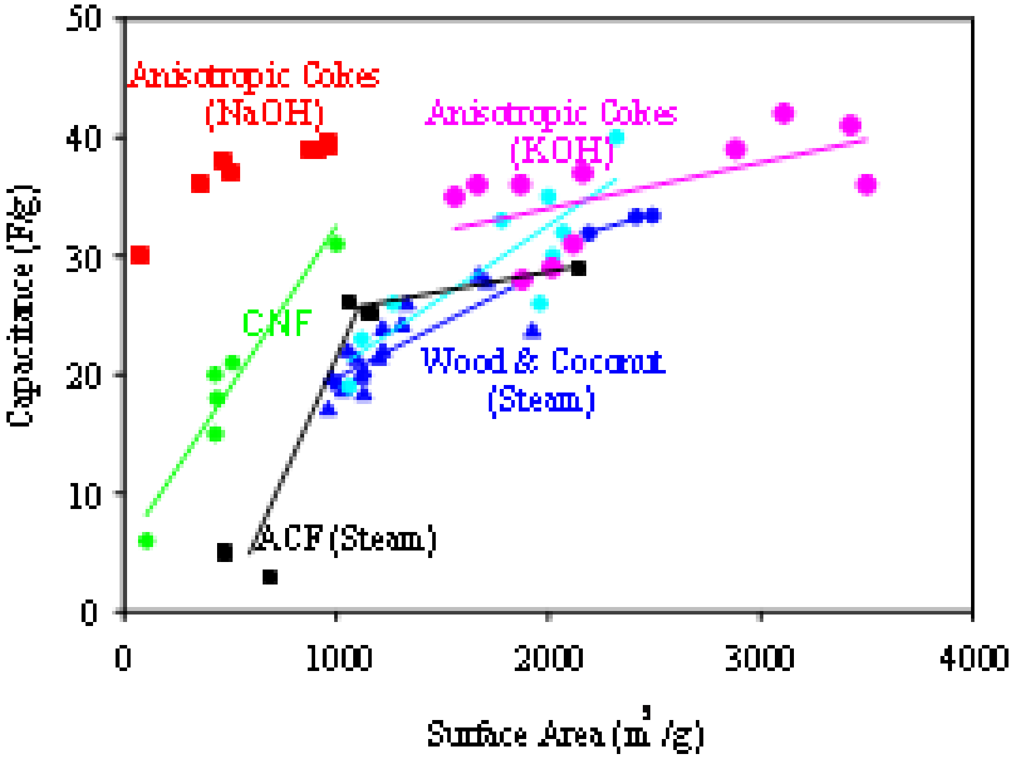




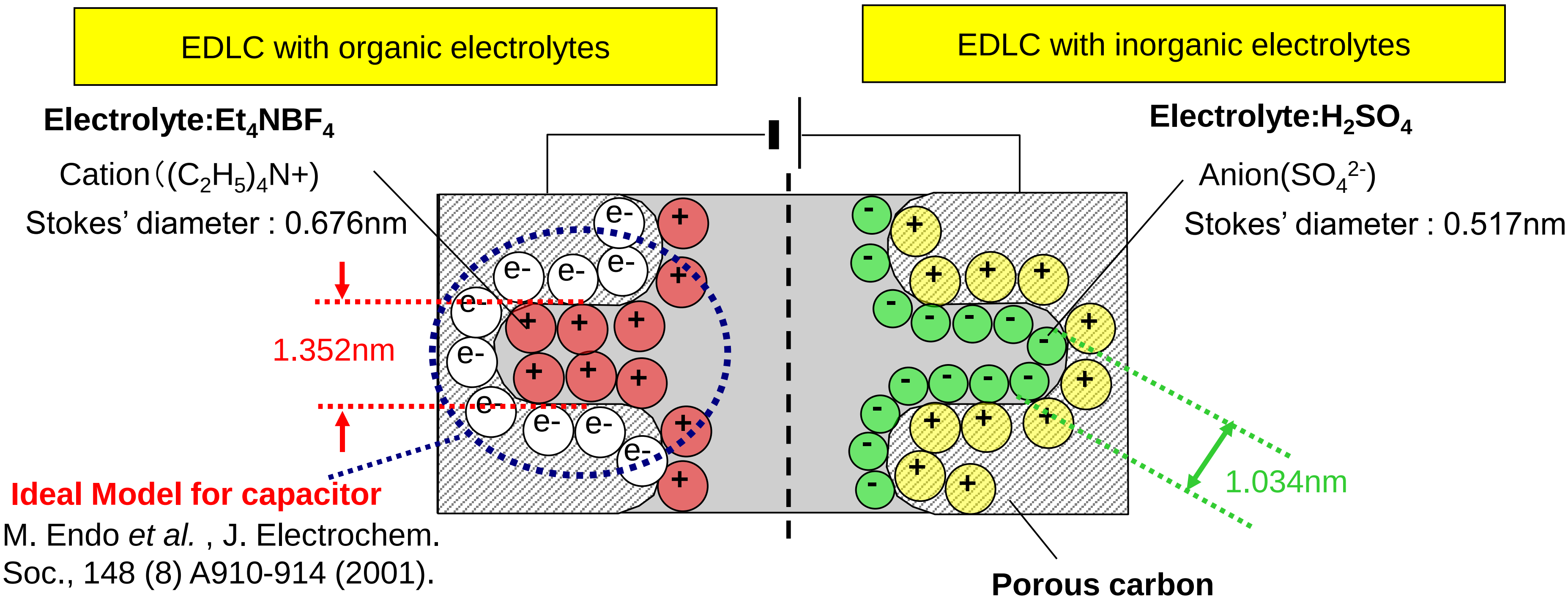
Relationship Between Organic Capacitance And Surface Area

1M Et_4NBF_4/PC, 2.7V, Capacitance per Volume

Surface Area vs. Capacitance Per Weight



Conjecture of pore size using capacitance data

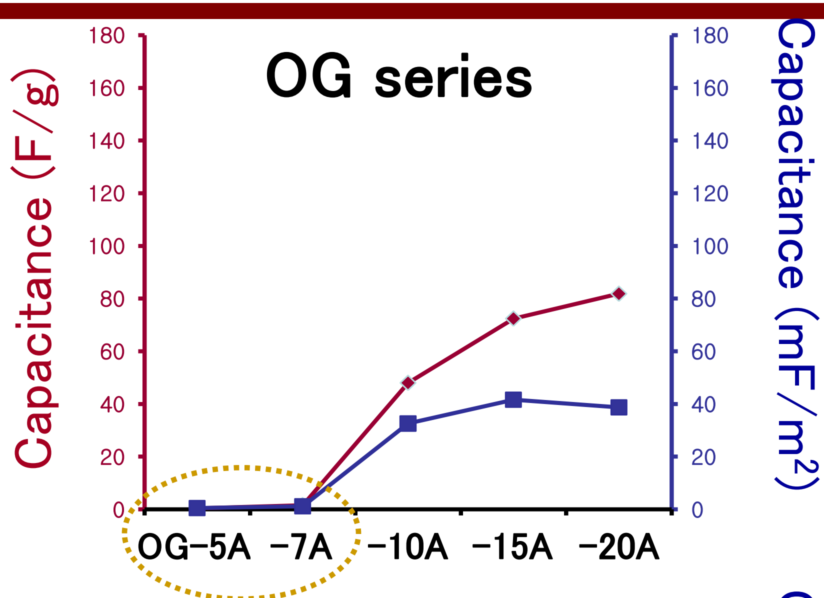


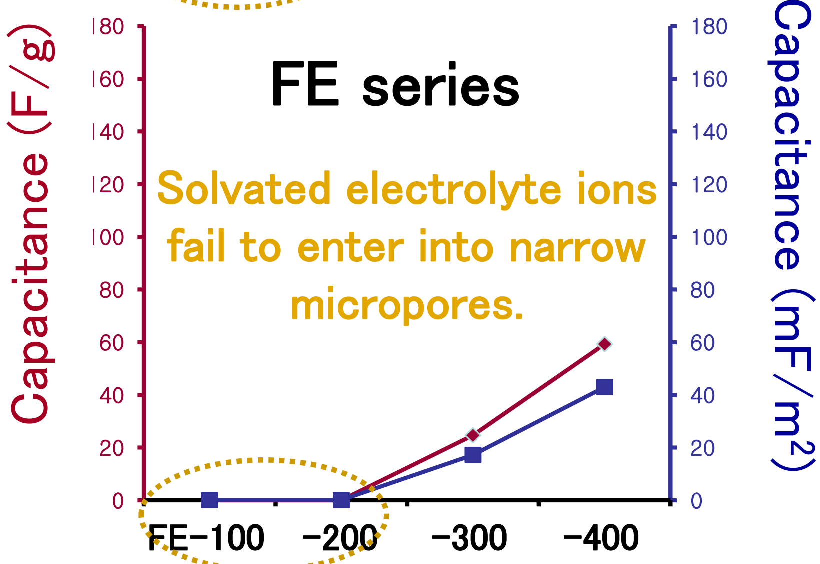
M. Endo *et al.* , J. Electrochem. Soc., 148 (8) A910-914 (2001).

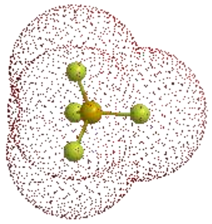
In using Et_4NBF_4 as an electrolyte, at least pore size larger than 1.3nm is necessary to have electric double layered capacitance.

In using H_2SO_4 as an electrolyte, pore size of about 1.0nm is enough to have electric double layered capacitance.

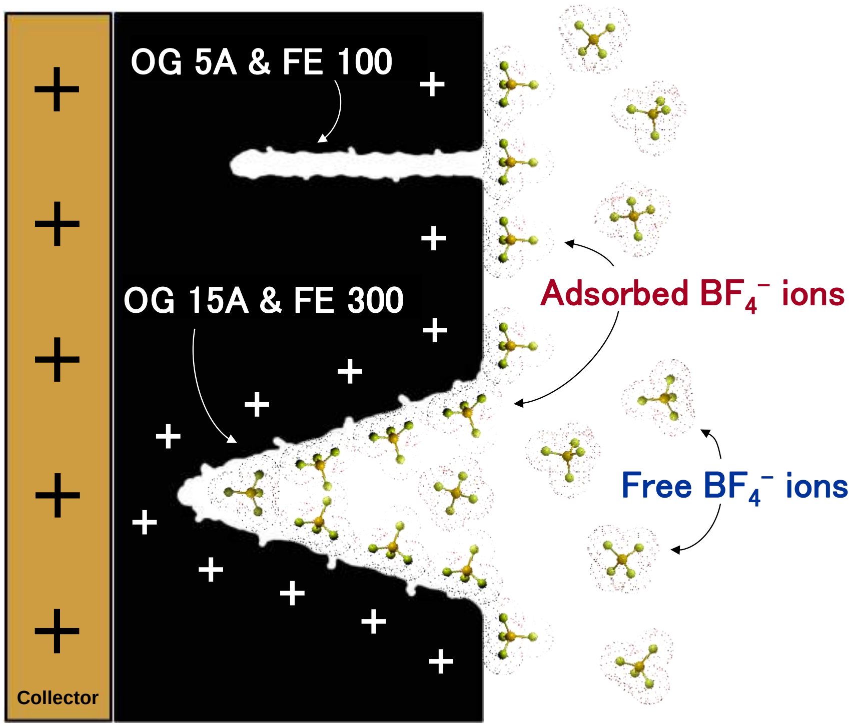
Specific Capacitances *in Non-Aqueous Electrolyte (Et_4NBF_4/PC)*







in Et_4NBF_4/PC



Conclusion

- Carbon is a key material for energy and environmental devices.
- High Utilization of coal and petroleum residues as resources for advanced functional carbon is most necessary to develop the advanced energy and environmental devices.
- Full understanding of carbon structure is necessary for improving the performance and useful applications of carbons

University:

- Creation and leading of projects
- Manpower cultivation

Thank you for your attentions!