Základy materiálů a nanostruktur

KFY/7ZMAN

Příklady použití nanostruktur

Mgr. Miroslav Kolos, Ph.D.

Příklady použití nanostruktur

Mechanické vlastnosti

- Pevnost
  - C-C vazba: 346 kJ/mol
  - Fe-Fe: 118 kJ/mol
  - Al-Al: 264 kJ/mol
- Lehkost
  - M(C): 12,01 g/mol
  - M(Fe): 55,85 g/mol
  - M(Al): 26,98 g/mol

- Uhlíková vlákna
- Uhlíková nanovlákna

Floyd Landis při výhře Tour de California 2006

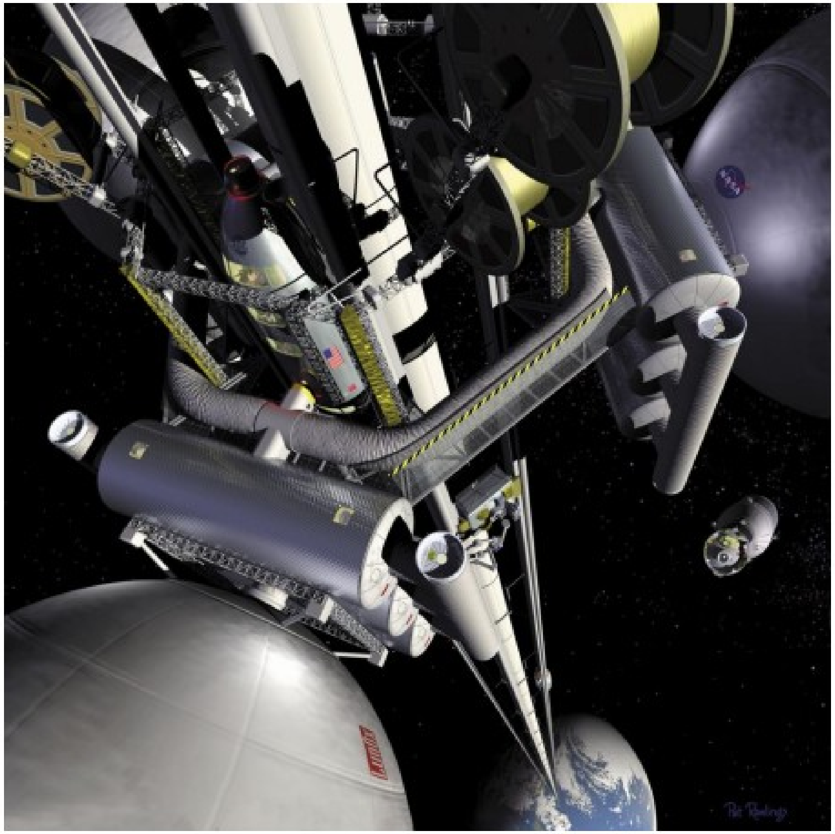
Formule Panoz DP1 se skořepinou z uhlíkových vláken

wolframalpha.com

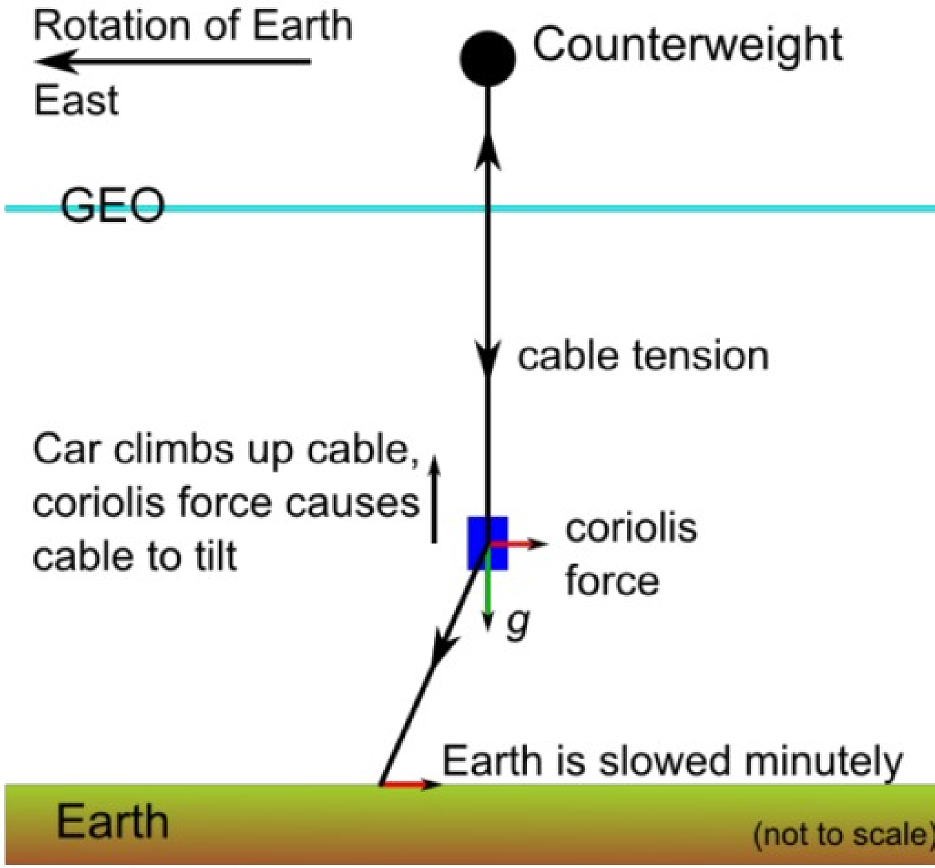
Příklady použití nanostruktur

Kosmický výtah

- Uhlíková nanovlákna jako řešení?



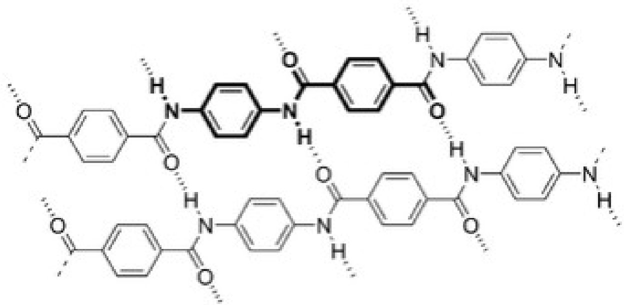
NASA



Příklady použití nanostruktur

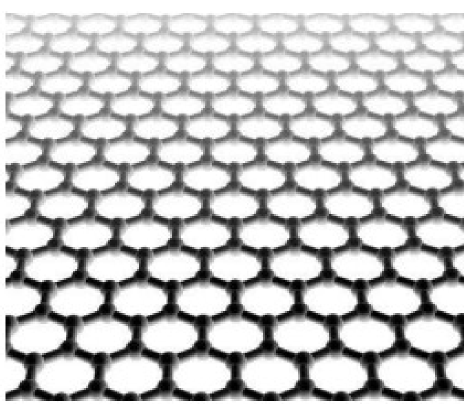
Tkaniny

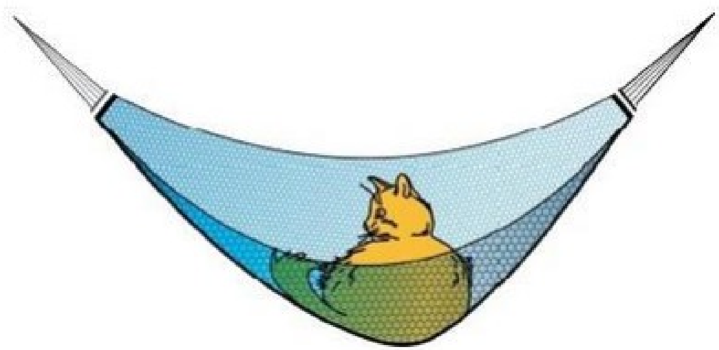
- Kevlar



vz.

- Grafen



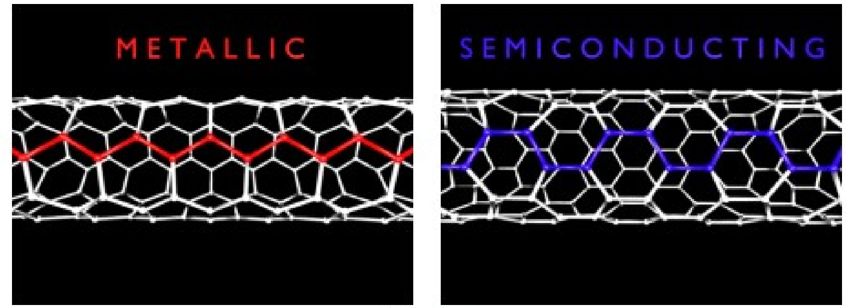


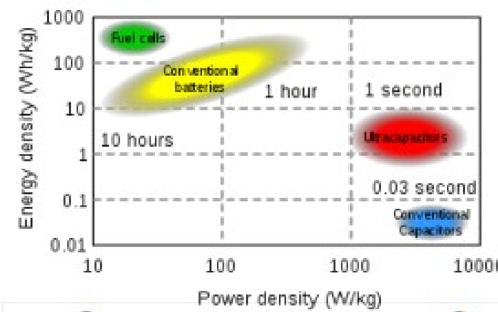
  – monomolekulární houpačka pro kočku :o)

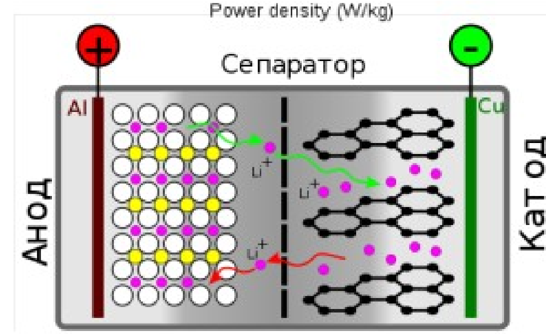
Příklady použití nanostruktur

Nanoelektronika

- Nanodráty
  - nanotrubičky, kumuleny
- Záchyt náboje (kondenzátory)
  - fullereny, uhlíkové cibule, grafen
- Tranzistory (počítače)
  - CNT, Grafenové deriváty
- Elektrody (např. v Li-ion akumulátorech)
  - grafit, CNT, grafen







Guldi, D.M. et al. Multifunctional molecular carbon materials-from fullerenes to carbon nanotubes. *Chemical Society reviews* **35**, 471-87(2006).
Lee, S.W. et al. High-power lithium batteries from functionalized carbon-nanotube electrodes. *Nature Nanotechnology* 1-7(2010)
Endo, M., Strano, M. & Ajayan, P. Potential applications of carbon nanotubes. *Topics Appl. Physics* **111**, 13–62(2008).

Vize uhlíkové nanoelektroniky

https://www.youtube.com/watch?v=3sAc4nqAbOs

https://www.youtube.com/watch?v=-YbS-YyvCl4

https://www.thekitchenstyler.com/

Příklady použití vdW heterostruktur

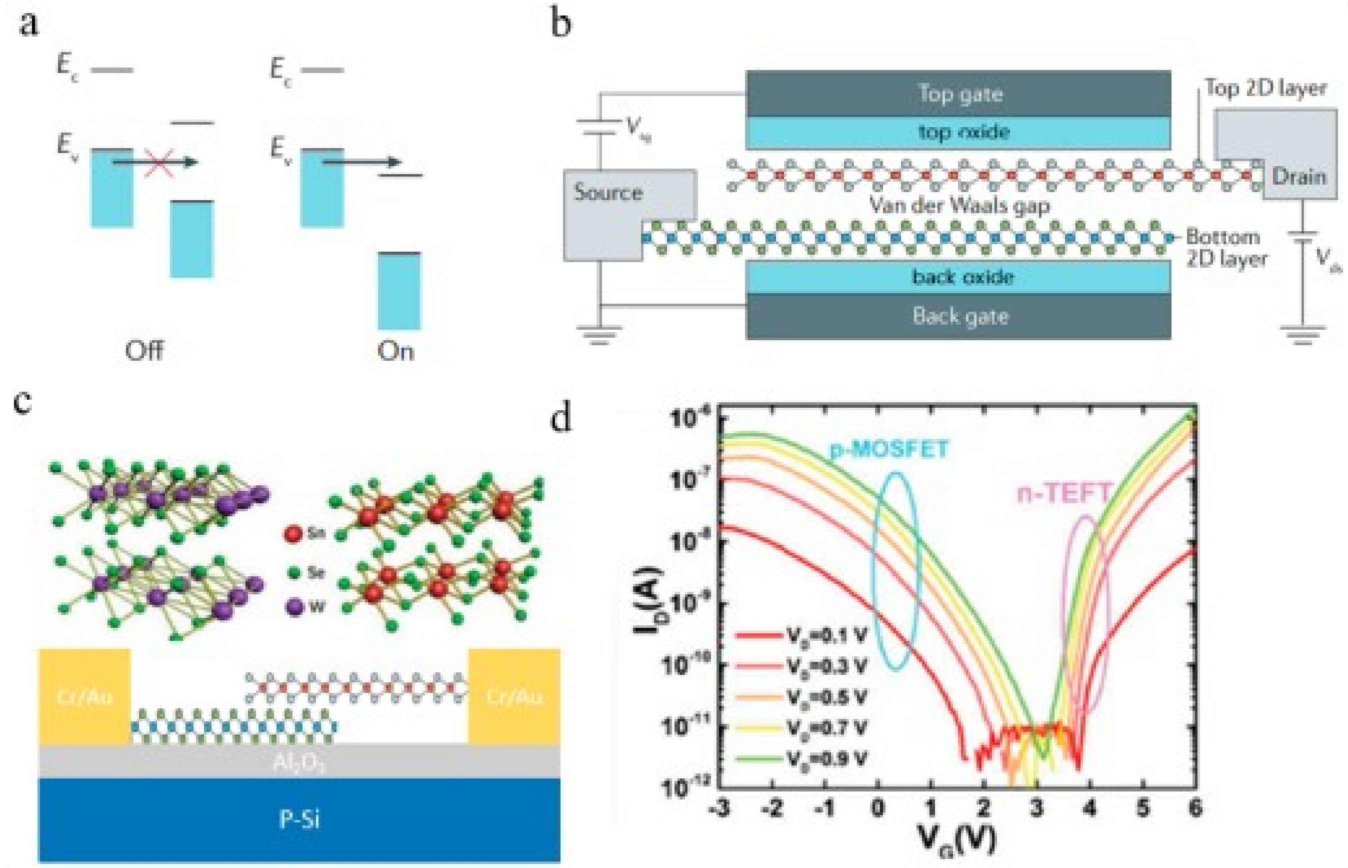


Figure 7. Tunneling field effect transistors structure and transfer curve (**a**) Band offset of p-type semiconductor and n-type semiconductor. (**b**) A schematic illustration of TFETs. The devices consist of ultrathin p-type layer and n-type layer connected to source and drain, respectively. V_{tg} is the gate tunable voltage and V_{ds} is the drain voltage. (**c**) $WSe_2/SnSe_2$ heterostructure based TFET schematic diagram. (**d**) Transfer curve of $WSe_2/SnSe_2$ TFET with the gate voltage of 0.1 V, 0.3 V, 0.5 V, 0.7 V, 0.9 V. (**a**,**b**) are adapted with the permission of Nature publishing Group in ref [6] (**c**,**d**)are adapted with the permission of John Wiley & Sons, Inc. in Ref [91].

Příklady použití vdW heterostruktur

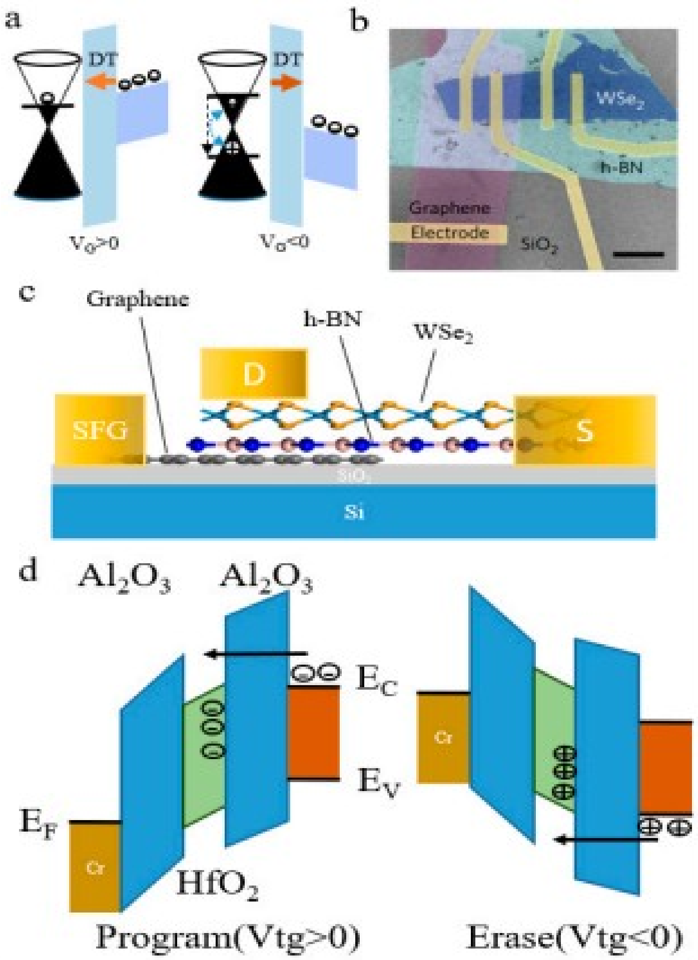


Figure 11. Semi-floating gate flash memory and band structure diagram of SIM heterostructure: (**a**) band structure with different gate voltage and charge carriers following direction; (**b**) SEM image of semi-floating gate memory based on WSe_2/h-BN/Graphene stack; (**c**) schematic diagram of SFG device; and (**d**) band structure of charge trap memory operations. (**a–c**) are reproduced with permission from Nature Publishing Group, Ref [124]. (**d**) is reproduced with permission from American Chemical Society Publishing Group in Ref [121].

Příklady použití vdW heterostruktur

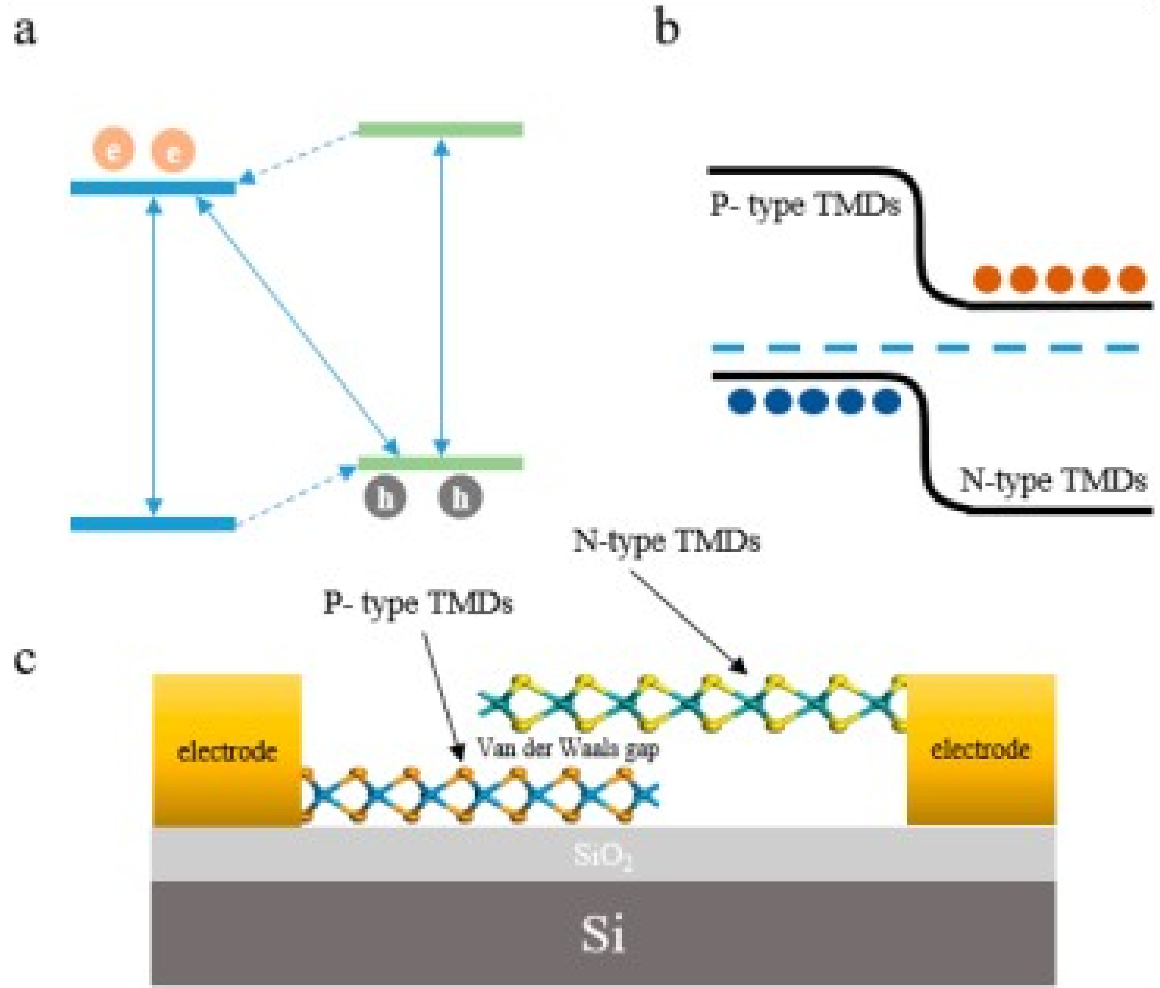
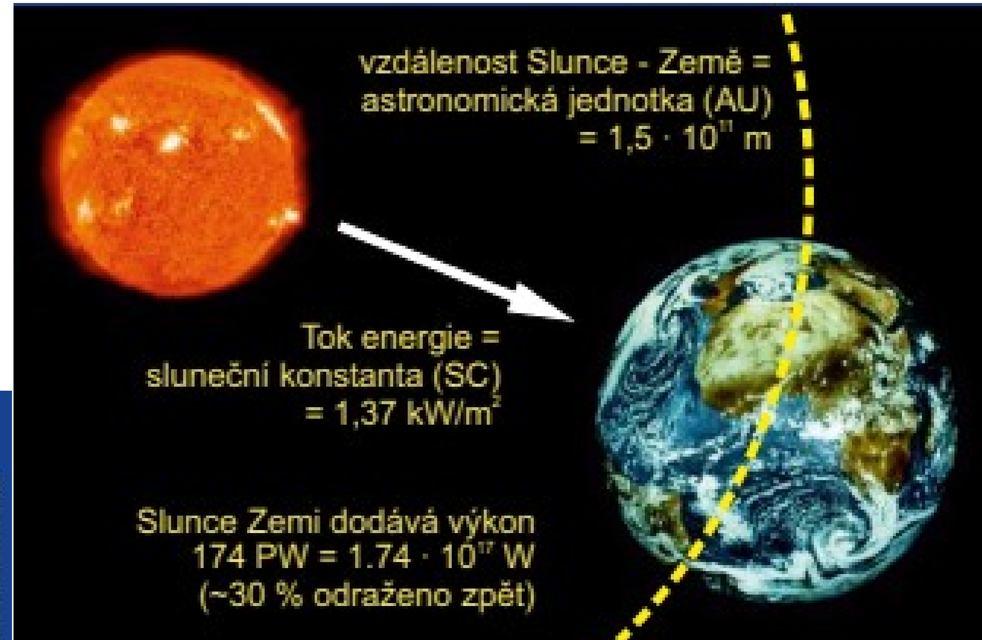
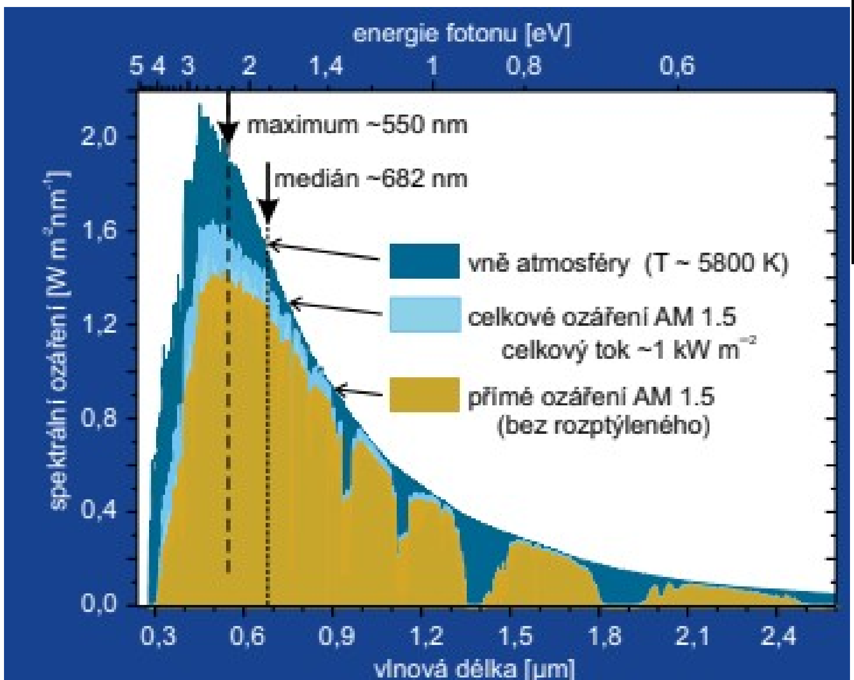


Figure 9. Photodetector and diodes schematic diagram: (**a**) photoexcited pairs generate in MoS_2/WSe_2 heterostructure; (**b**) band structure of n-MoS_2 and p-WSe_2 p-n junction; and (**c**) schematic illustration of vertical stack p-n diode based on two-dimensional TMDs.

Příklady použití nanostruktur

- Fotovoltaika
  - Sluneční spektrum

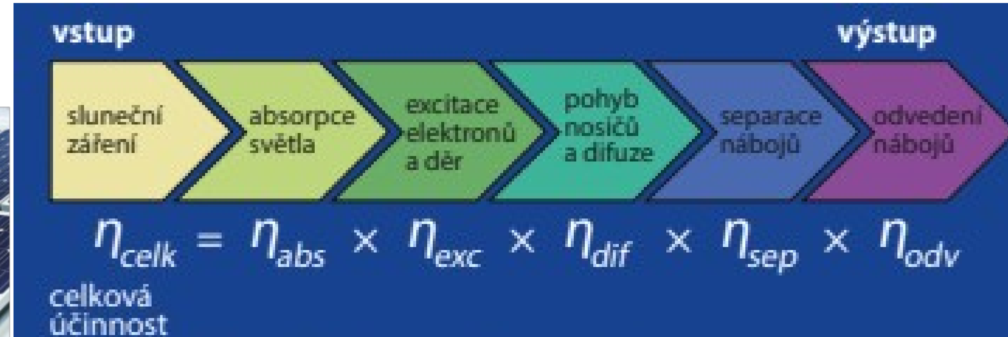




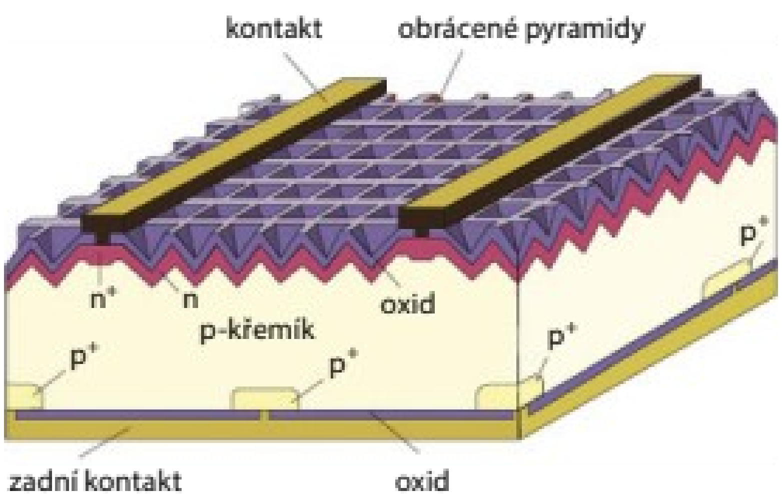
$$E = h\nu = \frac{hc}{\lambda}, \quad E\left[eV\right] = \frac{1239.5}{\lambda\left[nm\right]}$$

Příklady použití nanostruktur

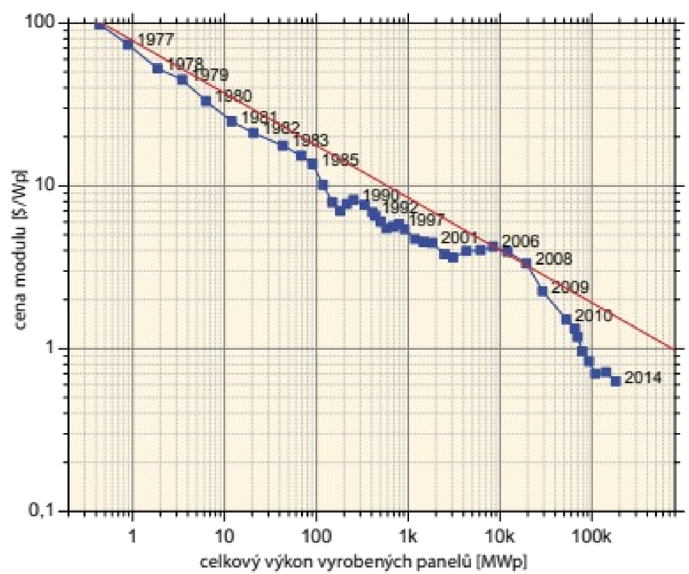
- Fotovoltaika
  - články



Obr. 4 Celková účinnost přeměny sluneční energie na elektrickou energii (upraveno podle [Tonio Buonassisi: 2.627 *Fundamentals of Photovoltaics*. Fall 2013. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu]).



Obr. 3 Sluneční článek označovaný jako PERL (*Passivated Emitter Rear Locally-diffused*) z laboratoře Martina Greena z australské univerzity v Novém Jižním Walesu. *Upraveno z http://www.pveducation.org/pvcdrom/manufacturing/high-efficiency.*



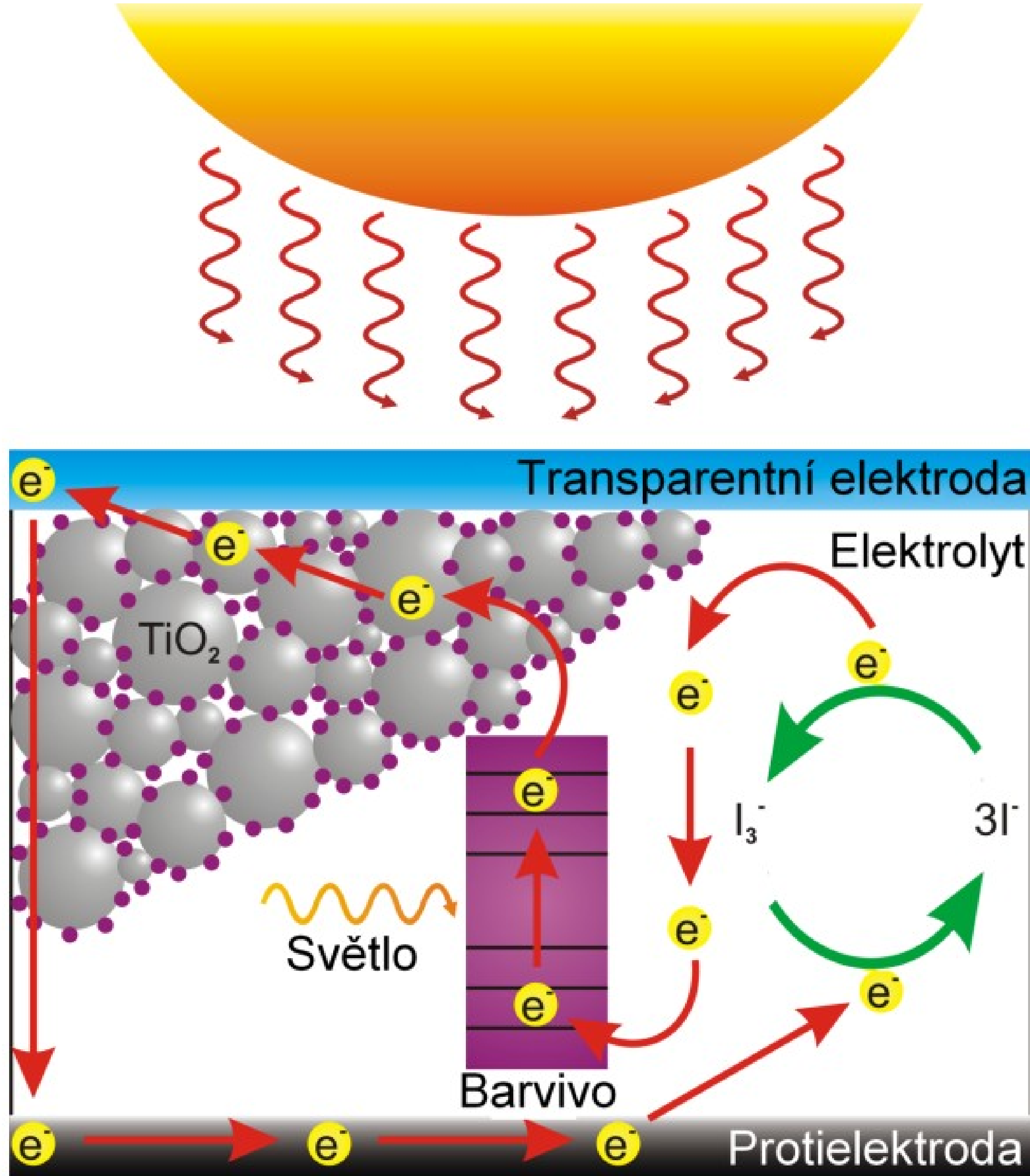
Obr. 5 Swansonův zákon, tedy učební křivka fotovoltaiky [20].

Příklady použití nanostruktur

Fotovoltaika

Graetzelův článek

- odvedení náboje
  - CNT, fullereny, uhlíkové nanotečky
- transparentní elloda
  - grafen

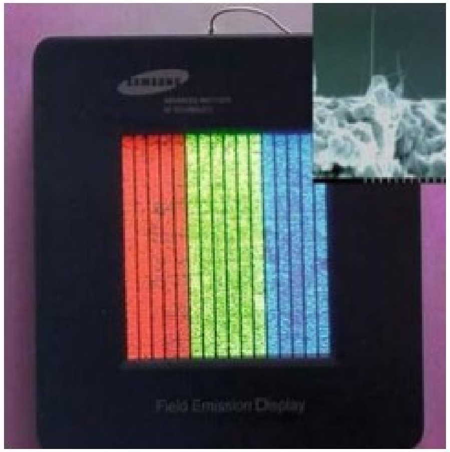


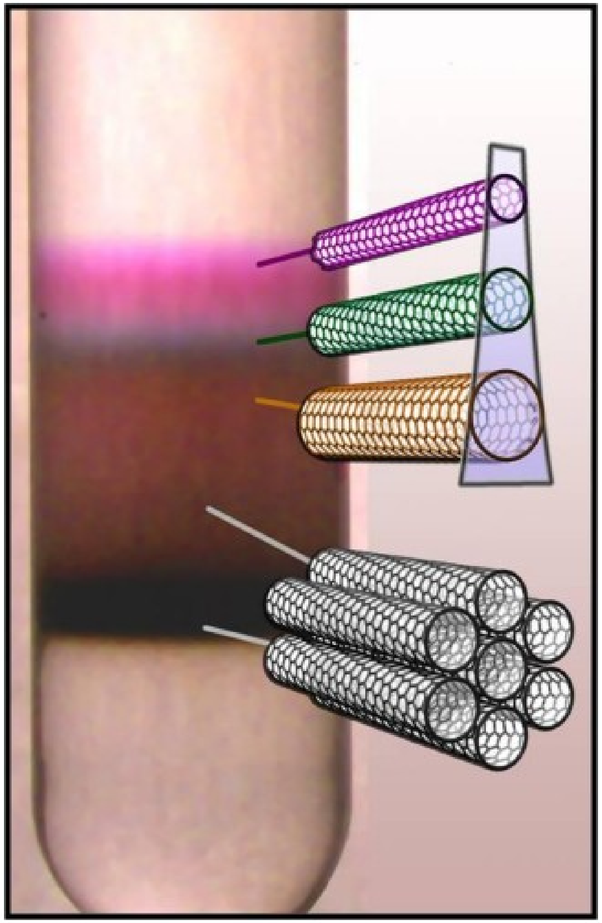
Příklady použití nanostruktur

Optické vlastnosti

- fluorescence CNT
  - závisí na tvaru a velikosti

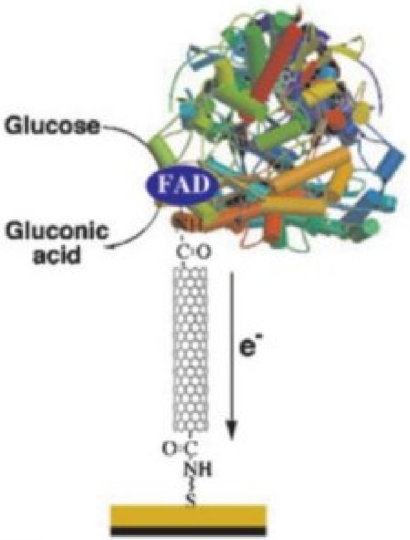
FED displej
  - měl být náhradou za LCD





Příklady použití nanostruktur

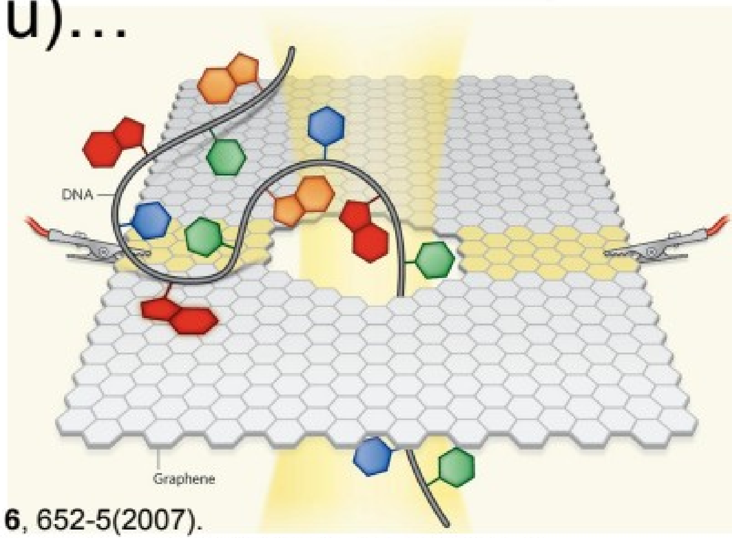
Senzory



- CNT:
  - plyny (NO_2, NH_3, H_2, CO)
  - biosenzory (uchycení protilátek ev. enzymů na povrchu a připojení na elektrodu)…
- grafen:
  - detekce jednotlivých molekul

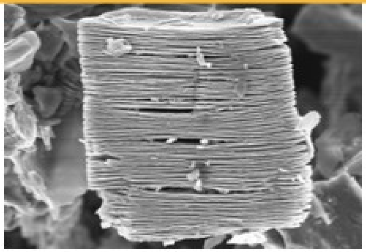
  (lab-on-chip)

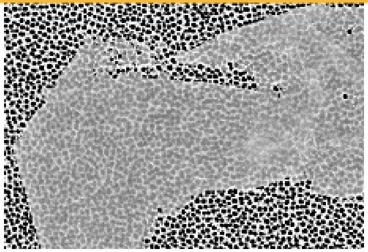
  - DNA sekvenace

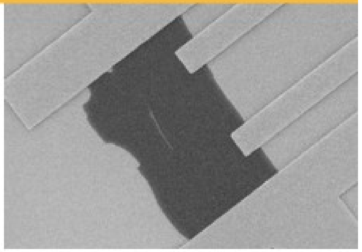


Geim, A.K. Graphene: status and prospects. *Science* **324**, 1530-4(2009).
Schedin, F. et al. Detection of individual gas molecules adsorbed on graphene. *Nature Mat.* **6**, 652-5(2007).
Yang, W. et al. Carbon nanomaterials in biosensors: should you use nanotubes or graphene? *Angewandte Chemie* **49**, 2114-38(2010).
Wang, J. Carbon-Nanotube Based Electrochemical Biosensors: A Review. *Electroanalysis* **17**, 7-14(2005).
Chen, D., Tang, L. & Li, J. Graphene-based materials in electrochemistry. *Chemical Society reviews* 3157-3180(2010)

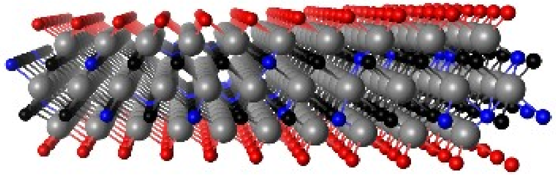
ABOUT MXenes

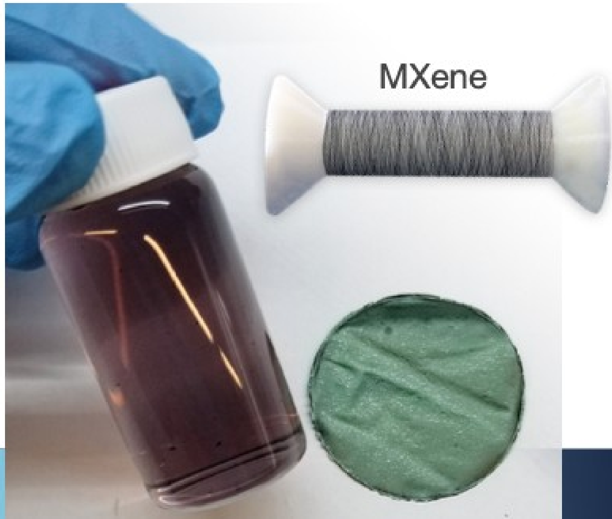






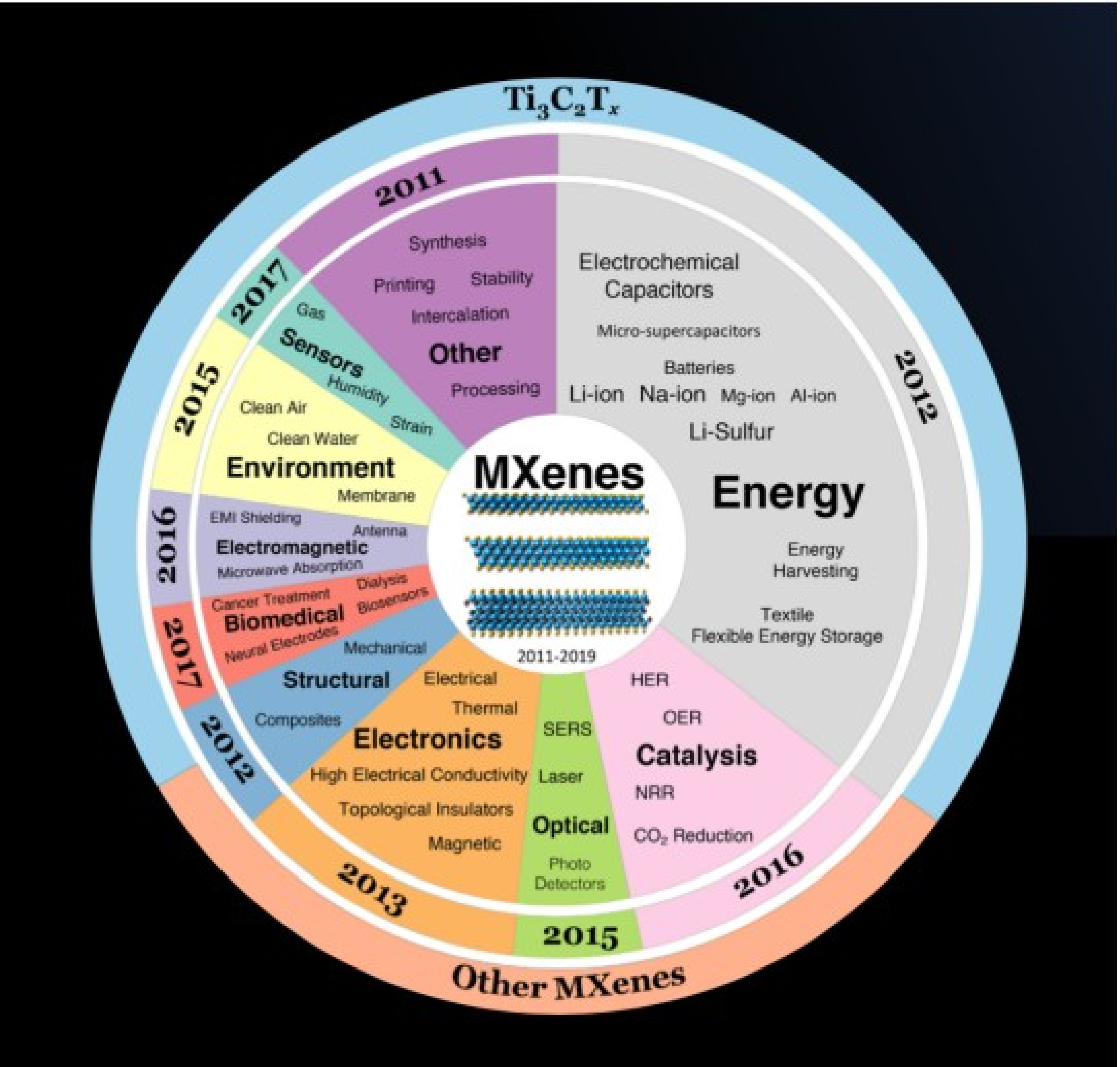
MXenes conduct electricity like metals, but they are nanometer (one billionth of a meter) thin flakes like graphene. They can also be dispersed in water like clay.





CAPABILITIES:

- Store energy much faster than carbon and other materials used in current batteries and supercapacitors
- Protect our electronics (cell phones, etc.) from electromagnetic noise and also protect our credit card information from being stolen
- Purify water and produce drinking water from salt water
- Sense dangerous species in air
- Remove toxic heavy and radioactive elements from water
- Treat cancer
- Make wearable kidney a reality
- Increase strength of plastics, metals and ceramics
- Create energy storing windows that can change color when a small voltage is applied
- Generate printable antennas for 5G communication and Internet of Things
- Enable a new generation of flexible and printable electronic and optoelectronic devices

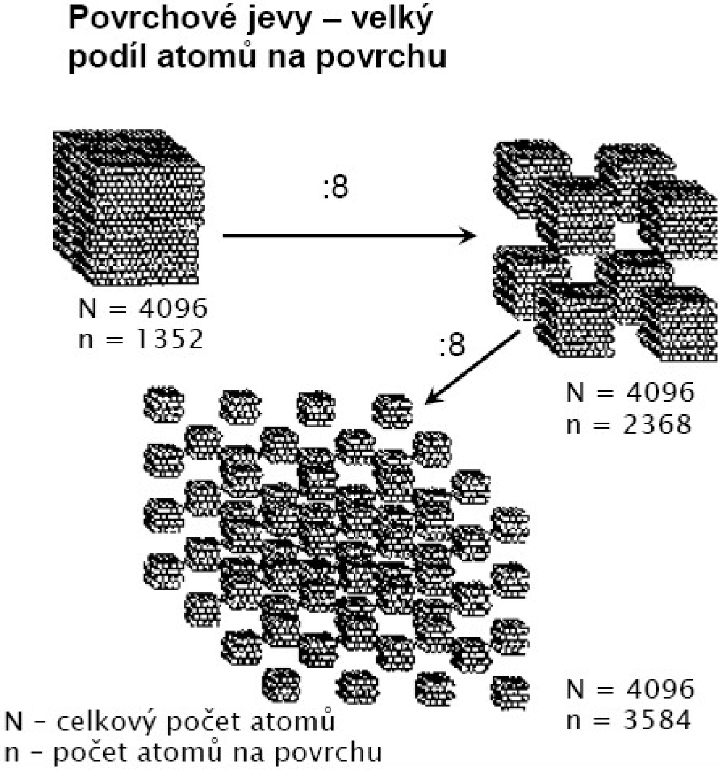

Ti3C2Tx
2011
2012
2017
2015
2016
2017
2012
2013
2015
2016
Other MXenes
Synthesis
Printing
Stability
Intercalation
Other
Processing
Electrochemical
Capacitors
Micro-supercapacitors
Batteries
Li-ion Na-ion Mg-ion Al-ion
Li-Sulfur
Energy
Energy
Harvesting
Textile
Flexible Energy Storage
Gas
Sensors
Humidity
Strain
Clean Air
Clean Water
Environment
Membrane
EMI Shielding
Antenna
Electromagnetic
Microwave Absorption
Cancer Treatment
Dialysis
Biosensors
Biomedical
Neural Electrodes
Mechanical
Structural
Composites
Electrical
Thermal
Electronics
High Electrical Conductivity
Topological Insulators
Magnetic
SERS
Laser
Optical
Photo
Detectors
HER
OER
Catalysis
NRR
CO2 Reduction
MXenes
2011-2019


DID YOU KNOW?
MXene inks can be printed onto almost any surface and they don't require any additives — just disperse MXene flakes in water and print, stamp, paint or infiltrate with it.
MXenes come in a variety of colors. They can be produced as single flakes/layers of one nanometer in thickness, as well as films, powders and even fibers.

©Drexel Uni

Kovové nanočástice

- katalýza (Fe, Co, Ni, Zn, Cu, Pd, Pt, Ag, Au)
- antibakteriální použití (Ag, Zn)
- biosenzory (Ag, Au)
- redukční technologie při čištění vody (Fe, Al)
- magnetické a biomagnetické aplikace (Fe, Co, Ni)



Stříbro ve službách člověka

- starověk a středověk – dezinfekce a konzervace
- konec 19. stol – fotografický proces
- počátek 20. stol – sloučeniny stříbra v medicíně
- 60. léta 20. stol – „silver(I) sulfadiazine“
- konec 70. let 20. stol – objev SERS
- konec 20. stol – „single molecule spectroscopy“
- počátek 21. stol – antibakteriální materiály „nanosilver“

Jaká je asi budoucnost nanoAg

- skvělá z hlediska využití antibakteriálních účinků při úpravě textilu
- Jaká je asi budoucnost nanoAg
- asi skvělá při léčbě kožních problémů a v kosmetice
- záhadná z hlediska perorálního využití v medicíně (argyrie) http
- černá z hlediska ekologického
- a) nanotechnologie b) těžký kov
- **Ale jsou tu další možnosti – SERS a detektory, katalýza!**

Nanočástice Fe a živ. prostředí

- redukční technologie v čištění podzemních a odpadních vod: nulmocné železo (ZVI, nZVI, nanoFe^0)
- dekontaminace různých (tab.) polutantů
- generovány netoxické látky (Fe_3O_4, Fe_2O_3, FeOOH)

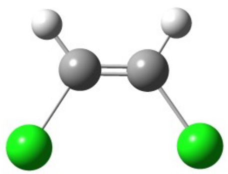
Chlorinated methanes
- Carbon tetrachloride (CCl_4)
- Chloroform ($CHCl_3$)
- Dichloromethane (CH_2Cl_2)
- Chloromethane (CH_3Cl)

Chlorinated benzenes
- Hexachlorobenzene (C_6Cl_6)
- Pentachlorobenzene (C_6HCl_5)
- Tetrachlorobenzenes ($C_6H_2Cl_4$)
- Trichlorobenzenes ($C_6H_3Cl_3$)
- Dichlorobenzenes ($C_6H_4Cl_2$)
- Chlorobenzene (C_6H_5Cl)

Trihalomethanes
- Bromoform ($CHBr_3$)
- Dibromochloromethane ($CHBr_2Cl$)
- Dichlorobromomethane ($CHBrCl_2$)

Chlorinated ethenes
- Tetrachloroethene (C_2Cl_4)
- Trichloroethene (C_2HCl_3)
- *cis*-Dichloroethene ($C_2H_2Cl_2$)
- *trans*-Dichloroethene ($C_2H_2Cl_2$)
- 1,1-Dichloroethene ($C_2H_2Cl_2$)
- Vinyl chloride (C_2H_3Cl)

Other polychlorinated hydrocarbons



Pesticides
- DDT ($C_{14}H_9Cl_5$)
- Lindane ($C_6H_6Cl_6$)

Organic dyes
- Orange II ($C_{16}H_{11}N_2NaO_4S$)
- Chrysoidine ($C_{12}H_{13}ClN_4$)
- Tropaeolin O ($C_{12}H_9N_2NaO_5S$)
- Acid Orange
- Acid Red

Heavy metal ions
- Mercury (Hg^{2+})
- Nickel (Ni^{2+})
- Silver (Ag^+)
- Cadmium (Cd^{2+})

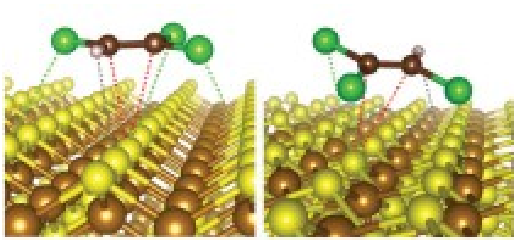
- PCBs
- Dioxins
- Pentachlorophenol (C_6HCl_5O)

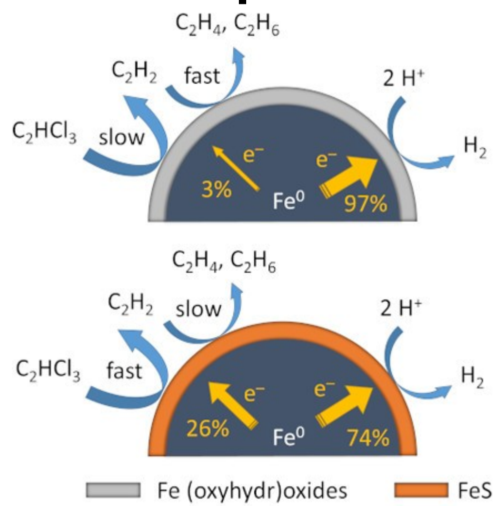
Other organic contaminants
- N-nitrosodimethylamine (NDMA) ($C_4H_{10}N_2O$)
- TNT ($C_7H_5N_3O_6$)

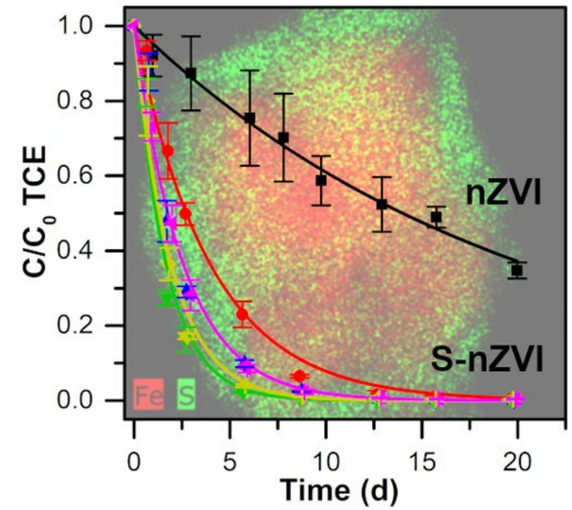
Inorganic anions
- Dichromate ($Cr_2O_7^{2-}$)
- Arsenic (AsO_4^{3-})
- Perchlorate (ClO_4^-)
- Nitrate (NO_3^-)

Modifikované nanočástice železa

- Core–Shell Fe/FeS Nanoparticles with Controlled Shell Thickness



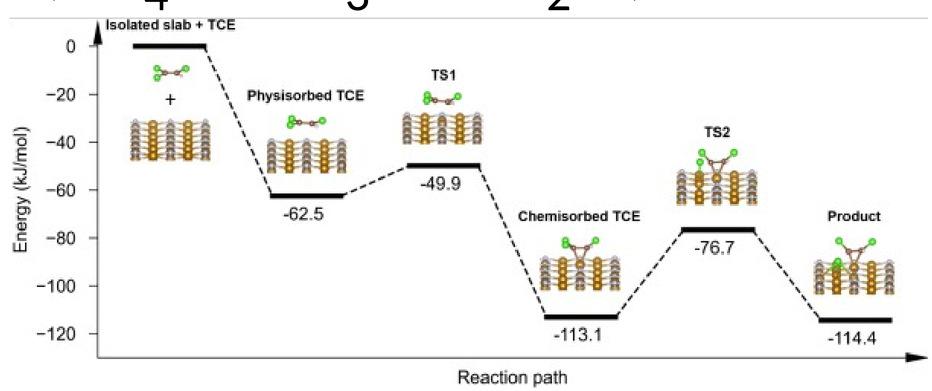




Phys. Chem. Chem. Phys. 2020, 22, 23258

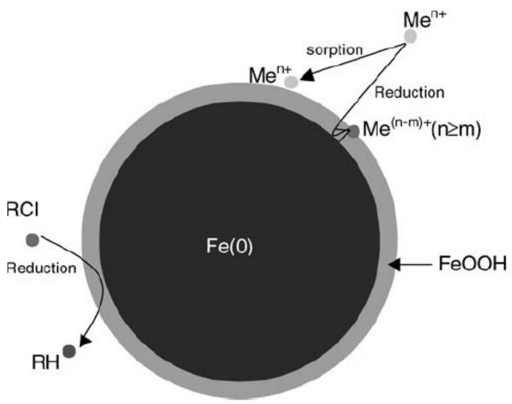
ACS Appl. Mater. Interfaces 2020, 12, 31, 35424

- FeN Nanoparticles (Fe_4N, Fe_3N, Fe_2N)



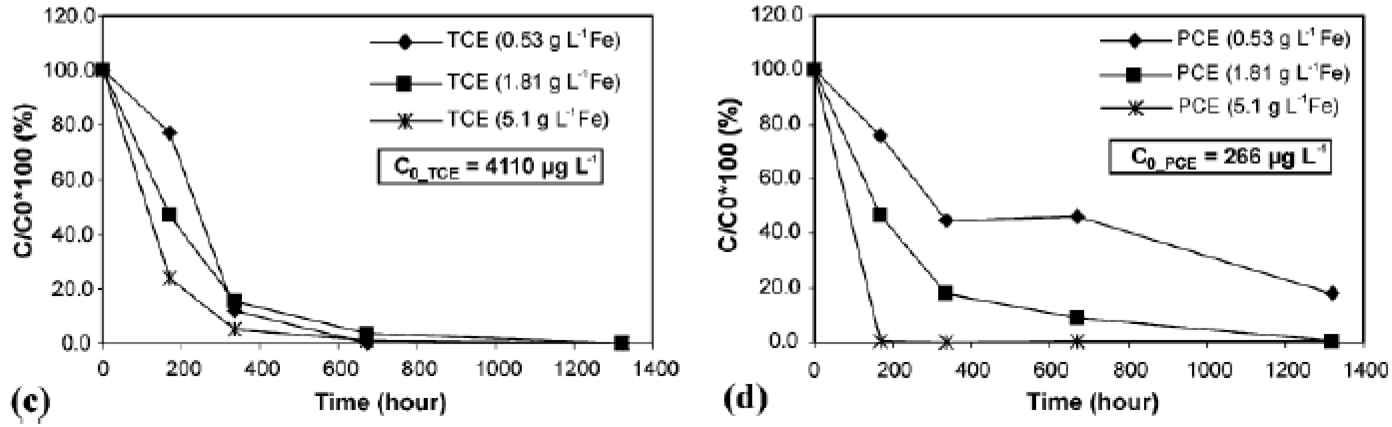
Nanočástice nulamocného železa v reduktivních technologiích čištění podzemních vodpodzemních vod

- Vhodný rozměr částic s úzkou velikostní distribucí (30-100 nm)
- Velká plocha povrchu → vysoká reaktivita
- Vysoký obsah Fe(0)
- Vhodná povrchová modifikace zabezpečující vysokou stabilitu vůči agregaci a vůči oxidaci při skladování ve vodném prostředí → dobré migrační vlastnosti v horninovém prostředí



Technologie čištění vody

- Nanočástice nulamocného železa v reduktivních technologiích čištění podzemních vod

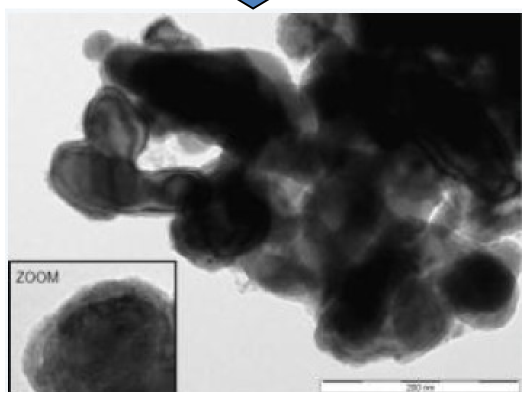


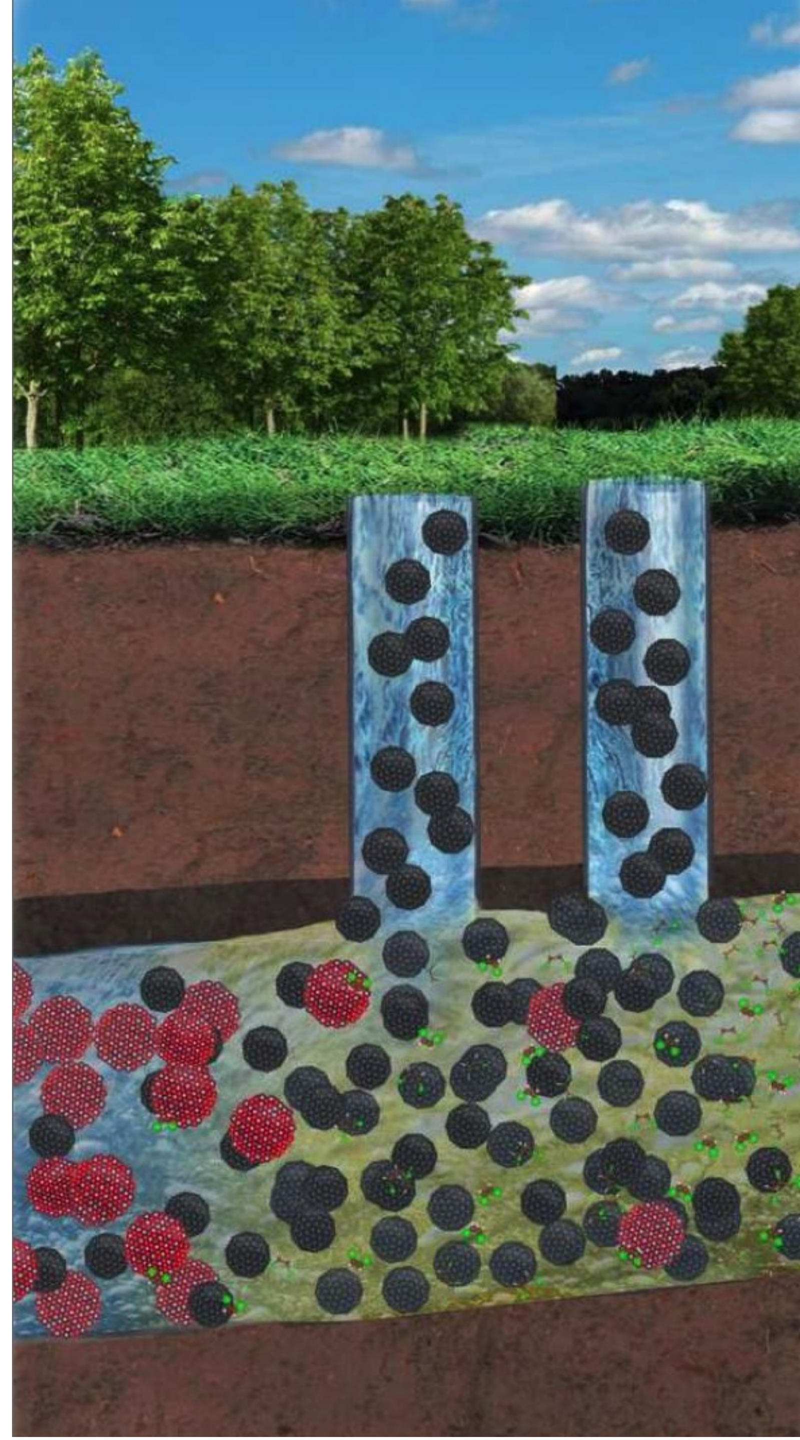
1,1,2 – trichloreten (TCE), 1,1,2,2-tetrachloreten (perchloreten, PCE).

- Odbourání chlorovaných uhlovodíků s využitím Fe/FeO nanočástic různé koncentracenanočástic koncentrace

Jak?

Pyrophoric behavior of
NANOFER 25P in contact
with air oxygen





nZVI APPLICATION

matter of time

SLURRY MANUFACTURING → SHIPPING → STORAGE → DILUTION → INJECTION

Conventional delivery and application process of nZVI

15-60 days

1 day

POWDER SHIPPING → STORAGE → SLURRY MANUFACTURING → DILUTION → INJECTION

Innovative application process of nZVI

PÍSEČNÁ

- Former dangerous waste landfill, drinking water source in neighborhood
- Contamination: chlorinated ethanes and ethenes
- High reactivity of nZVI is needed for TCA degradation
- Fractured bedrock area

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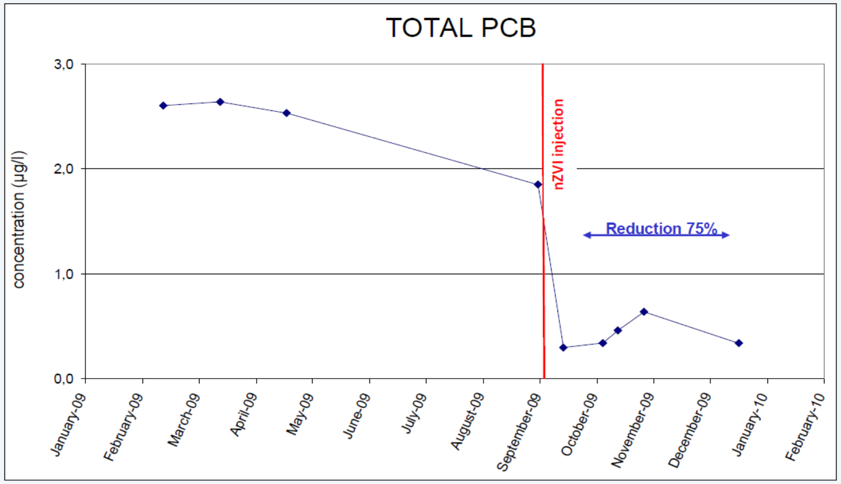
ROŽMITÁL POD TŘEMŠÍNEM

- Pilot injection of 100kg of nZVI



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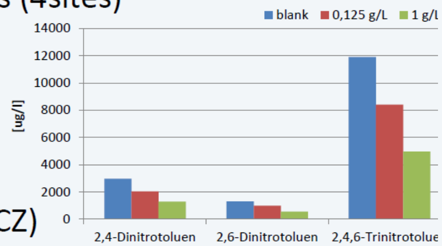
OTHER SITES and STUDIES

- CHC Pilot injection in Netherlands (4sites)
- CHC Pilot injection in Portugal
- CHC Pilot injection in USA
- Pesticides pilot injection (CZ)
- TNT laboratory study (Portugal)
- Mine tailings remediation (CAN, CZ)
- Wastewater treatment (selenium, arsenic, chromium, …)
- More than 20 tons of NANOFER 25S applied on various sites around Europe.
- Others: 350 free-samples of NANOFER products shipped wordwide in past years, 75 to USA and Canada, mainly to universities, research institutes and remediation companies.



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COSTS

nZVI comparing to other products

- Application cost is important
  - Lower amount of nZVI is needed
  - Better mobility of nanoparticles = less injection wells
  - Faster application
  - Higher efficiency

All parameters affect remediation cost

Absolute cost of material ($/kg) is not representative