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Cesty k nanostrukturám a nanotechnologiím

Důmyslné formy hmoty otvírající široký prostor převratnému vývoji vědy a novým technologiím

Approach to nanostructures and nanotechnology

New sophisticated forms of matter to revolutionize future science and technology development

SUMMARY

Approach to nanostructures and nanotechnology

New sophisticated forms of matter to revolutionize future science and technology development

During the past two decades "small-particle" research has become quite popular in various fields of physics and chemistry. By "small particles" are meant clusters of atoms or molecules of metals, semiconductors and others materials, ranging in size from < 1 nm to almost 10 nm or having agglomeration numbers from <10 up to a few hundred, i.e., species representing the neglected dimension between single atoms or molecules and bulk materials.

Presentation intends to show some findings, ideas and opinions obtained during 14 years in the field of *nanoparticles* and *nanostructures* (in the EUREKA framework) and to attract attention to these phenomena based on such results.

Presentation is aimed at:

- explanation of the *nanoparticles* construction and creation
- behaviour and physical properties of *nanoparticles*

SOUHRN

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V průběhu posledních dvou desetiletí se výzkum „malých částic“ stal široce používaný v různých oblastech fyziky a chemie. Pod pojmem „malé částice“ rozumíme malé soubory atomů nebo molekul kovů, polovodičů a jiných materiálů, které mají rozměry od několika angstromů až po několik nanometrů, tedy v seskupení od několika molekul až po několik stovek nebo tisíce molekul. Pozornost byla věnována prostorovým útvarům, které reprezentují přechodovou oblast opomíjených rozměrů mezi jednotlivými atomy nebo molekulami až po velikosti odpovídající vlastnostem makrolátky.

Prezentace chce ukázat některé poznatky, myšlenky a názory získané ze 14-ti leté práce v oblasti nanočástic a nanostruktur (v rámci programu EUREKA) a obrátit pozornost na některé výsledky studia těchto fenoménů.

Prezentace je zaměřena na:

- vysvětlení konstrukce a tvorby nanočástic
- chování a fyzikální vlastnosti nanočástic

KEYWORDS

Klíčová slova:
nanočástice, nanostruktury, nanotechnologie, kvantový prostorový efekt, kvantové struktury, exciton, polarizovaný exciton, separace náboje, kvantová jáma, luminiscence, nosič náboje

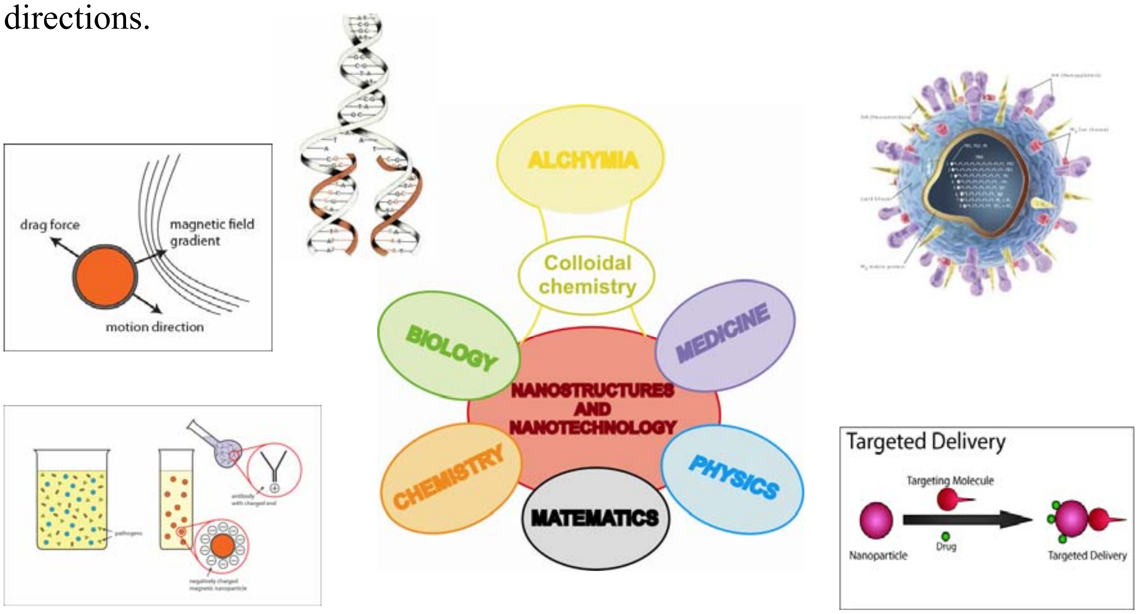
Keywords:
nanoparticles, nanostructures, nanotechnology, quantum size effect, quantum structures, excitans, polarized excitans, charge separation, quantum well, luminiscence, charge carrier

CONTENTS

1 Introduction

Contemporary science reached the level which makes possible to peep into very tiny pieces of matter to observe natural processes taking place inside. On top of that the modern technology allows interfering with these internal processes and working upon them. Very important are characteristics and properties which such form of matter exhibits as well as processes that take place on nanometers scale.

Nanostructures represent the new forms of matter which science and technology have been eagerly investigating during recent years. Problems of nanostructures belong to an inter-disciplinary field of research, where chemistry, physics, biology and mathematics, and perhaps some other branches of science as well, overlap in creating possibility to describe, study and employ these directions.



Nanotechnology is an inter-disciplinary branch of science

Nanophysics, nanochemistry, nanomedicine, nanobiology, and particle nanostructures are categories of current nanoscience which describes and studies these processes and characteristics. Today's technology already achieved the levels that makes possible to observe and copy the process of formation tiny structures and to imitate these structures in „nanosize" scale, or to find the ways how to prepare them. As these structures exhibit unique characteristics, unknown in the macro-world, it can be said that from the point of view of utilization of these structures for practical applications, doors are becoming wide open to undreamt-of development of science and technology. This area has received the name **nanotechnology**.

2 What is the nanotechnology ?

Nanostructures and related processes have been known to Nature since very long time ago: see e.g. the cell membrane, pumping protons through such membrane, saving vision related information in the eye pigmentation, nanofibers in spider's nets, muscular cells etc. If we look in the old temple on colored mosaics in windows, we can see colored manifestation of metal nanostructures in glass. We can see their optical characteristics, e.g. that the gold nanostructures are causing highly intense red coloring of the glass and nanostructures of other elements can produce some other colors. These several examples clearly demonstrate that mankind had been using these practical fabrications and processes even without being aware of anything like nanostructures and nanotechnology.

The interesting question is being often asked what's the *evolutional step*, how to describe this phenomenon. To reach the evolutional changes (fast changes are usually called revolutionary jump) it is necessary to get an efficient mutual feedback between scientific research and practical application, i.e. when practical applications of results provided by research and development are changing the principal way the exploitation of technical possibilities in this area, opening door to brand-new ways of practical utilization that would have an impact on human thinking.

E.g. discovery of transistors as such cannot be called the technical revolution. Only serial manufacturing and practical usage of transistors instead of electron valves made possible construction of the pocket radio, electronic micro-components and development of computer microchips. As a result of that the computer technology enabled major development of the research as such.

Thanks to their unique qualities nanostructures and nanotechnology offer the whole range of prospective unique applications. Practical utilization of some of them is paving the potential road towards revolutionary changes.

Provided that nanotechnology would make e.g. possible replacement of wire connections in computer chips by connections using an embedded coherent light source, the microchips performance would be raised by several orders of magnitude and the heat resistive losses, presently representing the major obstacle in microchip technology development, would be diminished. The clock rate and many other microchip parameters could be substantially improved. Such computers would make possible undreamed-of increase in efficiency and possibilities of solving new and more complicated research tasks - clearly demonstrating the feedback functioning.

Presently the features leading towards nanotechnology revolution are under very fast developments. Thus it might be quite useful to show what these nanostructures and nanotechnology really are, where their unique characteristics and properties are coming from, and for what practical applications they could be utilized.

Nanostructures

are 1-, 2- or 3- dimensional spatially restricted structures (surrounded or filled in by some other form of matter) which exhibit unique properties not occurring in macro-matter.

Nanotechnology

means engineering of nanostructures. It is a way of preparation or manipulation with nanoparticles aimed to creation of properties of nanostructures for study and practical applications.

Nanomaterials

are the results of aimed manipulations with nanostructures.

In other words:

nanotechnology is an inter-disciplinary branch of science dealing with very small material objects with dimensions of the order of nanometers (several units, tens, up to several hundreds) which have very unusual properties, exhibiting individual character and being unique by its construction and its functioning (e.g. biological engine of circular or pyramidal geometry on the surface of other metals demonstrating special effects, construction of regular and periodical structures, lattices etc.).

These unique properties can be studied and exploited by many branches of science, as well as used by them for many practical applications.

Methods of preparation and more importantly, manipulation, with small objects, molecules and atoms are called nanotechnology.

3 Some unique properties of nanostructures

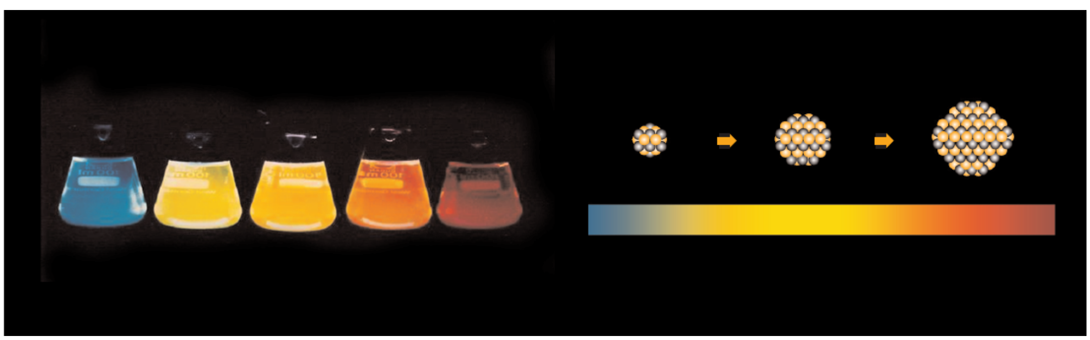
Nanostructures share similar phenomena:
unique physical and chemical properties quite different from those found in microcrystallines material (e.g. bulk material):

- Iron Fe is soluble and yellow.
- Semiconductor like Cd_3As_2 is red (can be made also yellow), exhibits strong luminescence, and is soluble.
- Carbon C is red and soluble.
- Silicon Si is yellowish, exhibits strong luminescence, and is soluble in organic solvents.
- Nanoceramics can withstand temperatures up to 3000°C (US Space shuttle).
- Nanowires (e.g. Carbon) and macro-component yield nanocomposite with unique properties (e.g. it is 14x lighter and 10x stronger than steel).
- Metal and carbon nanotubes yield metal-nanocomposite!
- Metal nanoparticles, under some conditions, split water and produce hydrogen!
- Magnetic nanoparticles help to liquidate viruses and bacteria!
- And many other things…

Unique characteristics and properties of nanoparticles and nanostructures are based on their *space restriction*. By shrinking enough at least one of spatial dimensions of some piece of matter the room for free movement of its electrons decreases. The only way for these free electrons to continue their existence as part of such structure is to shorten their respective wavelength. When electron shortens its wavelength, it also increases its energy and this way generates a higher energy level in the system resulting in changes of physical characteristics of such tiny pieces of matter, e.g. their color, solubility, etc.

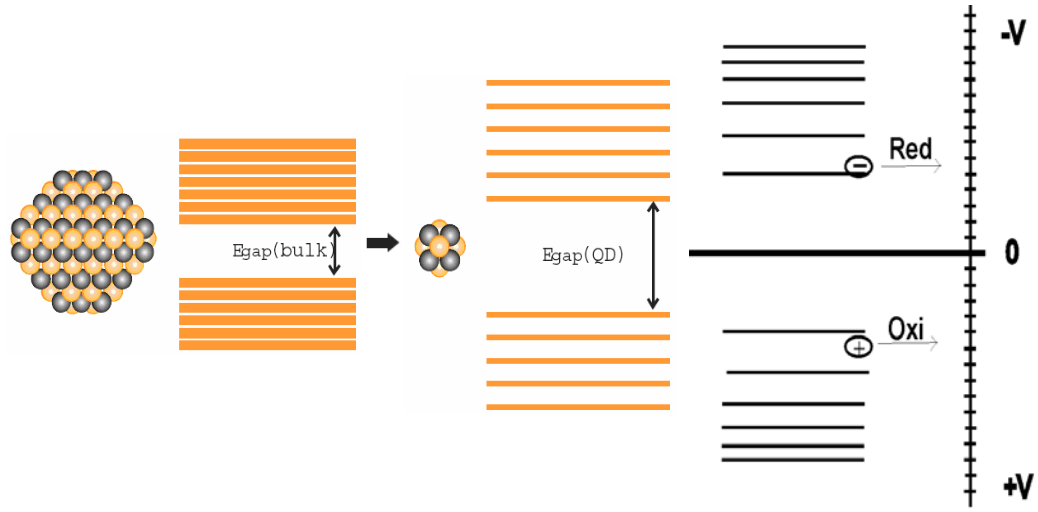
Quantum structure	Volume delocalization	Size restriction
Bulk material	3 (x,y,z)	0
Quantum well	2 (x,y)	1 (z)
Quantum wire	1 (x)	2 (y,z)
Quantum dot	0	3 (x,y,z)

Nanoparticles of Cd_3P_2 – luminescence



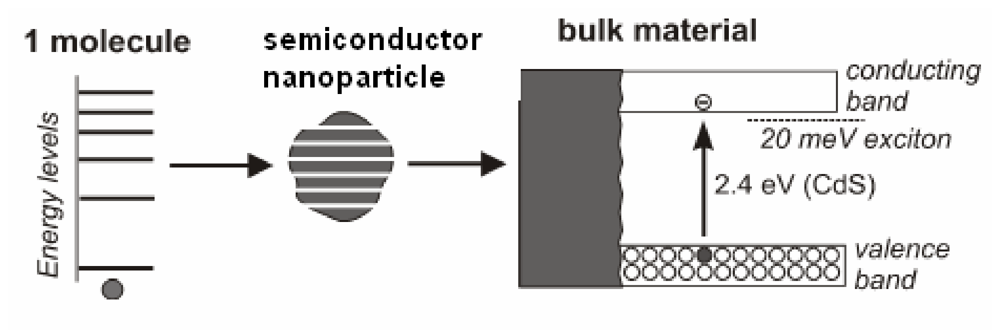
Increasing particle size from left to rigt

Priority is the *goal*. Ways of their preparation are of less importance.
Unique *qualities* come from their physical origin and that is done by their *size*.
They are determined by their *spatial restriction* in which they are created.

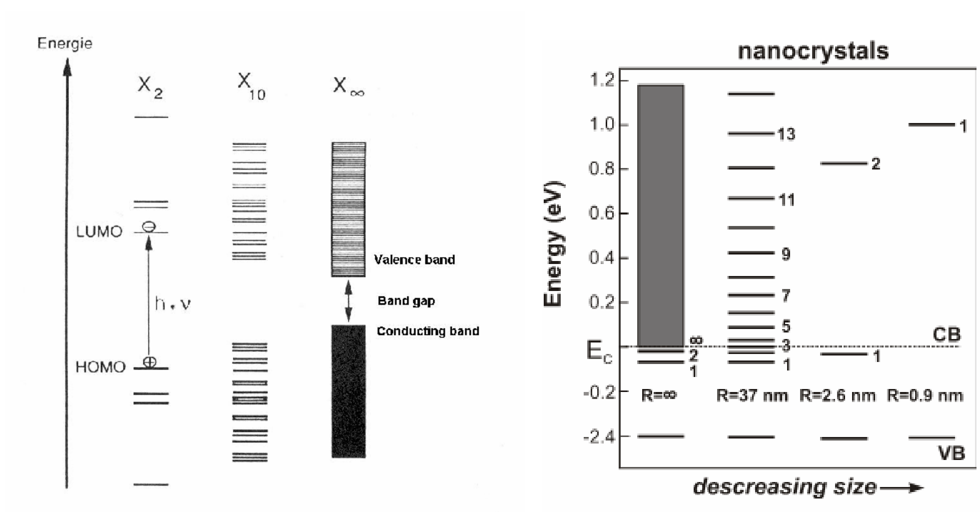


Band gap control by the size of particles to manipulate redox potential

Creation of nanoparticles



Schematics of a semiconductor nanoparticle (for example CdS-nc) as an intermediate state between the single molecule and bulk crystal



Evolution of energy states in nanoparticles of different size

5 Size quantization effect

The size effects are generally described by the well-known quantum mechanics of a „particle in box“. The electron and positive hole are confined to potential wells of small dimensions and this leads to a *quantization* of the *energy levels* (which in the *bulk material* constitute *virtual continuum* in the *conduction* and the *valence band*, respectively). These phenomena occur when the size of the particle becomes comparable to the DeBroglie wavelength of the carriers.

Maxwell-Boltzmann

$$E = \frac{3}{2}kT \qquad\qquad E_{300K} \doteq 0.04\,\text{eV}$$

where E is the kinetic energy of the carrier,
T is temperature in K , and $k = 1.38\times10^{-23}\ \text{JK}^{-1}$.

DeBroglie - duality of particles

$$\lambda = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda = \frac{h}{\sqrt{3mkT}}$$

where λ is the wavelength of the carrier with mass m and $h = 6.63\times10^{-34}$ Js.
In case of thermal electron $m = 9.1\times10^{-31}$ kg. at 300 K

$$\lambda \doteq 62\ \text{Å}$$

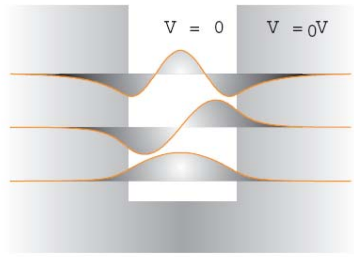
The quantization effects for an electron in an *evacuated box* become significant at the box dimensions of the order of 0.1 nm. However, in the case of *colloidal particles* the effects can already become visible at much larger particle sizes. The reason for this lies in the fact that the effective mass of the charge carrier, which moves in the periodic array of the crystal lattice of the constituent, is generally much lower than that of the electron in free space. This results in larger DeBroglie wavelength. Potential wells (a simple model is a square well) can exist in one, two, three, and other dimensions.

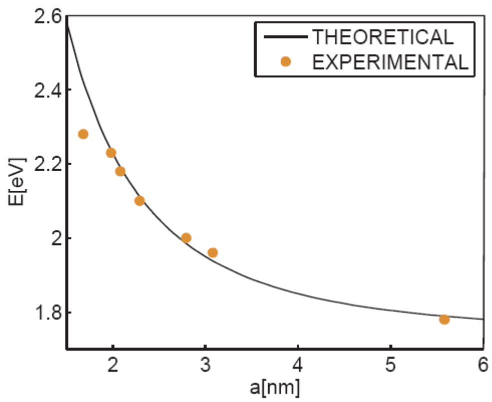
The set of wave functions Ψ and energies E determining the band structure, density of states, and optical properties can be obtained from the solution of the *stationary Schrödinger* equation [1]:

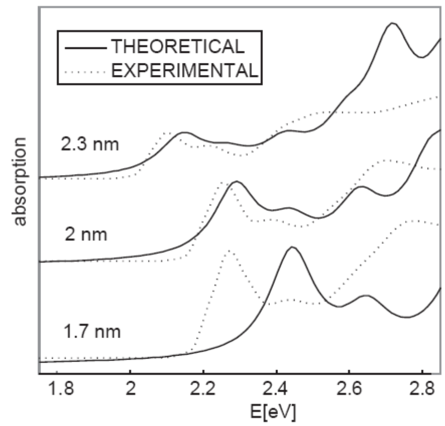
$$\mathbf{H}\Psi = E\Psi$$

CdSe

USED CONSTANTS	$m_e = 0.13m_0$	$m_h = 0.45m_0$	V = 3.8eV	E_{gap} = 1.75eV	$\varepsilon = 9.3\varepsilon_0$



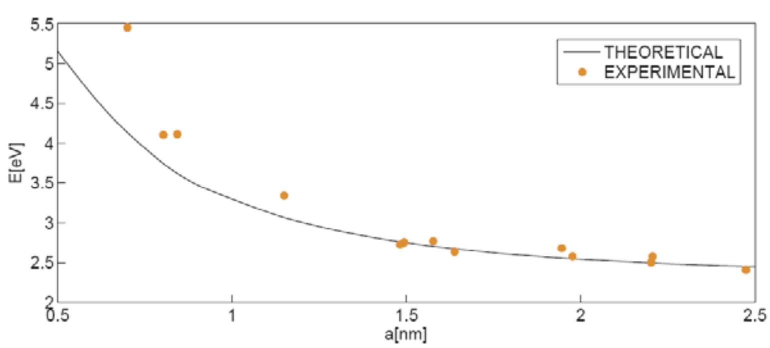


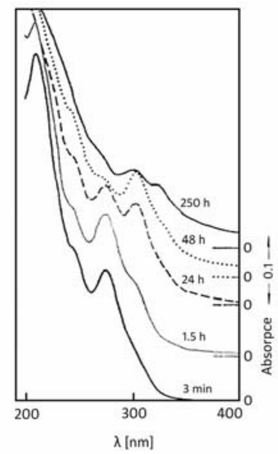


The smaller the effective mass of the charge carriers, the more pronounced are the optical size effects [1]. These effects can lead to drastic changes in the color of a given material, the color of its luminescence, and its catalytic properties. To indicate that such a material has unusual properties as compared to those of macrocrystalline material, we proposed using the prefix Q before the chemical formula [2, 3].

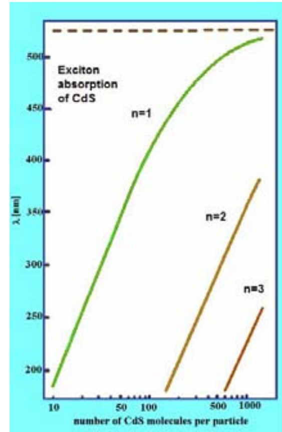
CdS

USED CONSTANTS	$m_e = 0.19m_0$	$m_h = 0.8m_0$	V = 3.8eV	E_{gap} = 2.58eV	$\varepsilon = 5.7\varepsilon_0$





λ nm	m
206	12
246	18
274	24
302	32
324	40
342	48
360	56
370	64
381	72
395	84



Semiconducting systems of low dimensionality, so-called superlattices, are frequently used in the field of micro-electronics.

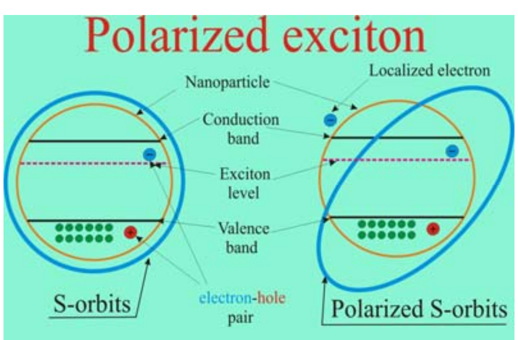
Potential wells for both, conduction band electrons and valence band holes are formed, and the position of these bands depends on the thickness of the wells and barriers.

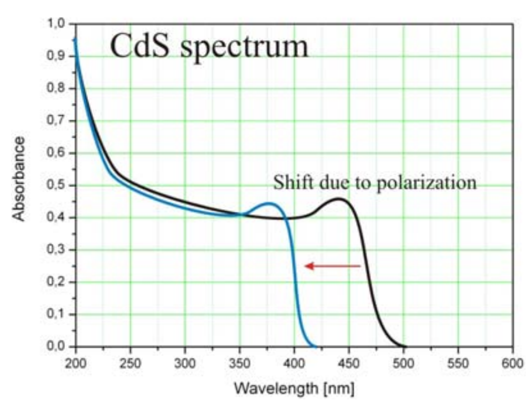
As the quantization occurs only in one dimension in these structures, the shifts of the electronic levels are only of the order of 0.1 eV, while the shifts in the colloidal particles, where quantization is present in all three dimensions, can amount to several eV.

It may be mentioned that the size quantization effects in the optical spectrum of CdS were observed for tiny crystals grown.

The fact that the *absorption spectrum* of Q-particles (e.g. CdS) changes when electrons are added to such particles may be regarded as a non-linear optical effect, i.e. a dependence of the absorption coefficient on the light intensity.

Polarisation of exitons or Q-particles [4].





Other non-linear effects, which are caused by the changes of refractive index with light intensity, are being investigated intesively.

6 Practical applications

Nanotechnology is a new branch of science. Some examples for practical applications are given:

1) Practical usage of optical, electrical and magnetic properties
   Example: an active mirror which reflects more light than it accepts, optical wires for communications, magnetic particles [16, 17, 18], magnetic liquids

2) Practical usage as a source of light radiation
   Example: Light emitting diodes LED and other LE structures [5], wire lasers

3) Information storage
   Example: Light induced charge transfer, storage of information on molecular level, molecular computer chips

4) Interaction with other structures and groups of molecules
   Example: sensors and detectors for environmental pollution [6], plasmon detectors for biological molecules

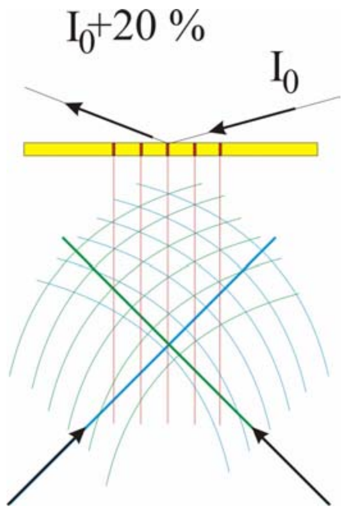
5) Usage in medicine and biology [7]
   Example: Necrotizing tumor using magnetic nanoparticles [16, 17, 18] as an electromagnetic valve, fighting against viruses (e.g. HIV) in vitro and in vivo (inside of the body), transport of medicals in bio systems

6) New nanomaterials
   Example: nanocomposite materials, nanoceramics, nanowires

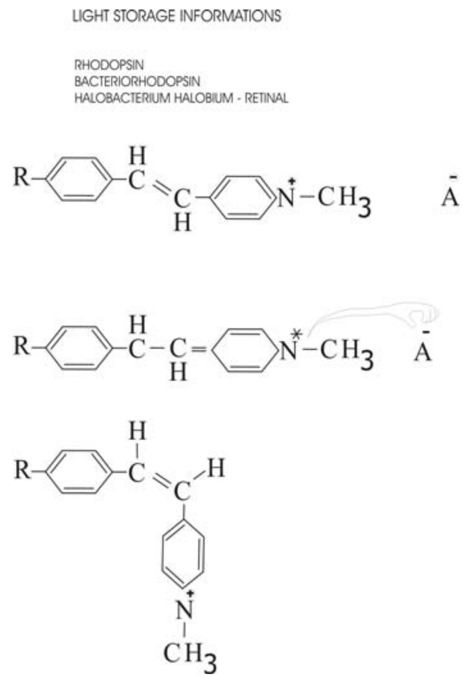
7) Nanotools, nanoinstruments, nanorobots and other applications

Nanstructures with dimensions from nanometers up to a micrometer have individual character and are distinct in their construction and functioning.

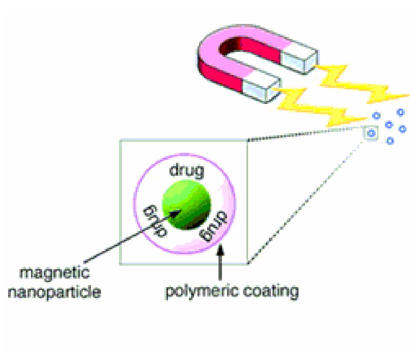
Hereafter are several examples for possible *practical applications*:



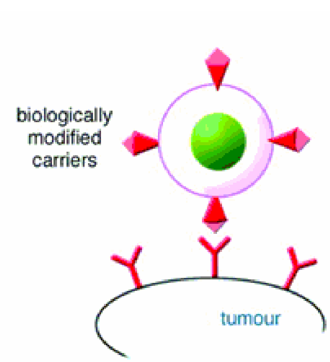
Active mirror



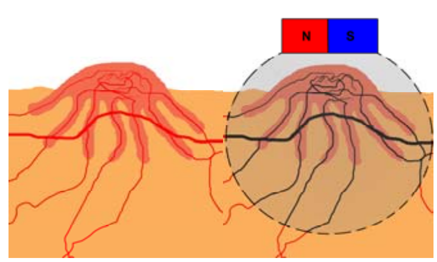
Light storge information



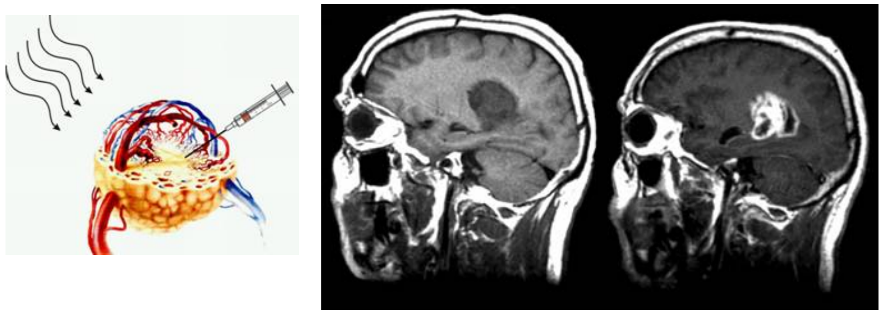
Hyperthermia



Magnetic nanoparticles (NP) application



Necrotizing of tumors using magnetic NP



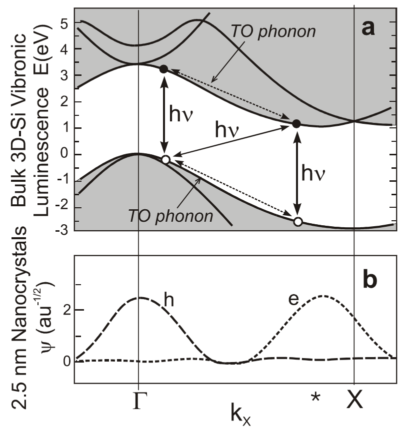
Bioimaging - MRI contrast enhancement

At present the chip-technology reached the level when it is possible to have 10^9 transistors per cm^2 and the density of wire-connections reached 10 km per cm^2. The conductivity and resistance thermal losses have already surpassed the hotplate and are getting near to the production of thermal densities inside of nuclear reactors. These heat losses are one of serious obstacles in development of microchip technologies. Question arises how to handle (i.e. cut-down) these thermal losses. A possibility exists to utilize nanotechnology in practice, in form of carbon nanotubes, which have unusually high capabilities for heat transfer and already demonstrated some positive results.

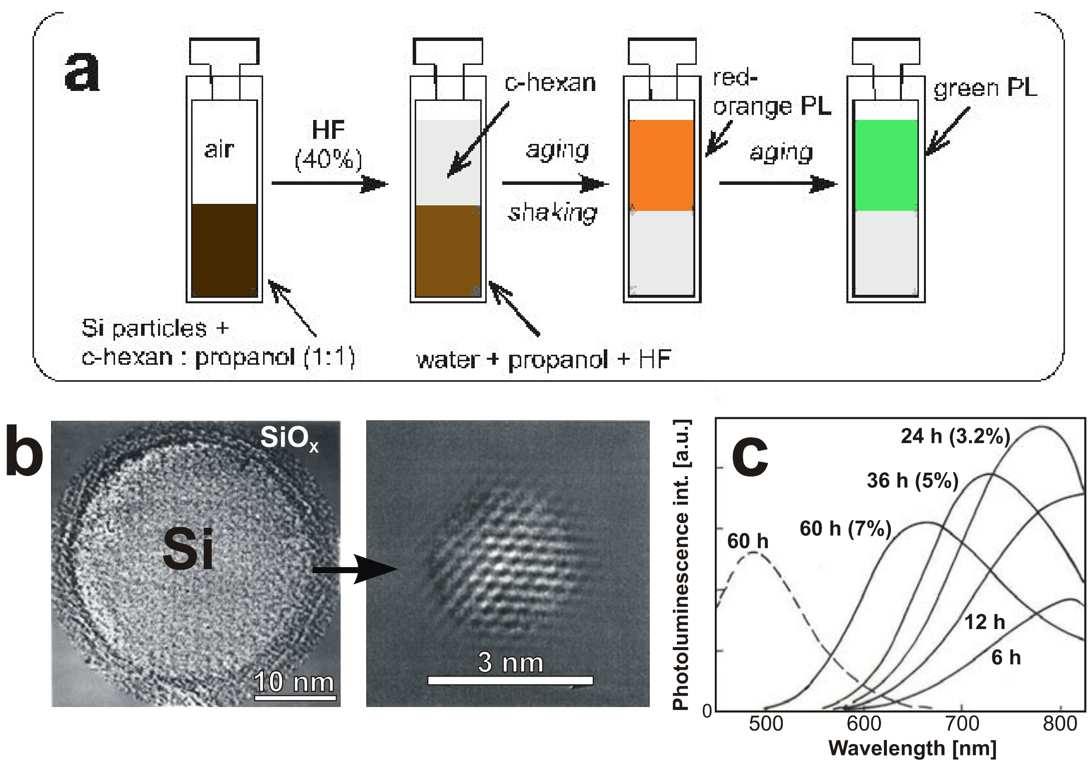
Next revolutionary step might be a possibility to replace mechanical wire connections inside of integrated circuits by coherent light beams. However, under normal circumstances, the major problem lies in the fact that silicon and germanium are semiconductors with an *indirect band gap* with very low light-emission efficiency. In that case an auxiliary phonon is needed to participate thus making the whole process of recombination accompanied by light emission rather unlikely. As a consequence of this defficiency these semiconductors are not suitable for usage as laser active media. Still, one of the rules in microchip technology states that it is impossible to use other materials beyond silicon in silicon chips or germanium in germanium chips [8].

Reason, why the above mentioned approach has been impossible so far, lies in the semiconductor's energy level structures containing points and axes of asymmetry. Use of nanotechnology approach suggest a possibility for construction of structures so small that the space restrictions cut off such points of asymmetry and structure gets into a state of *direct band-gap*, which is the necessary requirement for laser actions [9, 10].

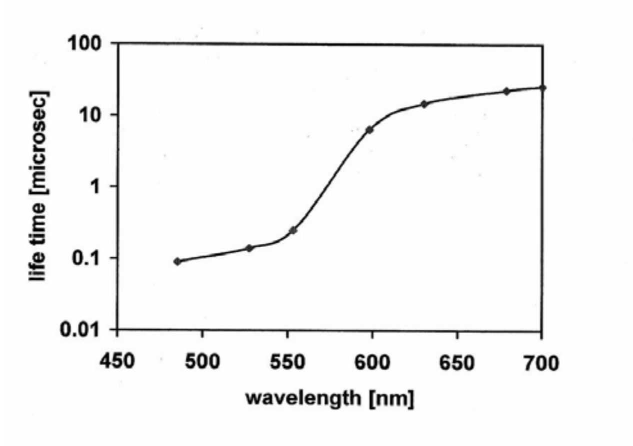
Using nanotechnology the first steps were made that indicated some optimism for this approach by preparation of nanostructures that already exhibited these direct band-gap characteristics and thus stimulated further research in this very challenging and lucrative area [11, 12, 13].



(a) Schematics of the indirect bandgap structure of bulk silicon,
(b) square of the electron and hole wave functions in small Si nanocrystals



Etching of Si-nc: (a) Composition and configuration of etching solutions in cuvettes. (b) HR-TEM images of Si nanoparticles. The initial size of tens of nm is reduced down to several nm. (c) PL spectra of Si-nc suspensions after annealing in different concentration of HF for various time. The PL peak is shifted with prolonged etching from near-IR to orange spectral region and eventually switched to a blue-green for Si-nc below ~2 nm. **[9, 11]**



Photoluminescence haftime decreases with decreased size of Si NP **[11]**

Nanostructures also showed their potential to be employed in biology for liquidation of bacteria. Some nanostructures as silver or magnesium enable strong bindings among sulfhydril group inside of bacteria and the active surface of metallic particles. Bacteria are biting the Ag+ ion from such metallic particles and as a consequence of that they are becoming effectively *biologically inactive* and losing their capacity for further reproduction. This feature was recently described and explained in detail [7] and it is ready for wider application.

Nanoparticles with *magnetic* properties can be used for liquidation of HIV virus. At first suitable anti-bodies sensitive to HIV viruses are tied up to the surface of such magnetic elements (the process of activation). Such activated magnetic nanoparticles are then introduced into the blood stream. Once there, the HIV viruses are gradually picked up by the anti-bodies. Subsequently, by application of the magnetic field, these nanoparticles can be extracted from the environment (blood) [16, 17, 18]. This process can be made in vitro the analogous way to cleaning blood by artificial kidney.

These days we are trying to increase the amount of anti-bodies on the surface of the nanoparticle from present 8-10% to at least 50-80%.

Gratings are known to be capable of reflecting light the way similar to the mirror (with efficiency 60-80% and for angles of incidence below a certain value). By using nanostructures with crossed laser beams some special gratings can be created which help to reflect the incident light with efficiency greater than 100% (usually 100-120%). By interaction of light with these structures it is possible to recover weak cosmic signals or to achieve laser amplification by multiple reflections (utilization in military applications).

Charge carriers separation in AgI/Ag2S colloidal nanoparticles for photosentive layers.

Extensive experimental study of the photochemical behavior of the AgI/Ag_2S colloid heterostructures was provided in [14, 15]. Pure AgI colloid solution exhibits strong blue luminiscence with maximum of 420 nm. (See in Fig. 1)

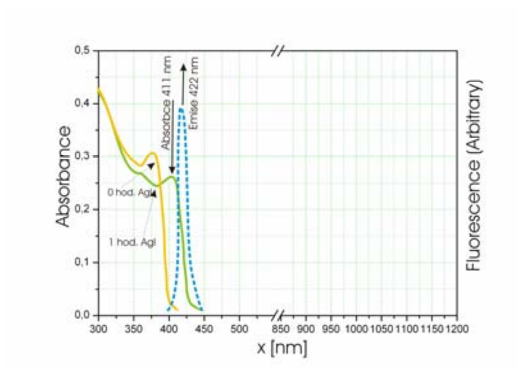


Fig. 1

The addition of sulphur in the solution of AgI caused qualitative changes in the luminiscence of AgI - small concentration of the sulphur quenched the blue luminescence (see in Fig. 2)

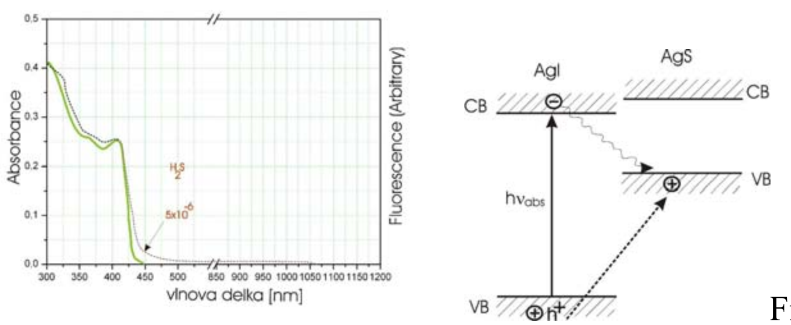


Fig. 2

and subsequent addition of sulphur introduced new luminiscence peak at 900 nm which was moving towards longer wavelengths. (See in Fig.3)

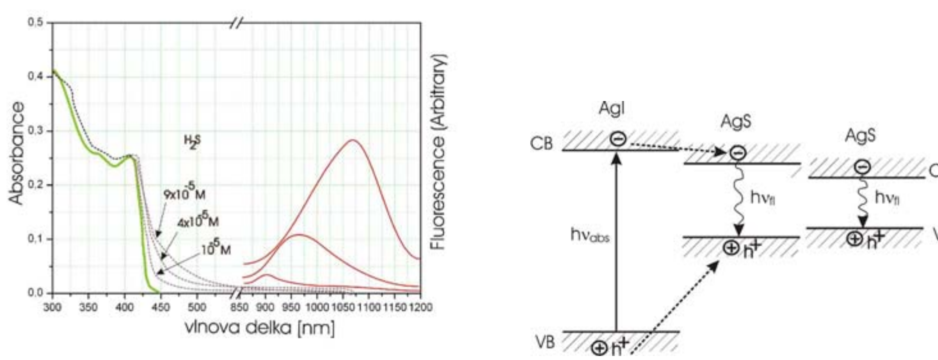


Fig. 3

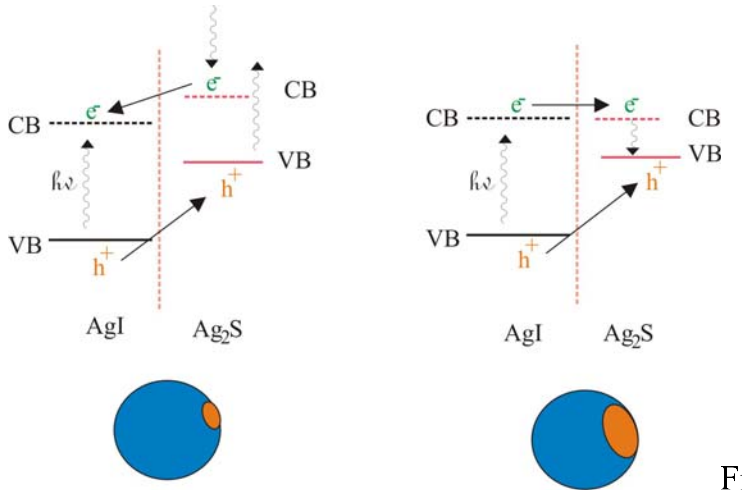
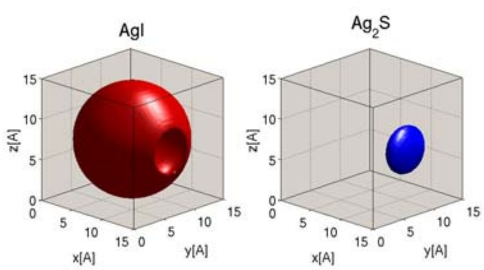


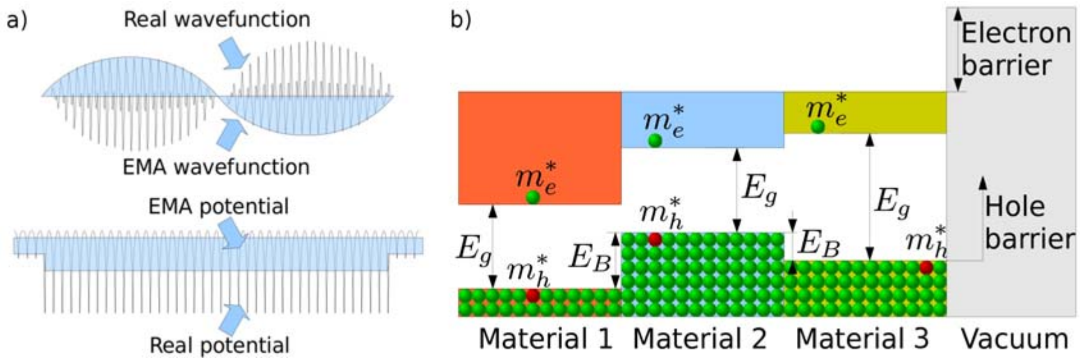
Fig. 4

We have performed a numerical modeling of the heterostructure in order to understand the underlying processes. (See in Fig.4) We have used the effective mass approximation to model the behavior of charge carriers in the structure and to explain the changes in the luminiscence spectra. We supposed that the addition of sulfur to the solution causes a formation of Ag_2S islands underneath the surface of AgI crystals. Volume of the islands is proportional to the concentration of sulphur added to the solution.

The calculation showed that these islands serve as traps for holes which lead to the charge separation and quenching of the luminiscence. Further growth of island leads to trapping of electrons and results is red-shifted luminiscence from the sulphide region. Introduction of the potential barrier in the interfacial region leads to better accordance of calculated peak position with experimental values. This predicates the importance of interfacial effects which cannot be accurately described in the framework of EMA.

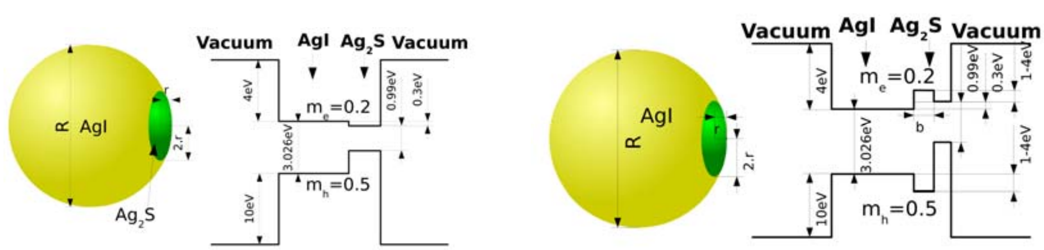


Geometry for the AgJ/Ag_2S nanoparticles

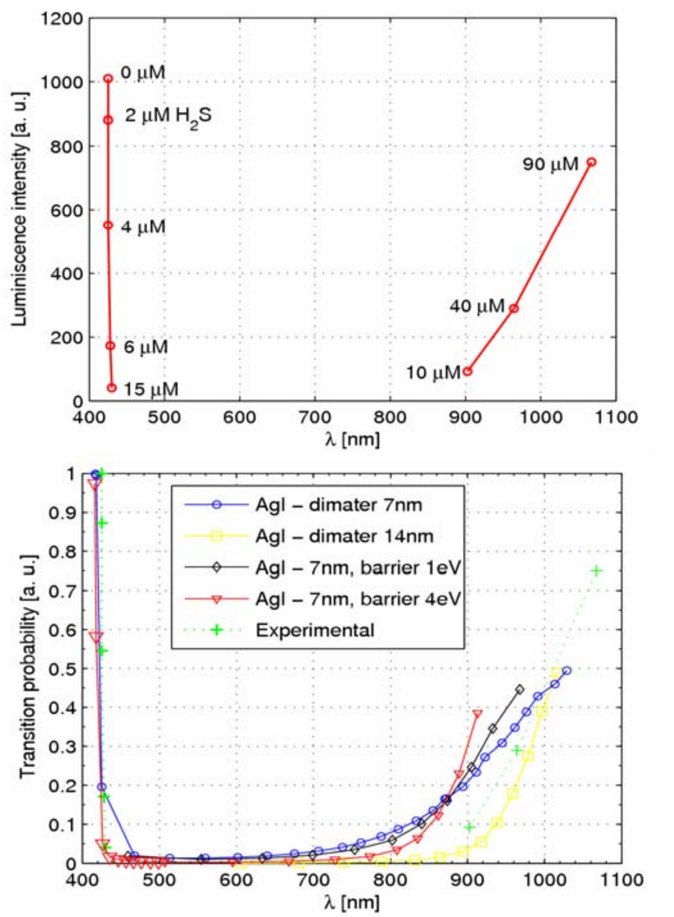


***Envelope function* a) *and EMA material parameters* b)**

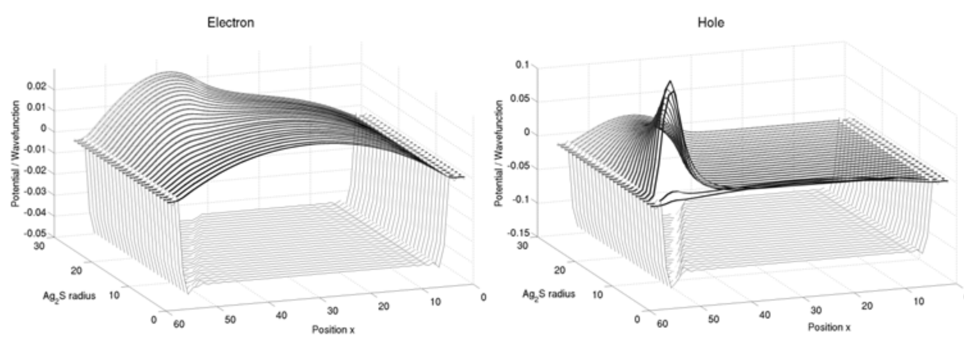
For the calculations we used our EMA (effective mass approximation) package that calculates the electron and hole lowest eigenstates in rectangular computational box using the plane-wave basis. The energy of the lowest transition is then given by the sum of electron and hole energy and the band-gap energy. Measure of coupling of the transition to the electromagnetic field is proportional to the overlap of the electron and hole wavefunctions. Further in the text, by the notation luminiscence intensity we mean the square of this overlap. We assumed the following geometry of the the calculation. Diameter of AgI nanocrystals has been taken to be 7nm and 14nm. Ag_2S regions have shape of a rotational ellipsoid with axes 2.r, 2.r and r with the volume proportional to the concentration of the sulphide added to the solution.



Geometry and parameters of AgI/Ag₂S heterostructure without and with the interfacial barrier



Position of luminiscence maximum with addition of sulphur



Electron and hole wavefunctions and potential along the symmetrical axis

We can see the comparison of the calculated positions of the luminiscence maximum for different geometries if the heterostructure with the experimental value.

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1957-1958 TU Bratislava, Matematicko-fyzikální fakulta a Chemická fakulta
1958-1962 ČVUT Praha Fakulta technické a jaderné fyziky, Jader. chemie a fyz. chemie
1962-1963 Ústav hygieny, Praha
1963-1991 Ústav fyz. chemie (UFCHE J.H.) ČSAV
1968-1970 Ústav Hahn-Meitnerové ,W.Berlin, PhD-Thesis: *Studium a modelování chemických procesů pomocí lin. urychlovače*
1972 UFCH ČSAV : *Studium dynamiky ultrarychlých radikálových v kond.systémech*.(CSc.)
1972-1991 Vedoucí odděleni Chemické reaktivity, vedoucí úseku Chemické fyziky
1992-1994 Ústav Hahn-Meitnerové-Berlin, Oddělení malých nanočástic
1994-1997 Technická Univerzita Mnichov, Garching, Oddělení fyziky
1998 Fakulta jaderná a fyz.inženýrská, Praha (X-ray lasery, nanotechnologie, kvantové nanostruktuktury a nanočástice)

Studijní pobyty

1979-1980 Argonne National Laboratory, Chicago and AT&T Bell Laboratories, Murray Hill, New Jersey
1980-1981 Institut fur Strahlenchemie, Mulheim a.d.Ruhr

Odborné zaměření:
Kapilární X-ray lasery, nanotechnologie, kvantové nanostruktuktury a nanočástic).
Fyzikální, fyz. chemické a chemické vlastnosti kvantových nanostruktur. Polovodiče, kovy a organické materiály. Příprava a prostorové modelování těchto útvarů. (Chemická a fyzikální manipulace). Vzájemná reaktivita těchto struktur - sendvičové struktury. Přenos a lokalizace náboje na nanočásticích. Optické vlastnosti – absorpční a emisní procesy povrchových a vnitřních stavů. Nekoherentní nelineární opt. vlastnosti. Elektronické a fotonické nanostruktury křemíku – příprava a modelování. Měření jejich fyzikálních a fyzikálně chemických parametrů.

Autor či spoluautor více než 130 vědeckých prací, které mají přes 1600 citací, Hirsch Index 19.

Jsem absolvent fakulty technické a jaderné fyziky, (nyní fakulta jaderná a fyzikálně inženýrská), uznávaným odborníkem s dlouholetou mezinárodní praxí v oblasti nanostruktur.

V letech 1982-1994 jsem stál u zrodu a formování studia kvantových nanostruktur na prestižním zahraničním pracovišti (Hahn-Meitner-Institut) v Berlíně. V letech 1994-1996 jsem se věnoval výzkumu kvantových nanostruktur Si v Ústavu fyziky v Garchingu, TU Mnichov. Hostoval jsem (středně-dlouhodobé pobyty) na několika zahraničních universitách (USA, SSSR). Jsem člen několika zahrahraničních vědeckých společností (např. *New York Academy of Science* a *American Association for the Advancement of Science* - *AAAS*).

Mám několik vědeckých a odborných ocenění (např. několikrát cenu Akademie věd ČSAV, ocenění rektora Univerzity Saigon za sérii nanotechnologických přednášek v roce 2007).

V letech 1972-76 jsem byl zodpovědný za vybudování pracoviště lineárních urychlovačů elektronů v UJV-Řež. Jsem autorem *radiační technologie barvení skla* a autorem dalších *pěti* patentů (např. patentu na barevnou fasádu Nové scény Národního divadla – státní vyznamenání; architektura řešena architektem K. Prágrem).

O mé odborné úrovni svědčí více něž 130 publikovaných původních prací ve významných zahraničních časopisech s vysokým *impact faktorem.* Značný ohlas těchto prací dokládá i vysoký počet citací (více něž 1600). Nově zavedené hodnotící kriterium – tzv. *Hirsch Index* – se v mém případě pohybuje na úrovni 19. Jsem uváděn jako vůbec první badatel, který v ČR začal experimentálně studovat *nanostruktury.* V letech 1986-88 byla naše práce: Weller H., Fojtik A., Henglein A. : *Photochemistry of semiconductor colloids – Properties of extremely small particles of* Cd_3P_2 *and* Zn_3P*, Chem. Phys. Letters* **117** (5):1985, p.485 uvedena mezi *stovkou nejvíce citovaných prací* na světě (na 47 místě dle citačních analýz Current Contents, Vol.28, No.48, 1988, pp 3-13).

Získal jsem rovněž bohaté a dlouholeté zkušenosti s vedením vědeckých týmů. V minulosti jsem vytvořil pracovní tým a vedl oddělení chemické reaktivity a oddělení fotochemie na ČSAV.

V posledních několika letech se společně s vedoucím katedry fyzikální elektroniky FJFI ČVUT profesorem P. Fialou aktivně podílím na formování a výuce v oblasti fyziky nanostruktur a přednáším problematiku nanostruktur. Zavedl jsem nové přednášky: *částicové nanostruktury, nanochemii* a *nanofyziku*.

Na experimentální problematice nanostruktur pracuje pod mým vedením v současné době 10 studentů v rámci rešeršních úkolů, bakalářských, výzkumných, diplomových a doktoradských prací (*Experimentální studium Si kvantových struktur*; *Spektrální vlastnosti kvantových nanostruktur; Optický zisk v Si nanostrukturách; Kovové a polovodičové nanočástice* a další). V letošním roce bylo v oblasti manipulace a modelování nanostruktur publikováno 10 prací, kde jsem uveden jako autor nebo spoluautor. Podrobnosti viz. (www.nanolab.cz)

About 130 scientific papers with more than 1600 citations, Hirsch Index 19.
List of some selected scientific papers:
Name of the scientist: **A. Fojtik.** Period 2002 – 2007
Times cited

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ELECTROCHEMISTRY OF COLLOIDAL SILVER PARTICLES IN AQUEOUS-SOLUTION - DEPOSITION OF LEAD AND INDIUM AND ACCOMPANYING OPTICAL EFFECTS Author(s): HENGLEIN A, MULVANEY P, HOLZWARTH A, SOSEBEE TE, FOJTIK A Source: BERICHTE DER BUNSEN-GESELLSCHAFT-PHYSICAL CHEMISTRY CHEMICAL PHYSICS 96 (6): 754-759 JUN 1992	**16**
PHOTOCHEMISTRY OF COLLOIDAL SEMICONDUCTORS .30. REACTIONS AND FLUORESCENCE OF AgI AND AgI - Ag_2S COLLOIDS Author(s): HENGLEIN A, GUTIERREZ M, WELLER H, FOJTIK A, JIRKOVSKY J Source: BERICHTE DER BUNSEN-GESELLSCHAFT-PHYSICAL CHEMISTRY CHEMICAL PHYSICS 93 (5): 593-600 MAY 1989	**12**
PHOTO-CHEMISTRY OF COLLOIDAL METAL SULFIDES .8. PHOTO-PHYSICS OF EXTREMELY SMALL CdS PARTICLES - Q-STATE CdS AND MAGIC AGGLOMERATION NUMBERS Author(s): FOJTIK A, WELLER H, KOCH U, HENGLEIN A Source: BERICHTE DER BUNSEN-GESELLSCHAFT-PHYSICAL CHEMISTRY CHEMICAL PHYSICS 88 (10): 969-977 1984	**31**
PHOTOCHEMISTRY OF SEMICONDUCTOR COLLOIDS .17. STRONG LUMINESCING CdS AND CdS-Ag_2S PARTICLES Author(s): SPANHEL L, WELLER H, FOJTIK A, HENGLEIN A Source: BERICHTE DER BUNSEN-GESELLSCHAFT-PHYSICAL CHEMISTRY CHEMICAL PHYSICS 91 (2): 88-94 FEB 1987	**24**
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PHOTOCHEMISTRY OF SEMICONDUCTOR COLLOIDS .14. PHOTOCHEMISTRY OF COLLOIDAL SEMICONDUCTORS - ONSET OF LIGHT-ABSORPTION AS A FUNCTION OF SIZE OF EXTREMELY SMALL CdS PARTICLES Author(s): WELLER H, SCHMIDT HM, KOCH U, FOJTIK A, BARAL S, HENGLEIN A, KUNATH W,WEISS K, DIEMAN E Source: CHEMICAL PHYSICS LETTERS 124 (6): 557-560 MAR 14 1986	**42**
PHOTOCHEMISTRY OF SEMICONDUCTOR COLLOIDS .13. PREPARATION OF EXTREMELY SMALL ZnO PARTICLES, FLUORESCENCE PHENOMENA AND SIZE QUANTIZATION EFFECTS Author(s): KOCH U, FOJTIK A, WELLER H, HENGLEIN A Source: CHEMICAL PHYSICS LETTERS 122 (5): 507-510 DEC 20 1985	**92**
PHOTOCHEMISTRY AND RADIATION-CHEMISTRY OF COLLOIDAL SEMICONDUCTORS.12. INTERMEDIATES OF THE OXIDATION OF EXTREMELY SMALL PARTICLES OF CdS, ZnS, AND Cd_3P_2 AND SIZE QUANTIZATION EFFECTS (A PULSE-RADIOLYSIS STUDY) Author(s): BARAL S, FOJTIK A, WELLER H, HENGLEIN A Source: JOURNAL OF THE AMERICAN CHEMICAL SOCIETY 108 (3): 375-378 FEB 5 1986	**15**

Number of citations of these 10 selected papers for period 2002 – 2007 is 332

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