



**FZU**

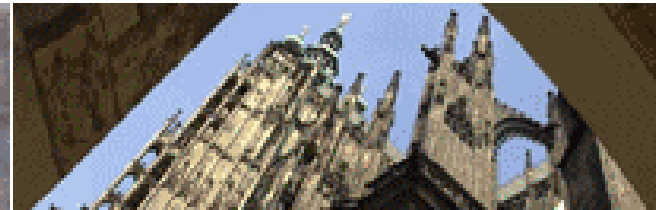
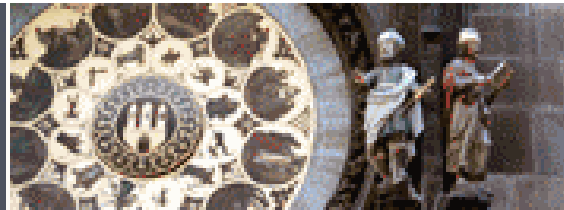
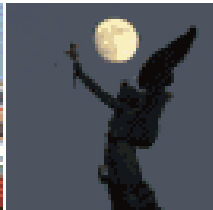
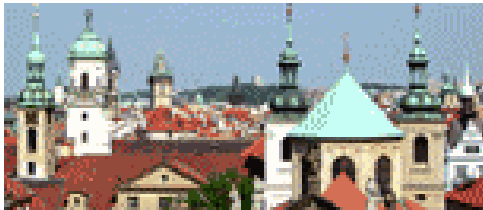
Institute of Physics  
of the Czech  
Academy of Sciences

**2023**

# Nanodiamonds, Biosensors and Their Applications

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## Who we are?



- Largest Institute of the Czech Academy of Sciences
- Public Research Institution
- History more than 60 years
- More than 1300 scientists working in different field
- All information is available at <https://www.fzu.cz>

# Diamond growth research group:



prof Alexander  
Kromka

Close collaborator



prof Bohuslav Rezek

**Czech Technical  
University in  
Prague  
(CVUT)**



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Jackivová



Štěpán  
Potocký



Dhananjay  
Sharma



Jan čermák

Ondrej  
Szabó

Oleg  
Babčenko

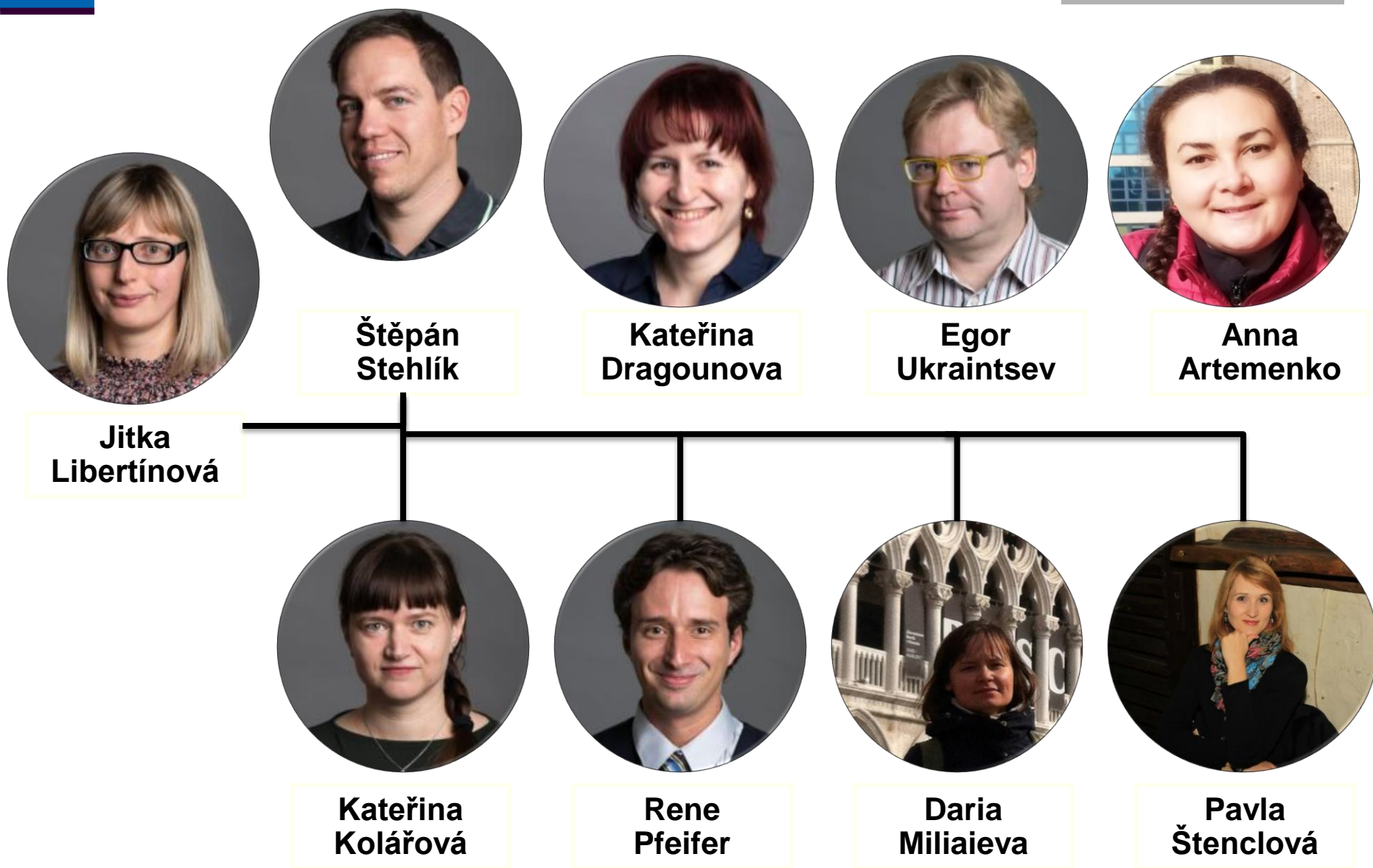
Michal Koči

Michal  
Augustín

Ekaterina  
Shagieva



# Nanoparticles, Interfaces and Analytical techniques research group



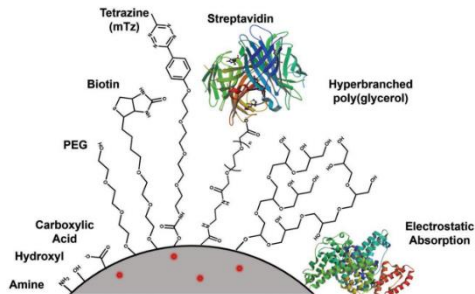
# Outline of the Presentation

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- Nanodiamonds (NDs);
- Synthesis of NDs;
- Properties of NDs;
- Doping of NDs;
  - SiV NDs;
  - NV NDs;
  - BDNDs;
- Biosensors and Applications

# Definition of Nanodiamonds (NDs)

- Are **0D** material with a size below 100 nm.

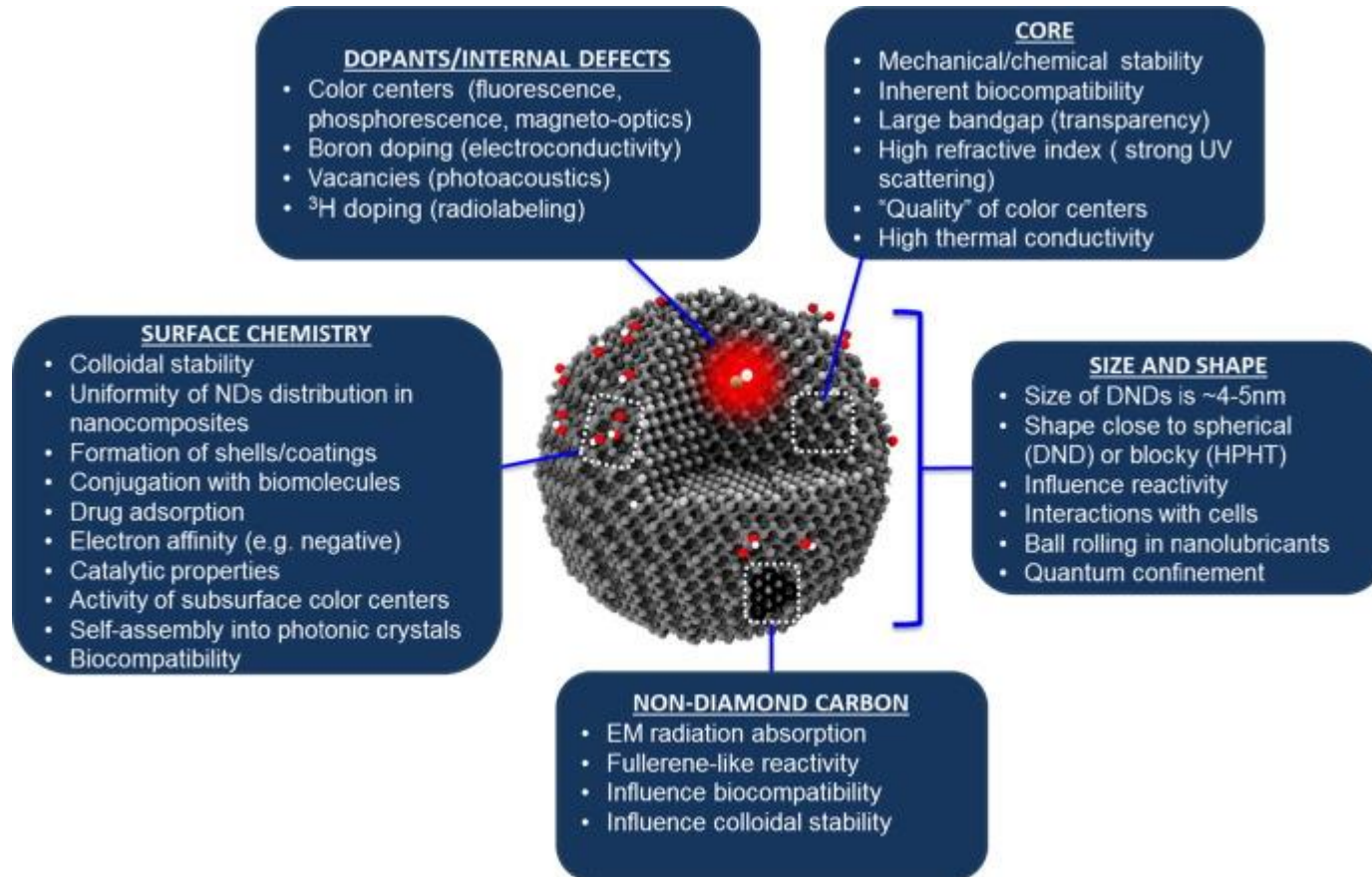


CARBON NANOSTRUCTURES				
0-D			1-D	2-D
Nanodiamonds (NDs)	Carbon Fullerenes (CFs)	Carbon Dots (CDs)	Carbon Nanotubes (CNTs)	Graphene

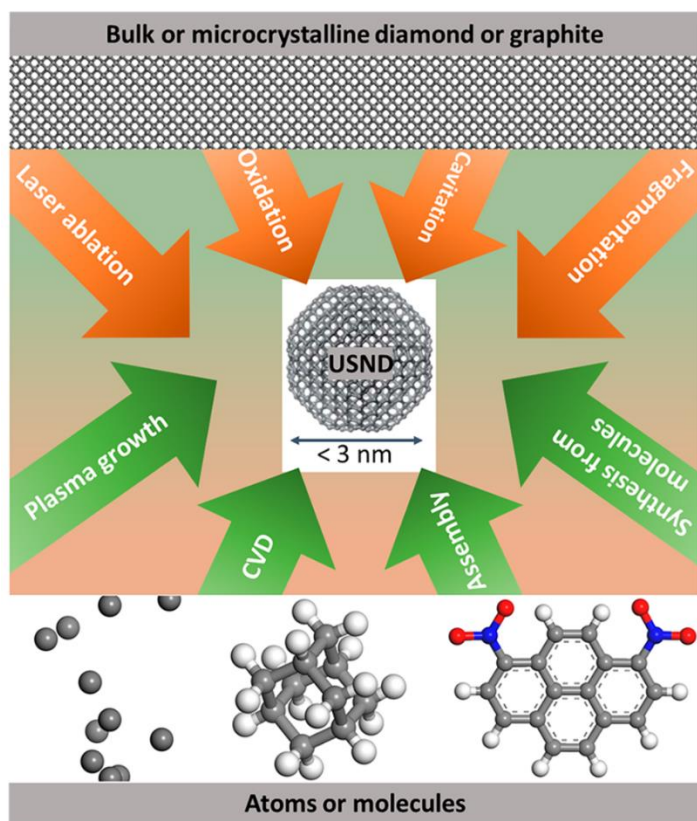


(DHO FAR 1989 – Oman 2010)

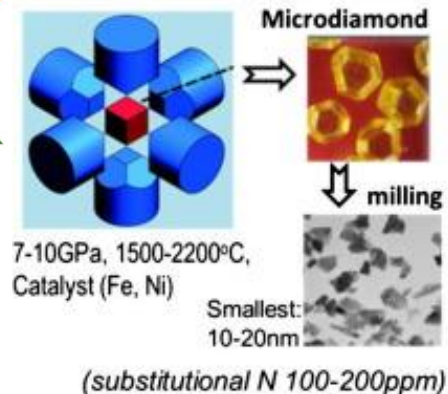
# Properties of Nanodiamonds (NDs)



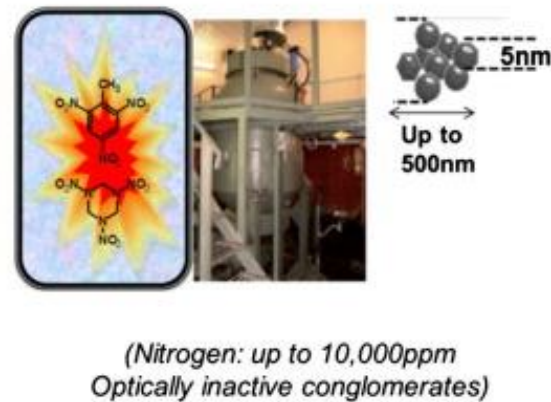
# Synthesis of NDs



(a) **Top-down**  
**ND of Static Synthesis**  
 High Pressure High Temperature (HPHT) Nanodiamond



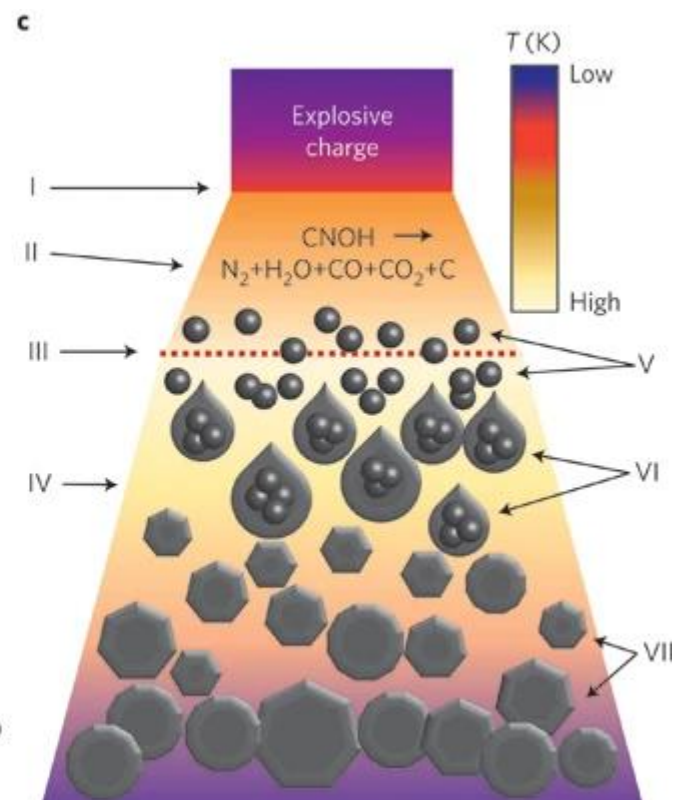
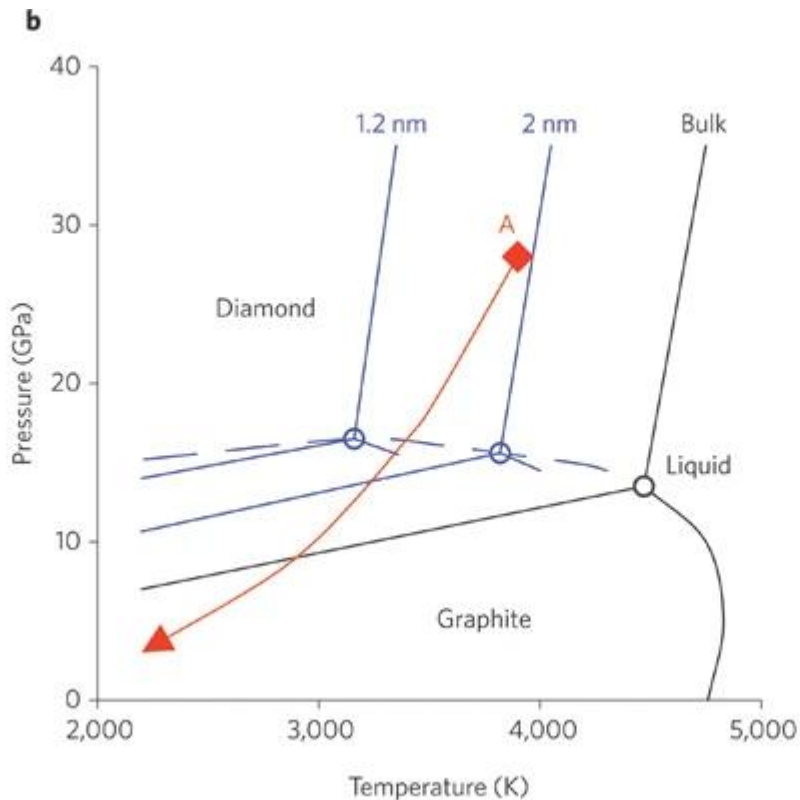
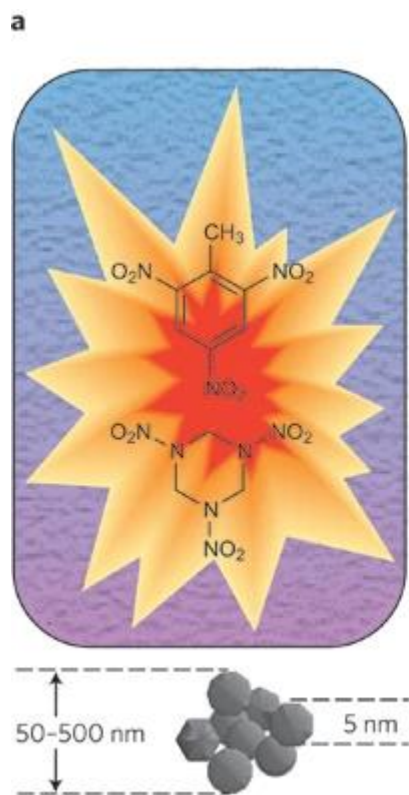
(b) **Bottom-up**  
**ND of Dynamic Synthesis**  
 Detonation Nanodiamond (DND)





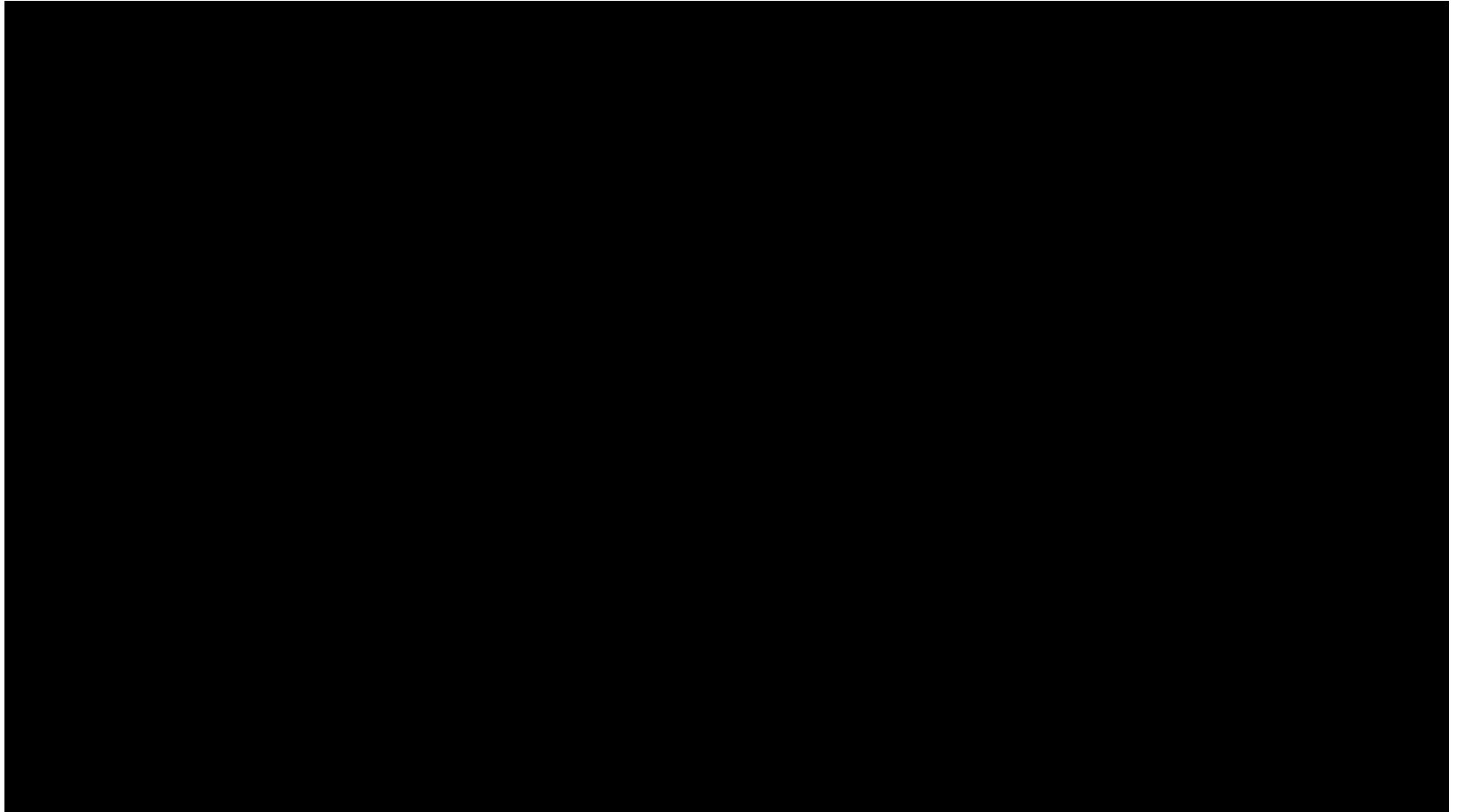
# Detonation Nanodiamonds (DNDs)

- Produce rounded NDs with an average size of 2-20 nm.

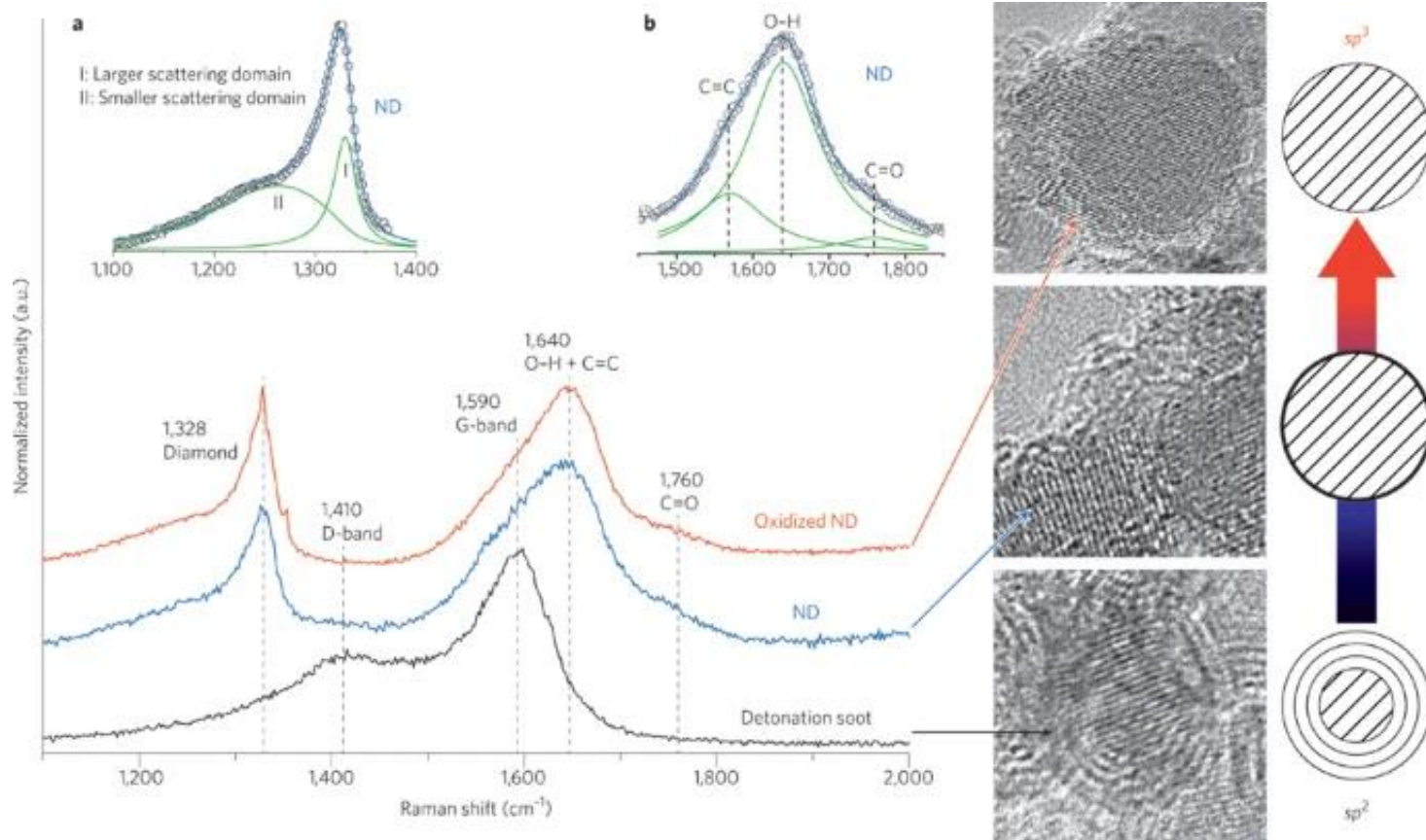


# Detonation Nanodiamonds (DNDs)

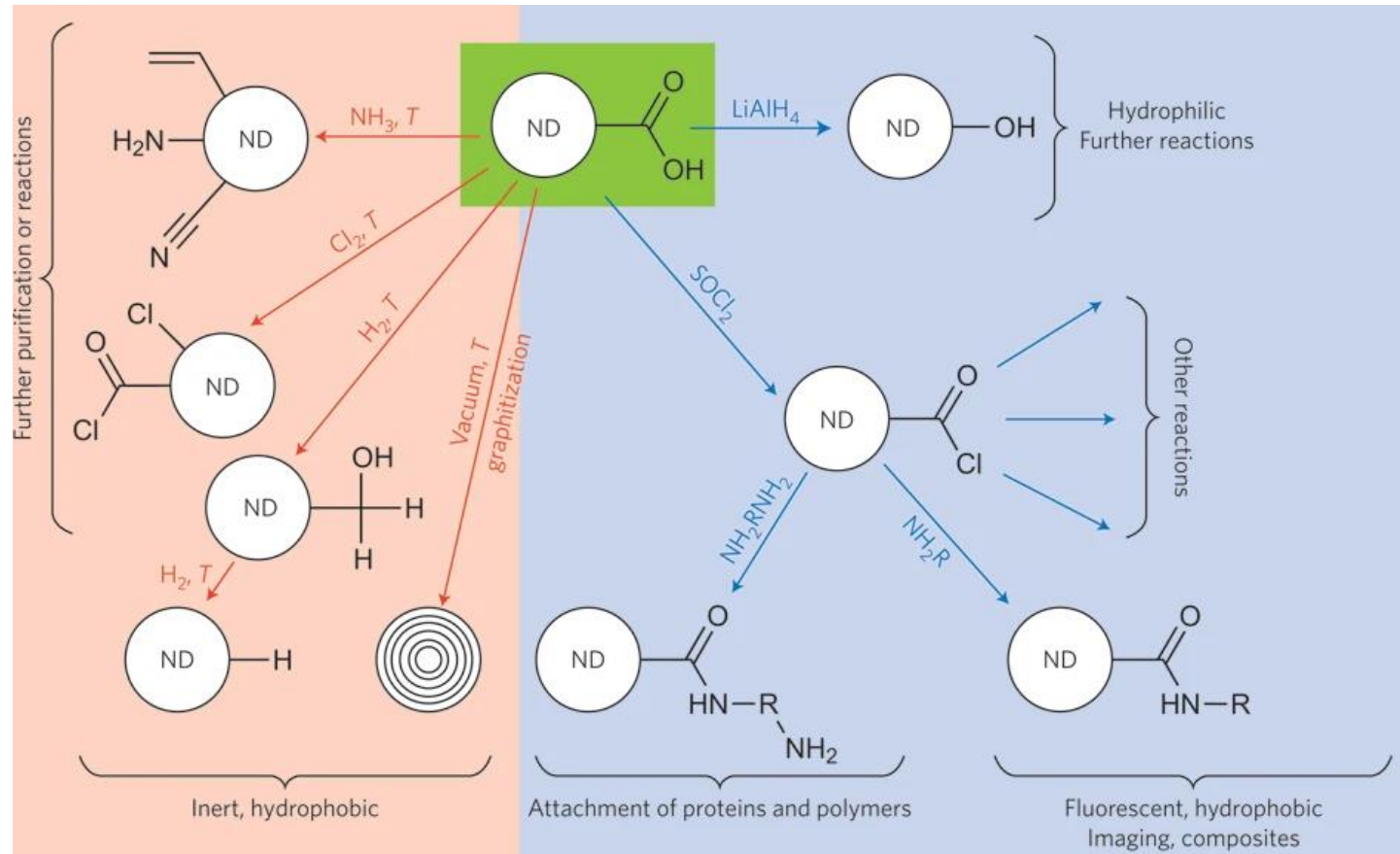
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# Raman - Characterization of DNDs

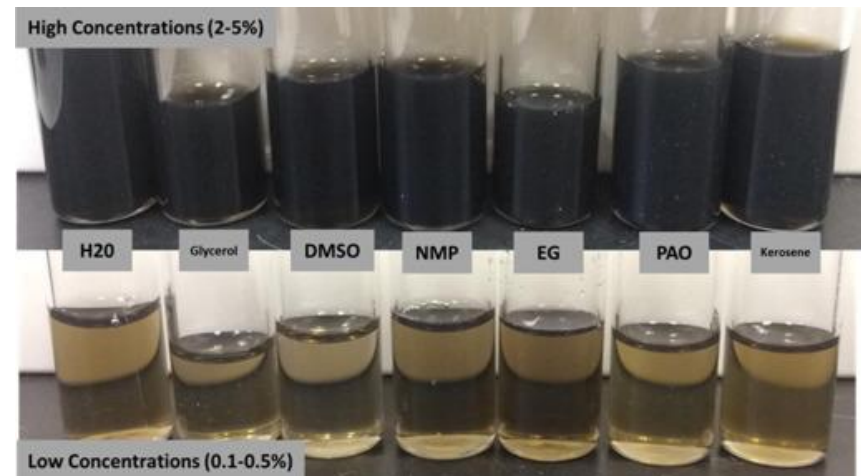
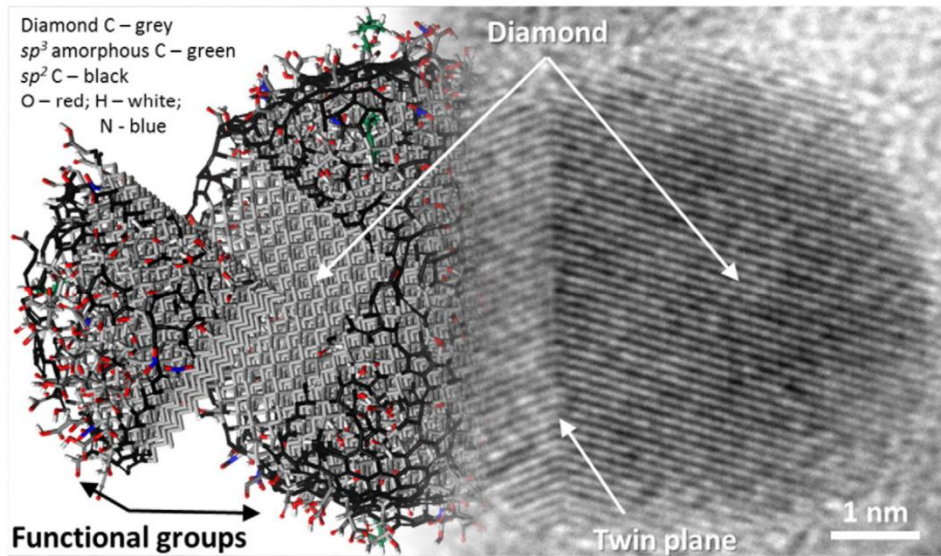


# Functionalization of DNDs



# Properties of DNDs

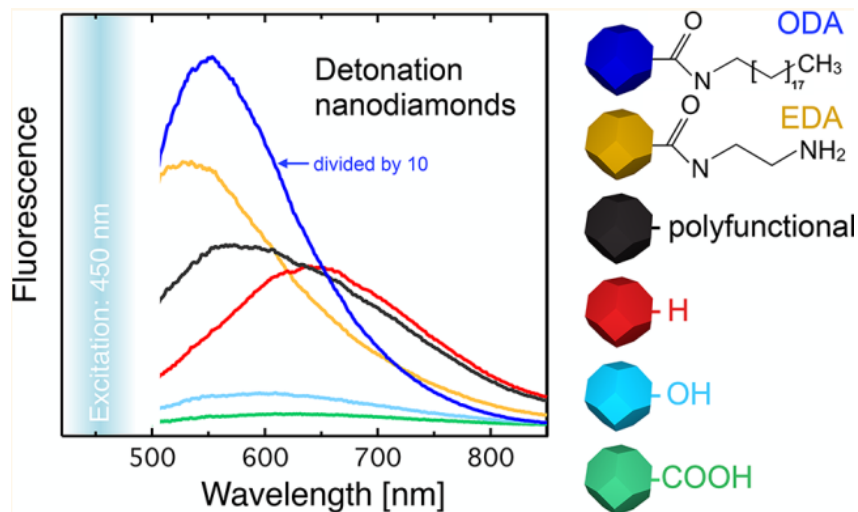
## ■ Solubility and functional groups:



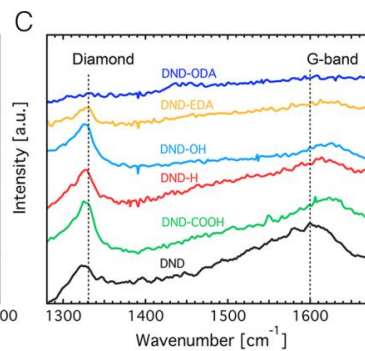
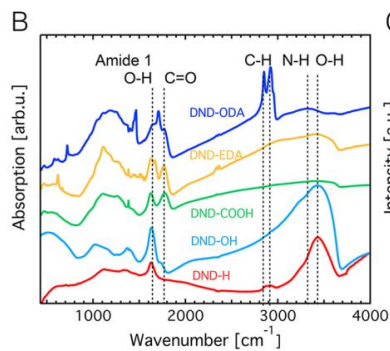
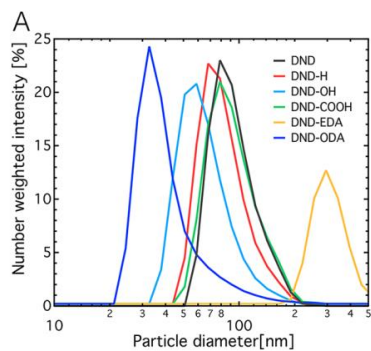
Dimethyl sulfoxide (DMSO)  
N-methyl pyrrolidone (NMP)  
ethylene glycol (EG)  
Poly-alpha olefin (synthetic oil) (PAO)

# Properties of DNDs

## Fluorescence

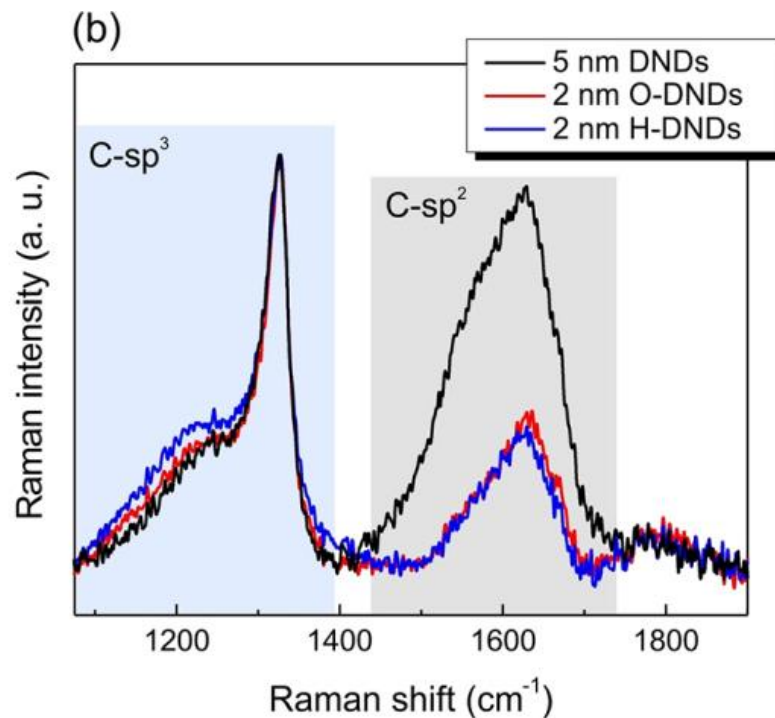
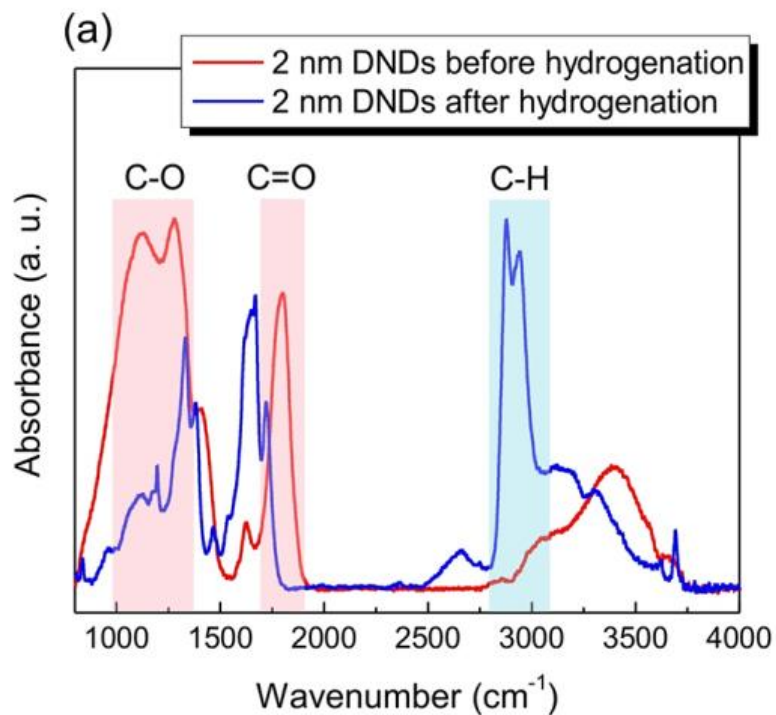


Abbreviation	DND	DND-H	DND-OH	DND-COOH	DND-EDA	DND-ODA
Functionalization						
Diameter	79 nm	60 nm	50 nm	72 nm	> 300 nm	44 nm
Zeta-potential	-29 mV	+56 mV	-32 mV	-46 mV	-19 mV	-5 mV
Dispersant	water	water	water	water	water	chloroform
Image						



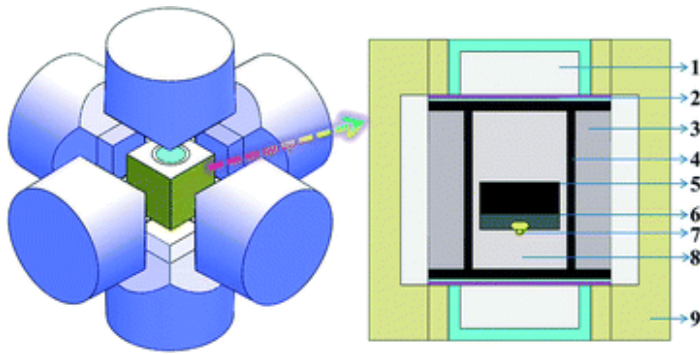


# Size of NDs



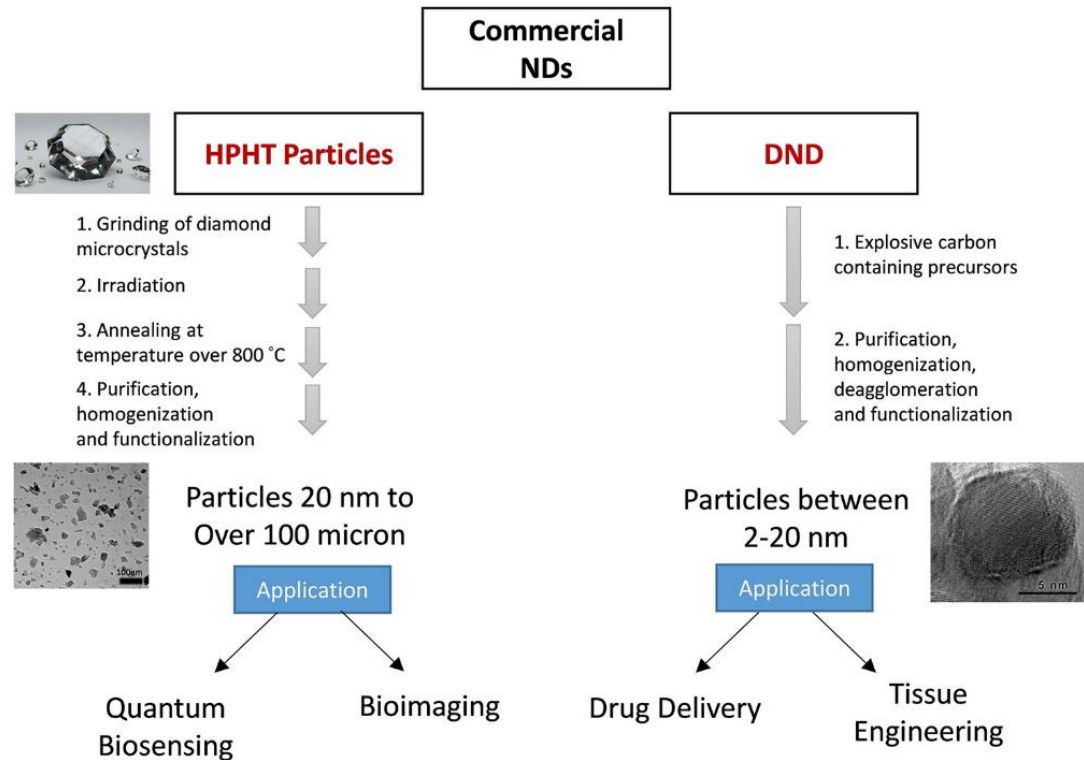
# High-Pressure High-Temperature Nanodiamonds (HPHT NDs)

- Produce blocky NDs with an average size of 20 nm - 100 μm.



1. steel cap;
2. Cu + Mo sheet;
3. NaCl + ZrO<sub>2</sub> sleeve;
4. graphite heater;
5. carbon source;

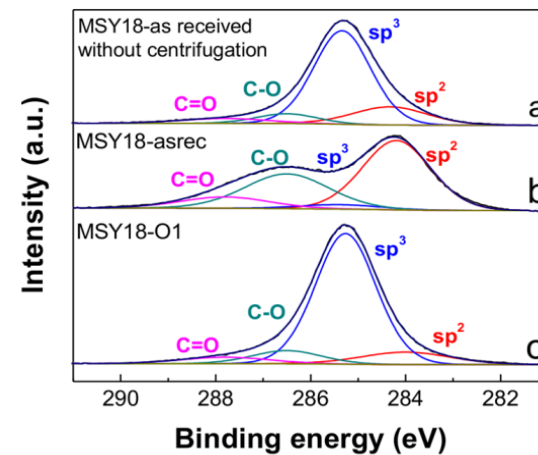
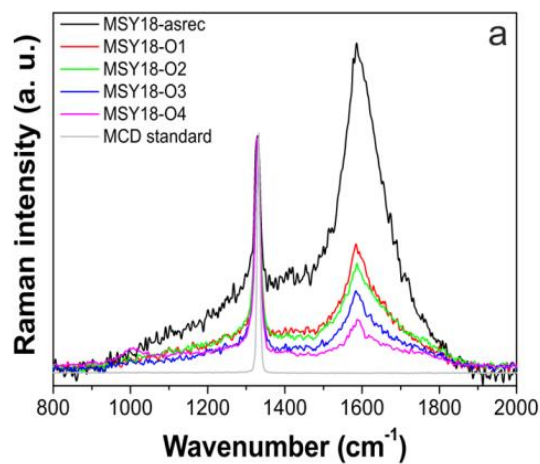
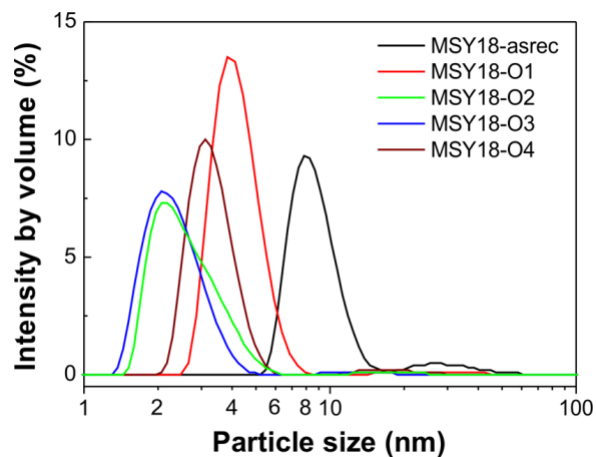
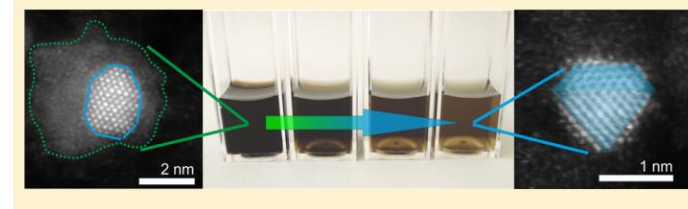
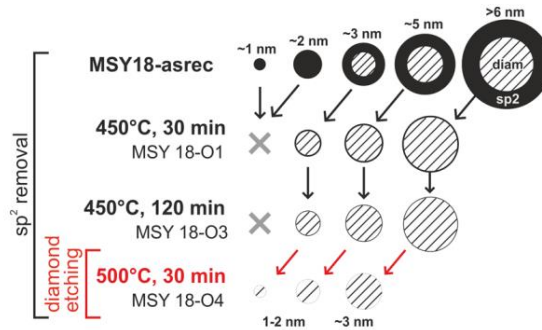
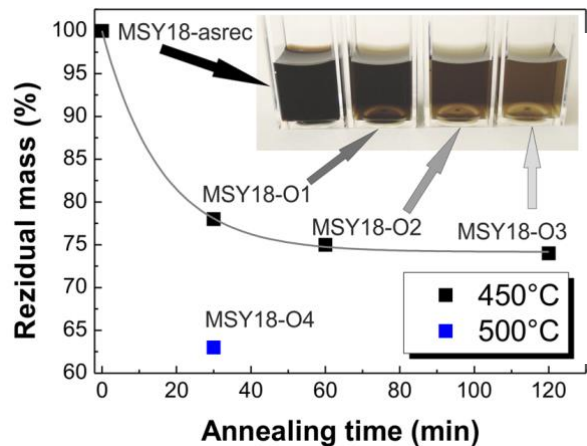
6. metal catalyst;
7. seed crystal;
8. ZrO<sub>2</sub> + MgO pillar;
9. pyrophyllite.





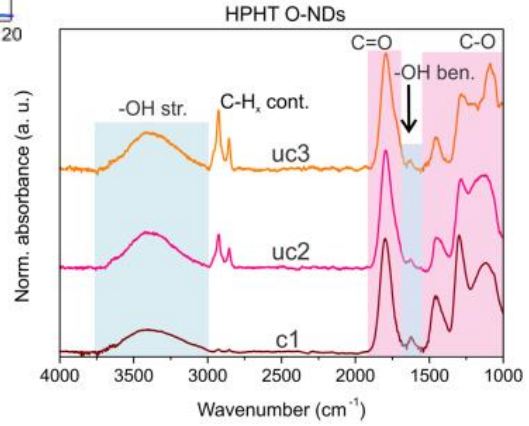
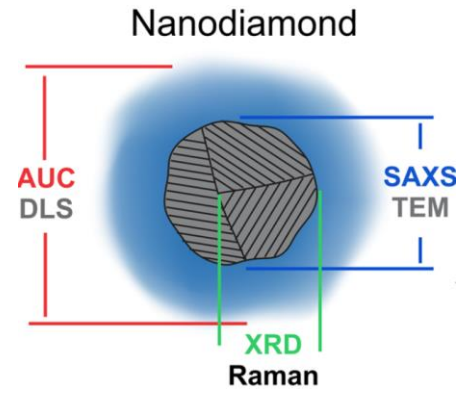
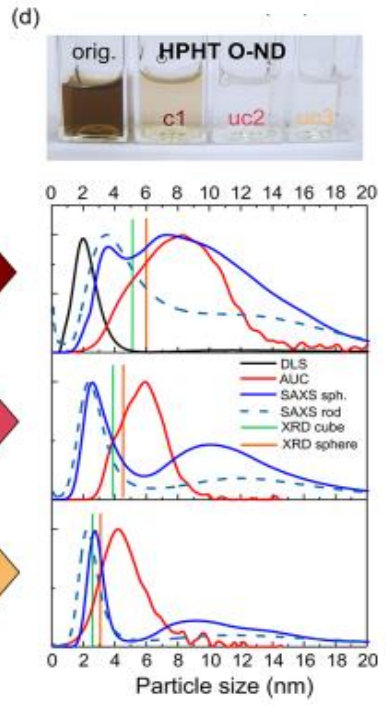
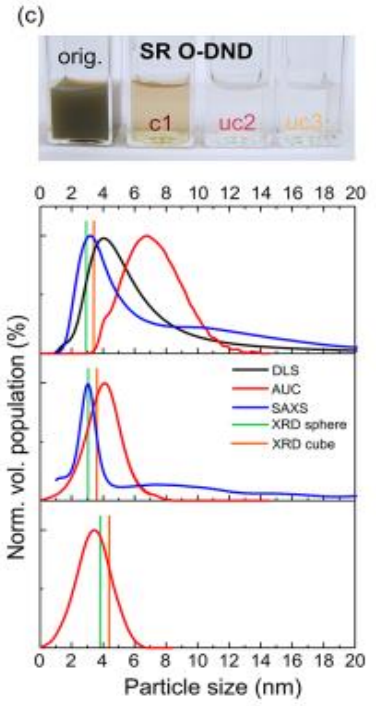
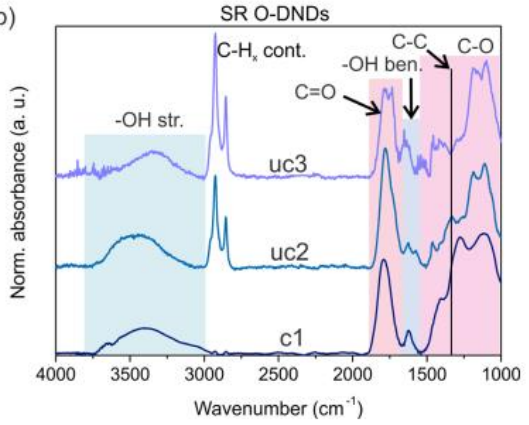
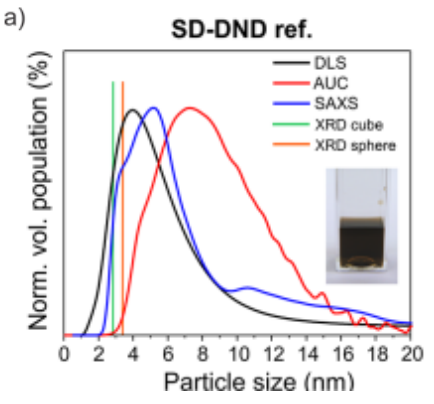


# Size of NDs



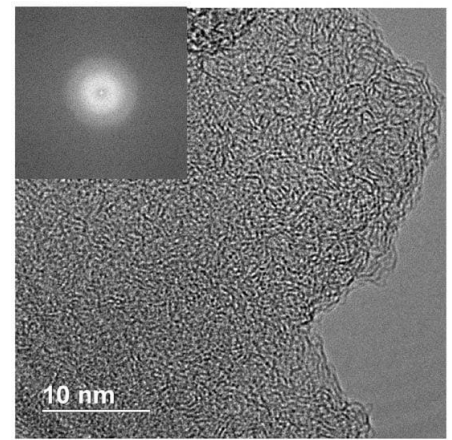
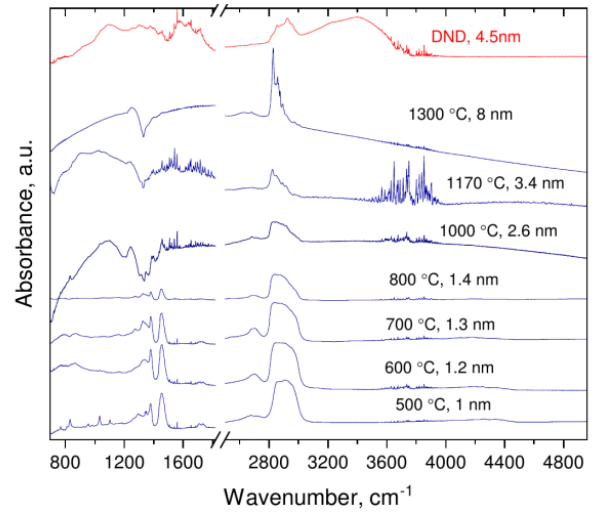
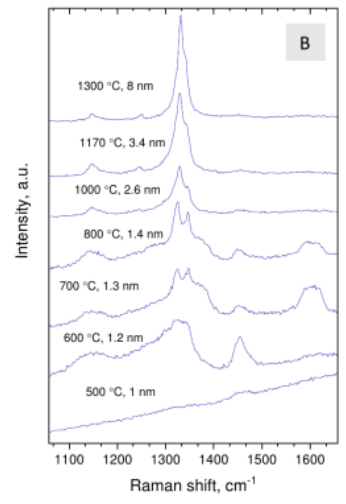
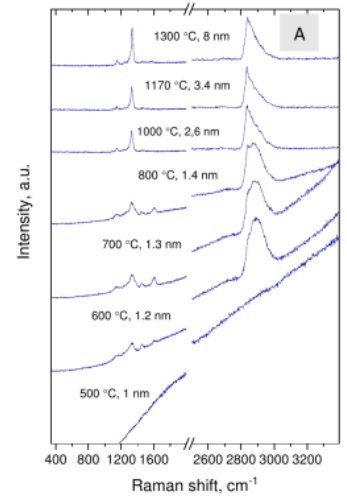
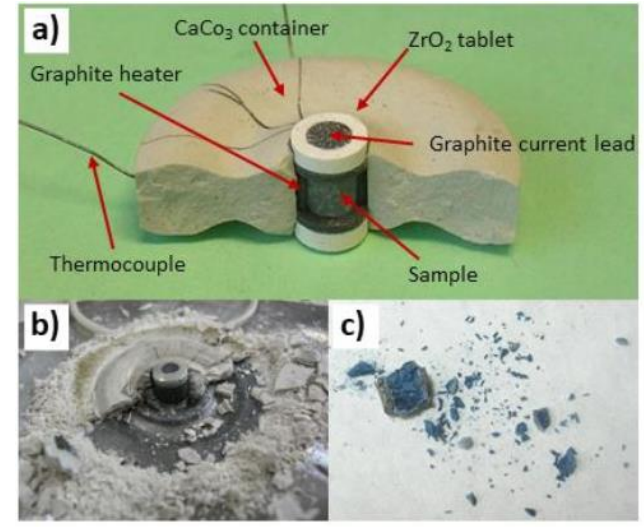
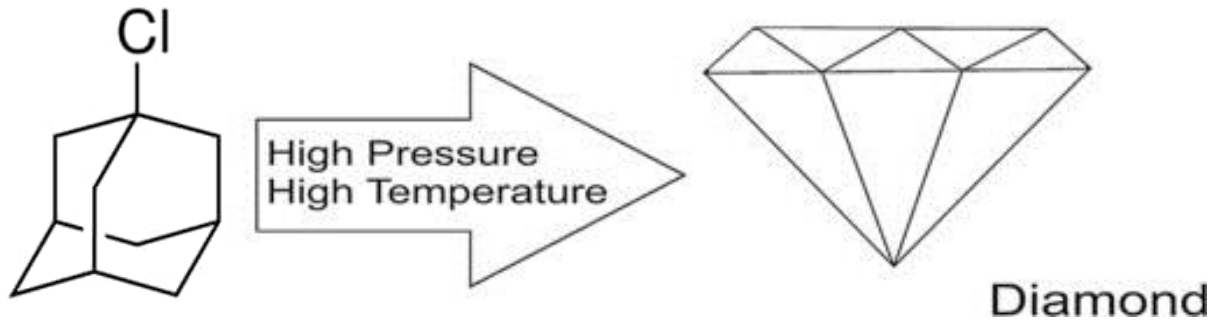


# Size of NDs





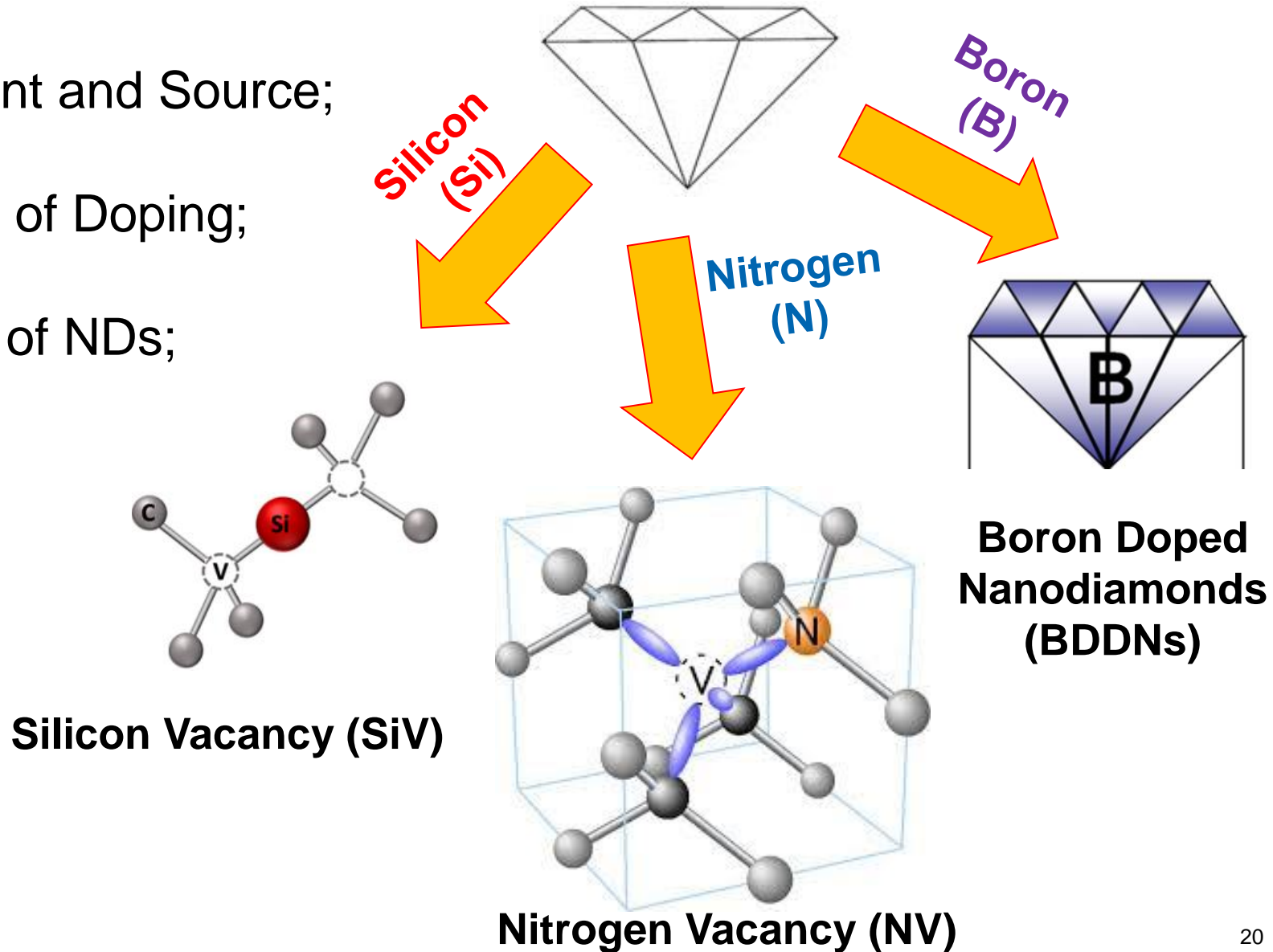
# Size NDs



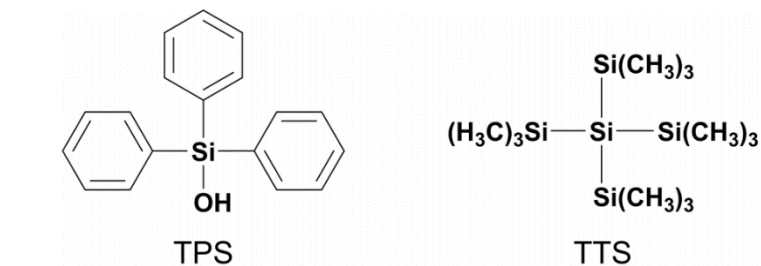
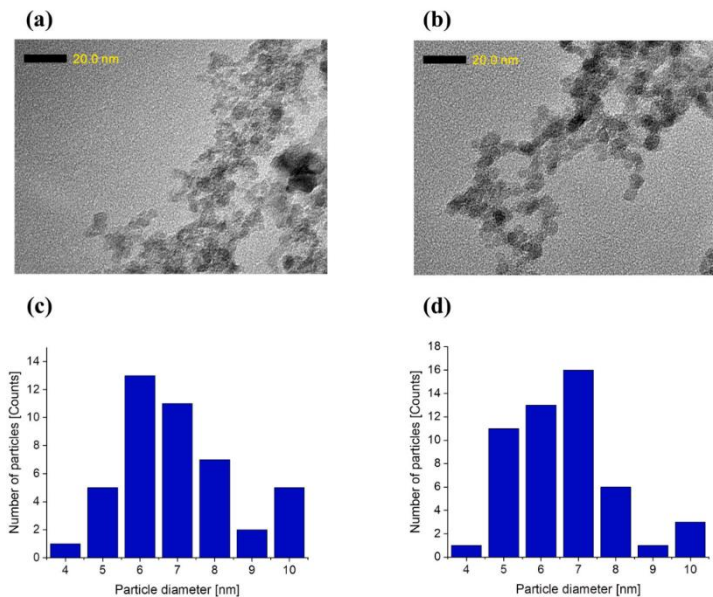
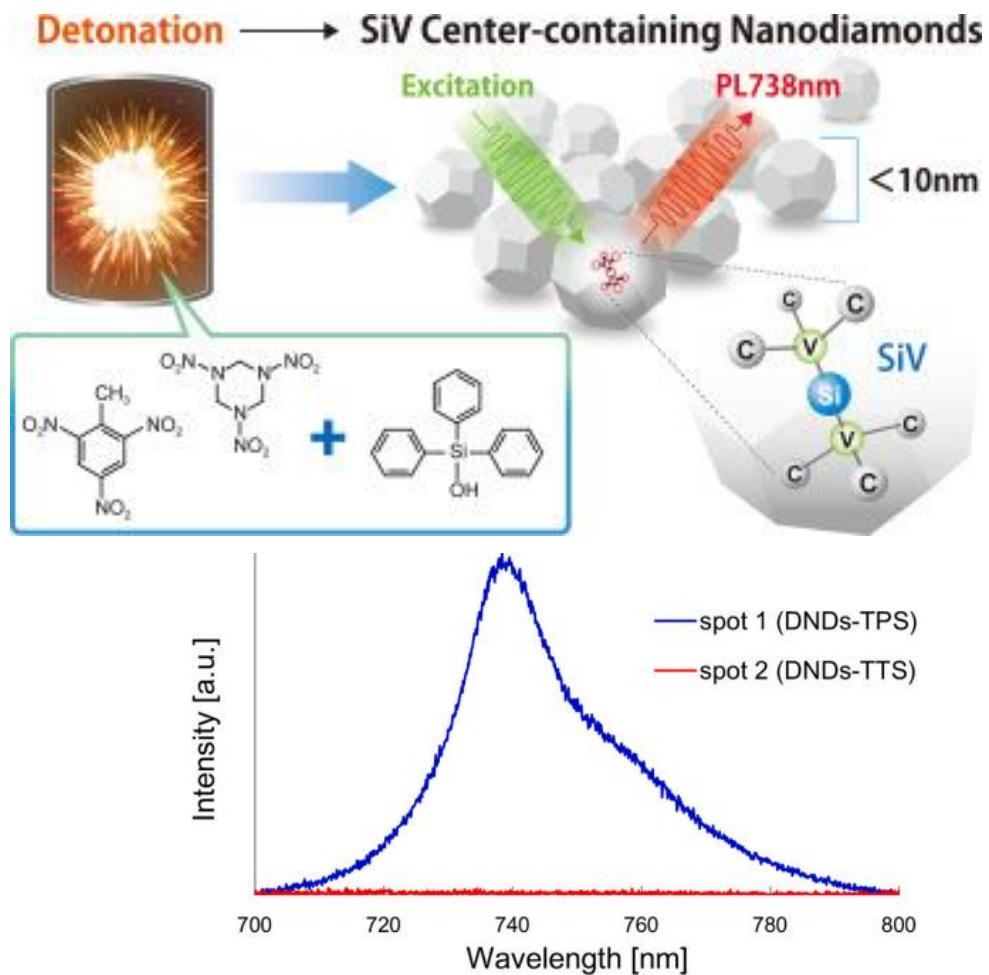
10.3390/nano12030351

# Doping of NDs

- Dopant and Source;
- Level of Doping;
- Type of NDs;

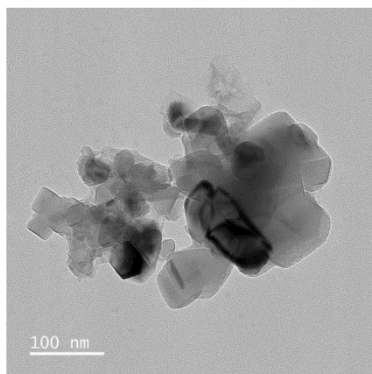
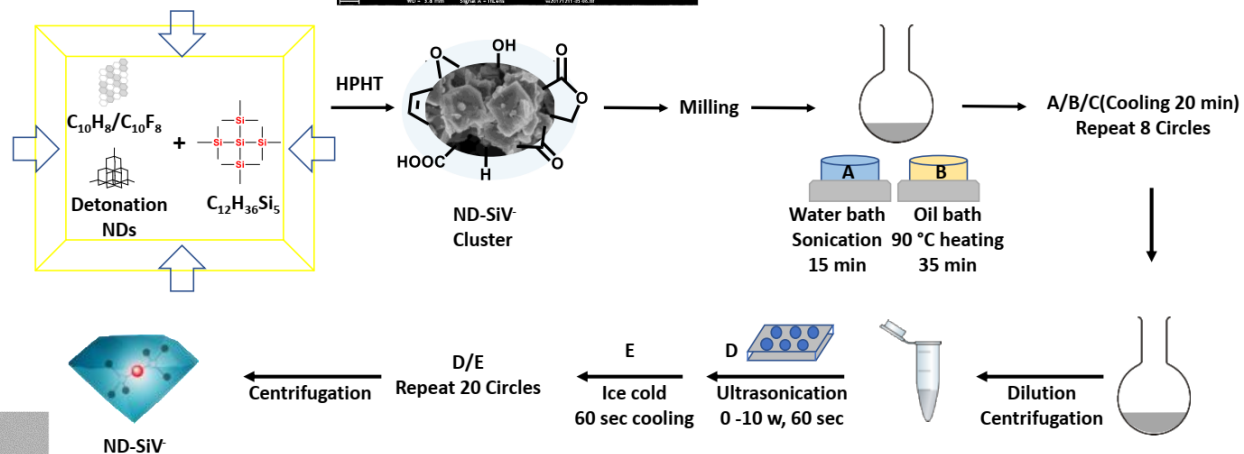
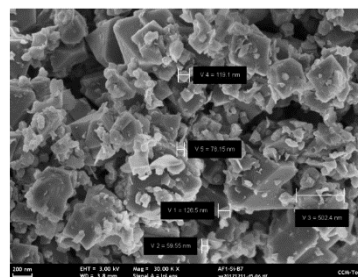
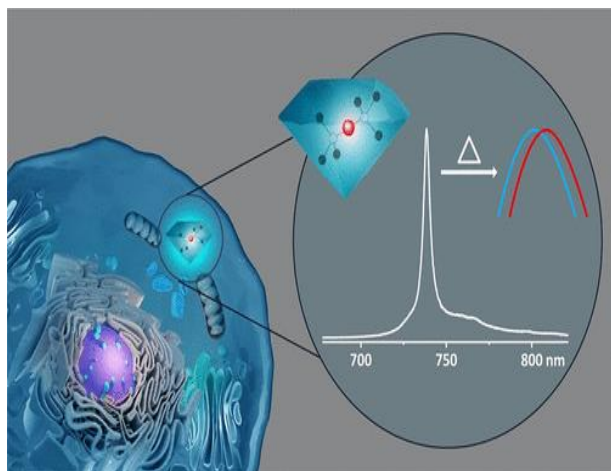


# SiV NDs Center



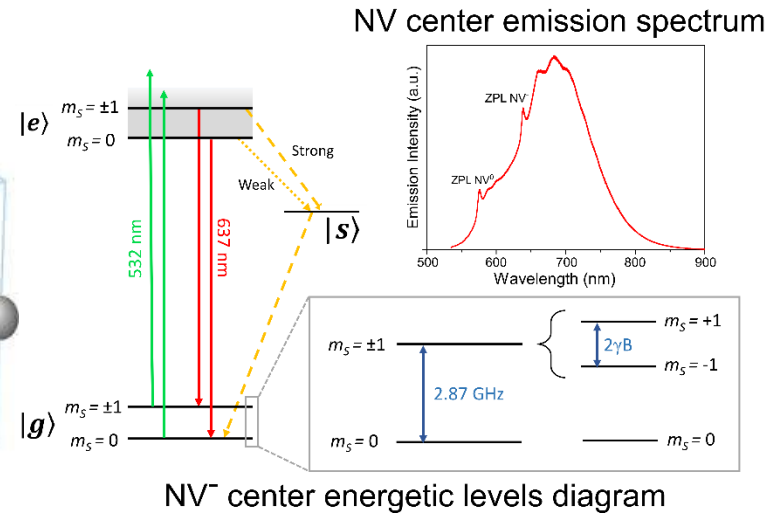
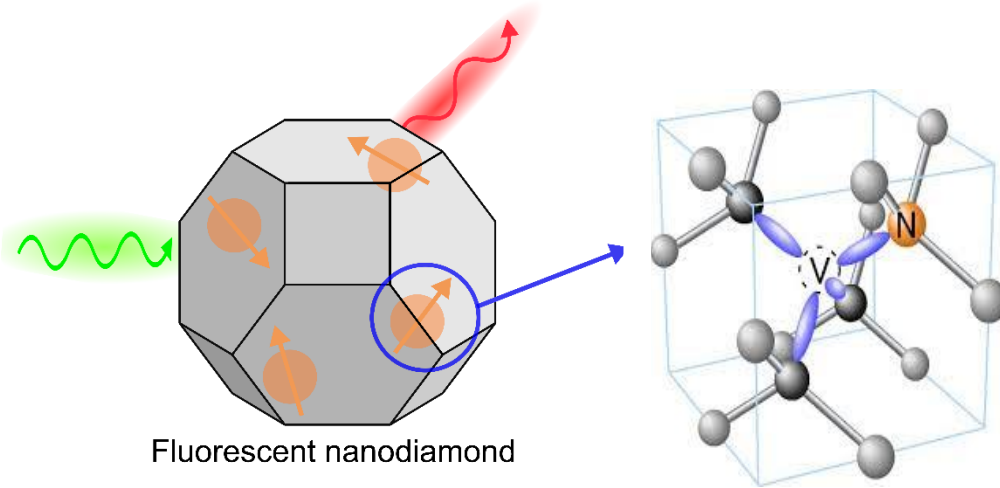
triphenyl silanol

# SiV NDs Center



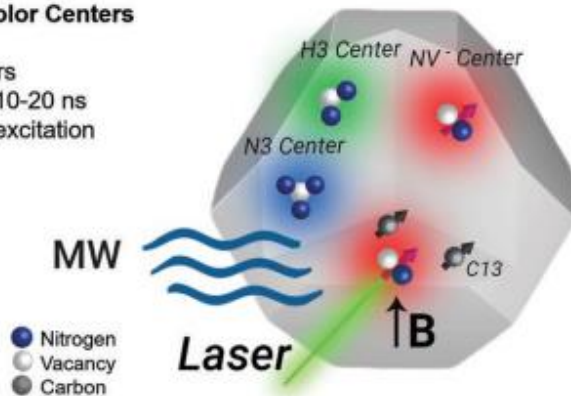
naphthalene ( $C_{10}H_8$ ),  
 octafluoronaphthalene ( $C_{10}F_8$ ), and  
 tetrakis(trimethylsilyl)silane ( $C_{12}H_{36}Si_5$ )

# ND NV Center



## Fluorescent Color Centers

- Photostable
- Multiple colors
- FL lifetime ~10-20 ns
- Multiphoton excitation



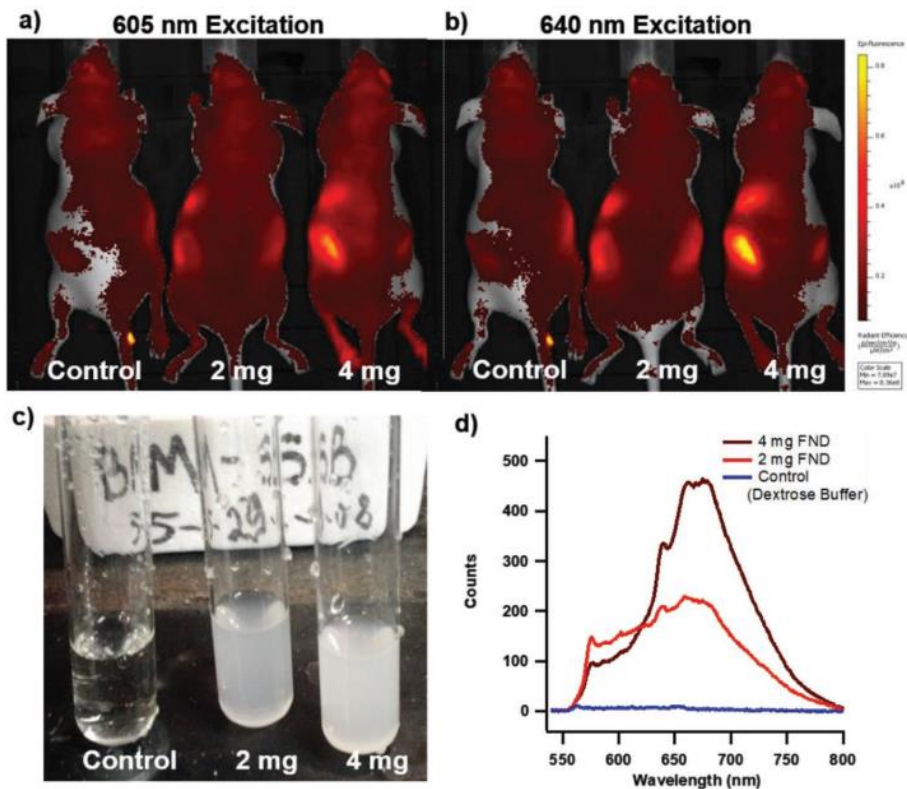
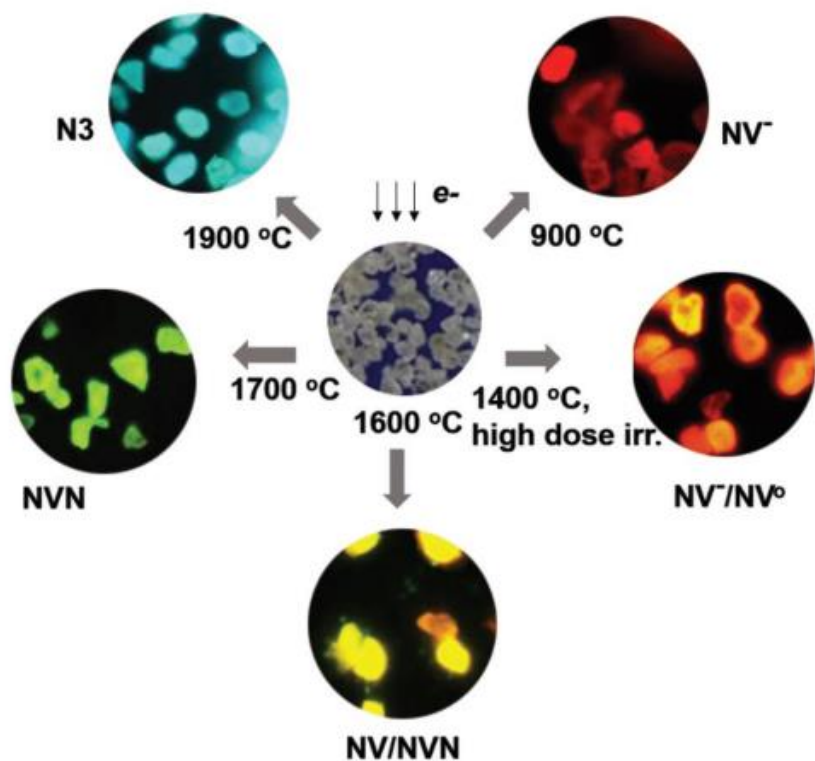
## Quantum sensing

(coupled fluorescence/magnetism)

- Optically detected magnetic resonance
- Sensitivity to variations in temperature, magnetic, & electric fields
- T1 based imaging & sensing

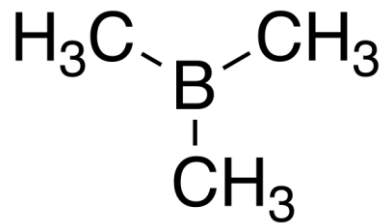
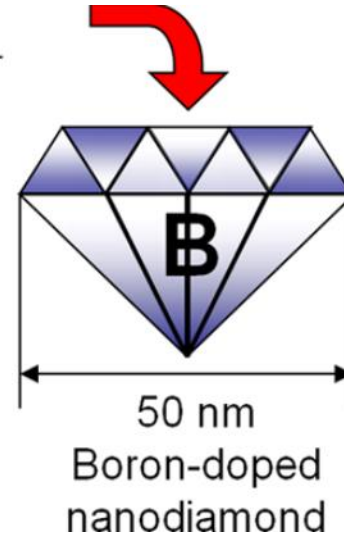
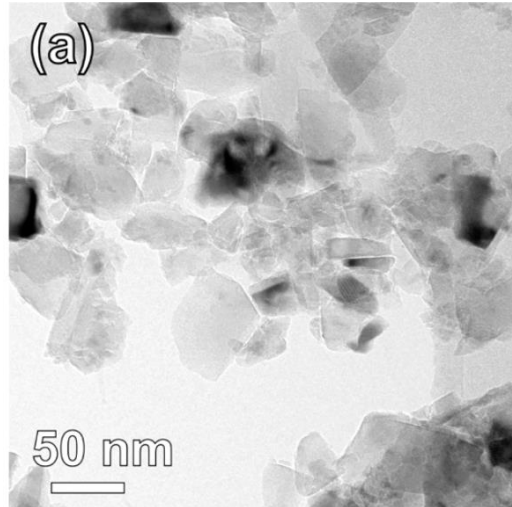
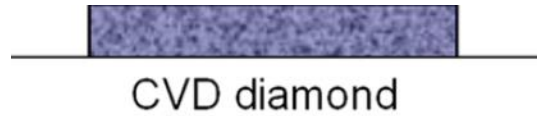


# NV ND Center

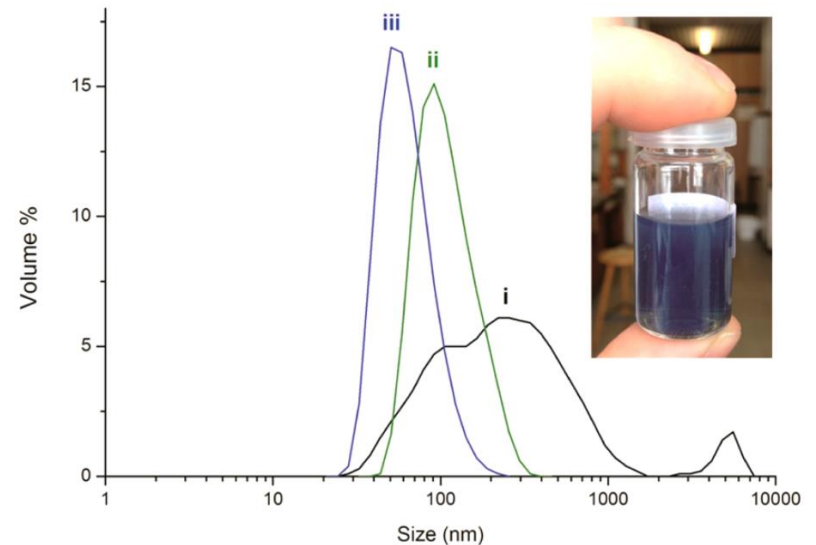




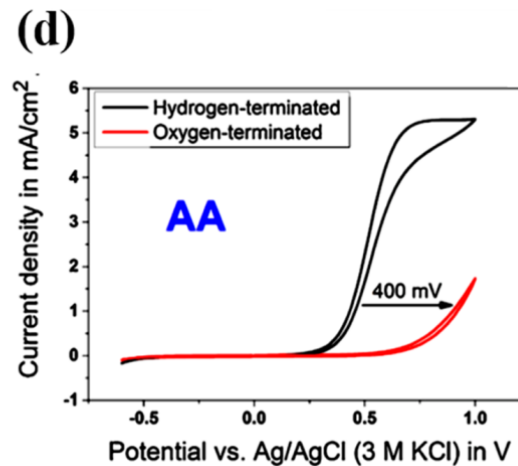
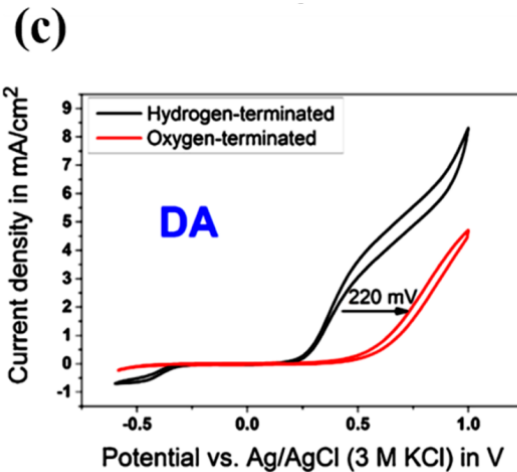
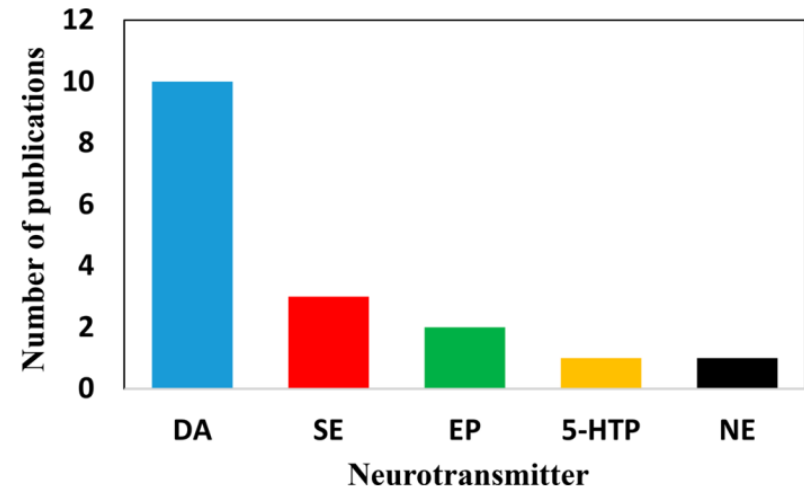
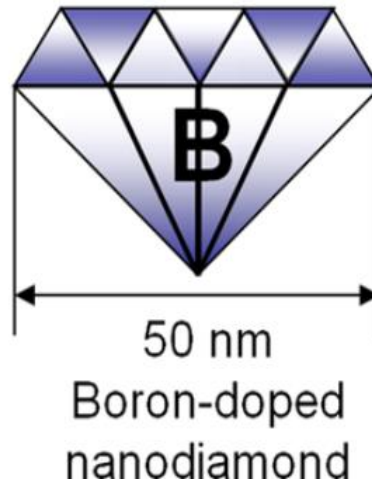
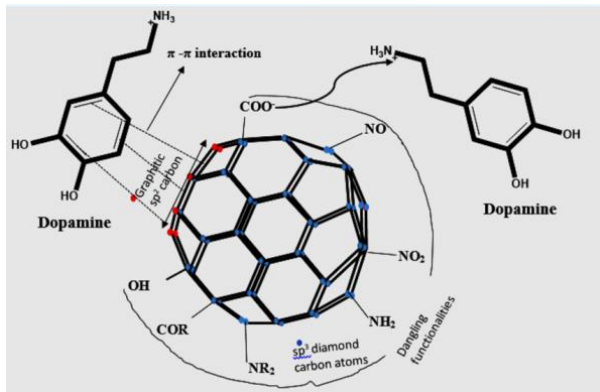
# BDNDs



Trimethylborane (TMB)



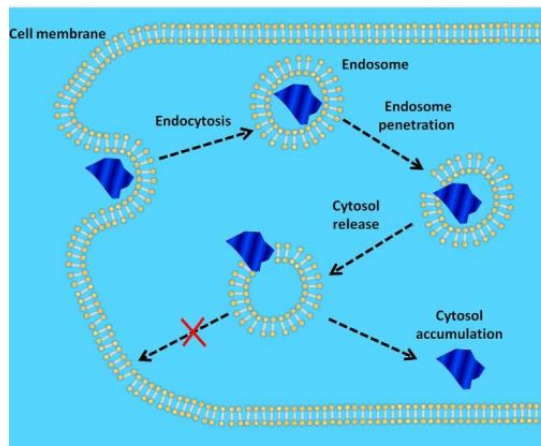
# BDNDs Biosensors



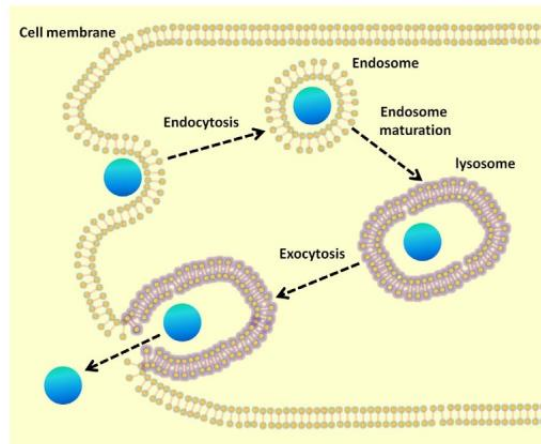
dopamine (DA),  
serotonin (SE),  
epinephrine (EP),  
norepinephrine (NE),  
5-hydroxytryptophan (5-HTP)

# NDs and drug delivery

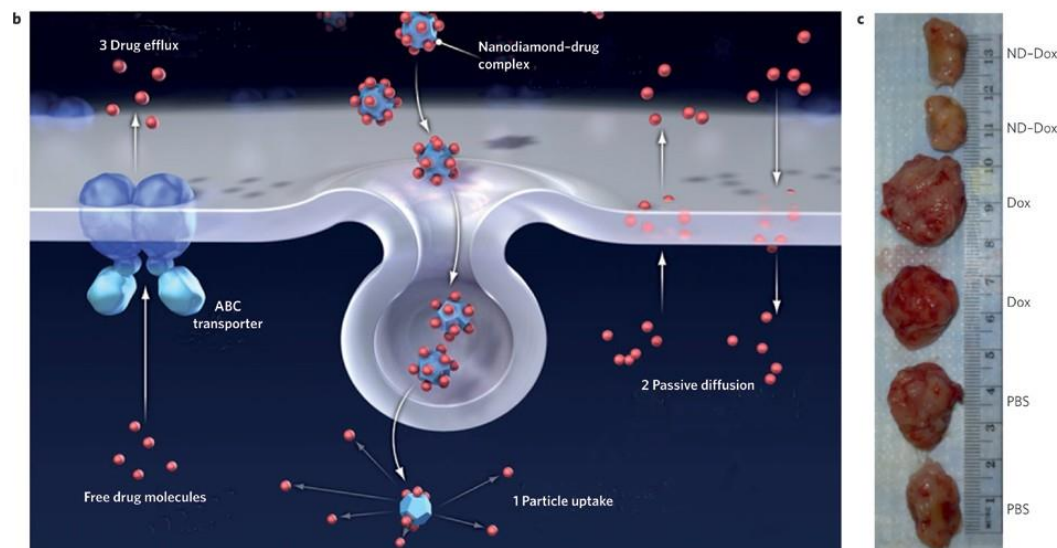
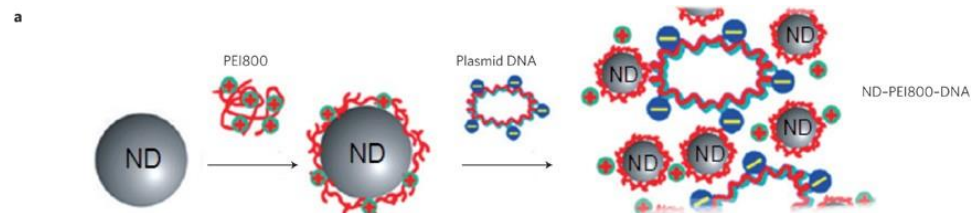
HPHT  
NDs



DNDs



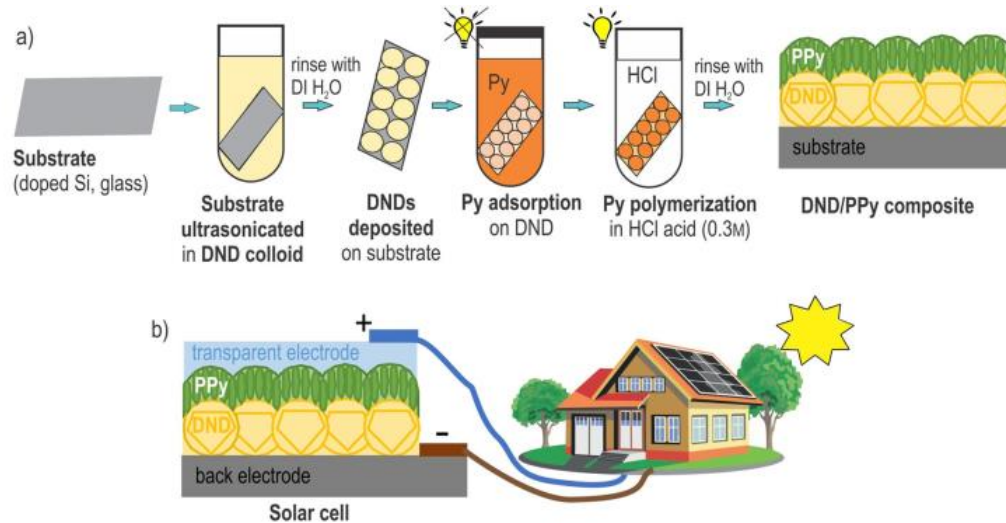
Breast-cancer tumors:



doxorubicin (Dox)

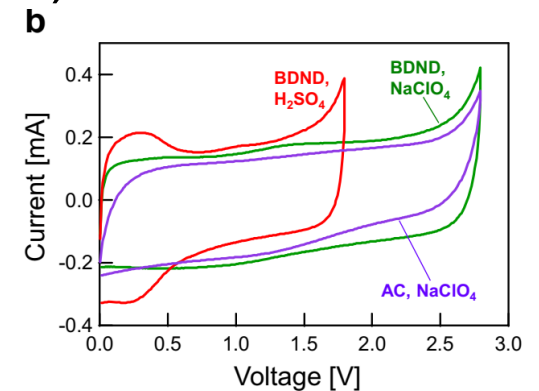
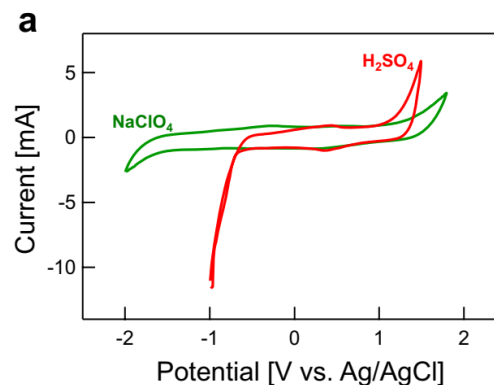
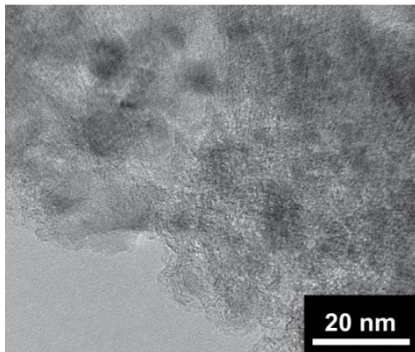
# NDs Applications

## ■ Solar Cells;



## ■ Energy Storage Devices (Supercapacitors);

**BDDNs**



10.1038/s41598-020-80438-3  
10.1038/s41598-019-54197-9

# Conclusions

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- Nanodiamonds are important materials for biomedical, optical and electronic applications;
- The properties, structure and doping of nanodiamonds define their application;
- ND NV center are the most successful for biomedical applications;
- BDNDs are the most promising material for energy storage devices and biosensors;



# Acknowledgments



## Thank you for your attention!





# Toxicity of NDs

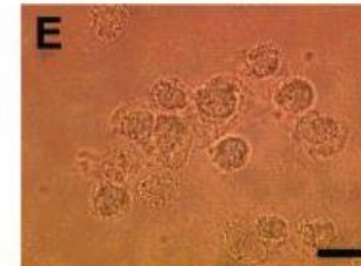
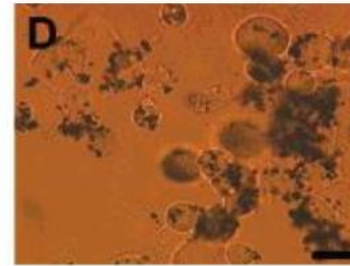
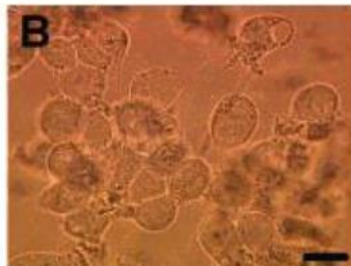
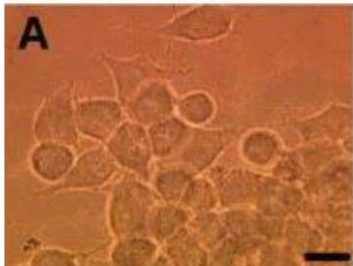
Control

ND-Raw  
100 $\mu$ g/ml

ND-COOH  
100 $\mu$ g/ml

CB  
100 $\mu$ g/ml

CB  
2.5 $\mu$ g/ml



CB – Carbon Black  
CdO – Cadmium oxide

Neuroblastoma  
Cancer Cells

