ISS Bukovel 2012

Surface Enhanced Spectroscopy for biomolecules and cells study

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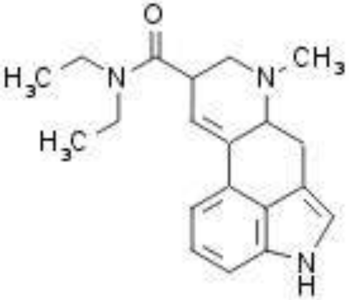
Suface Enhnced Spectroscopy

- 1)Surface Enhanced Infrared Absorption (SEIRA)
- Surface Enhanced Raman Scattering (SERS)
- Surface Enhanced Fluorescence (SEF)

Method SEIRA, SERS, SEF could be efficiently used:

- for determination of type of molecules and impurity in the probe of extremely small amount
- for analysis of conformation forms of biological macromolecules and their interactions
- for enhanced and contrast imaging of cells in vivo and in vitro

The Bio-Medical Market



Chemistry

(plant protective agent; antibiotics)

Pharmacy

Diagnostics

Nutrition

Health Care

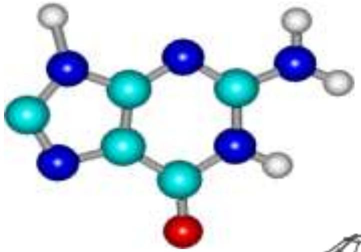
Medication

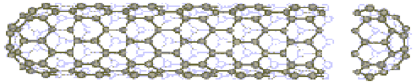
Biomedical Research

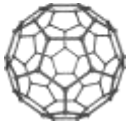
Earning on human health...

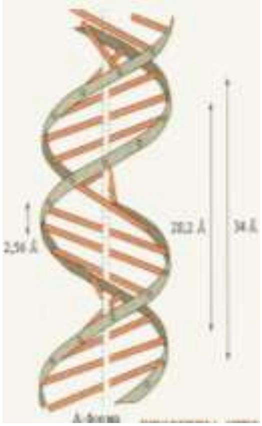
Molecules and cells under study

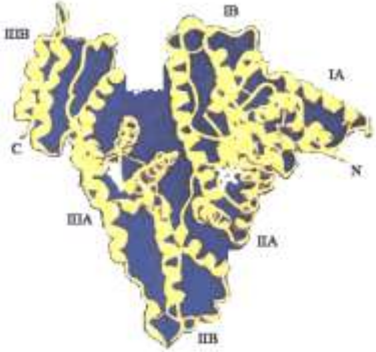
- ***Aminoacids, basis, proteins, nucleic acids, phospholipids, dr***
- ***carbon nanotubes, graphene, metal oxides, etc.***

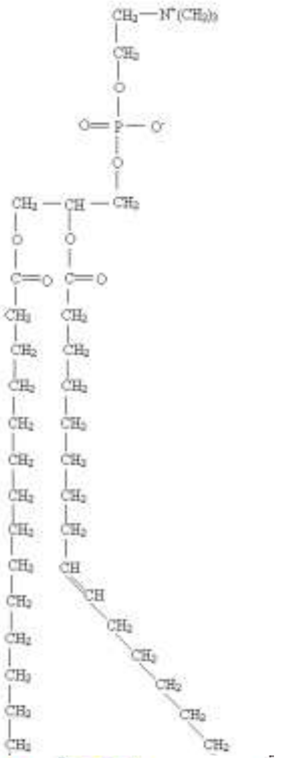


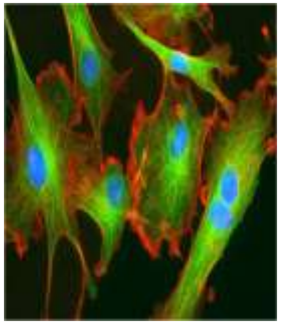




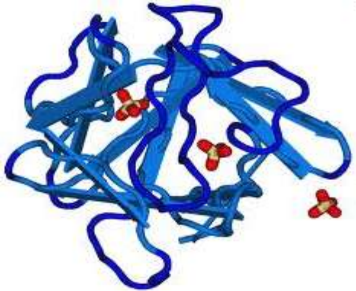




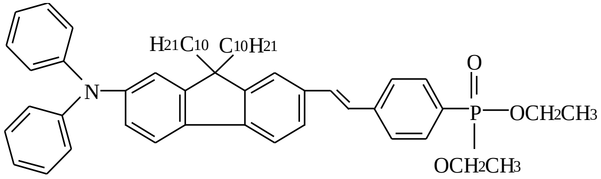


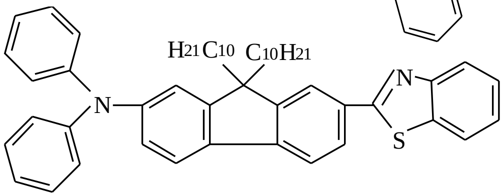


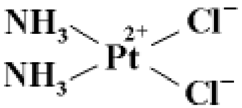
fibroblasts

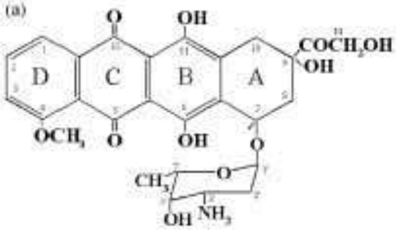


Plazma rich in grows factors (PRGF)



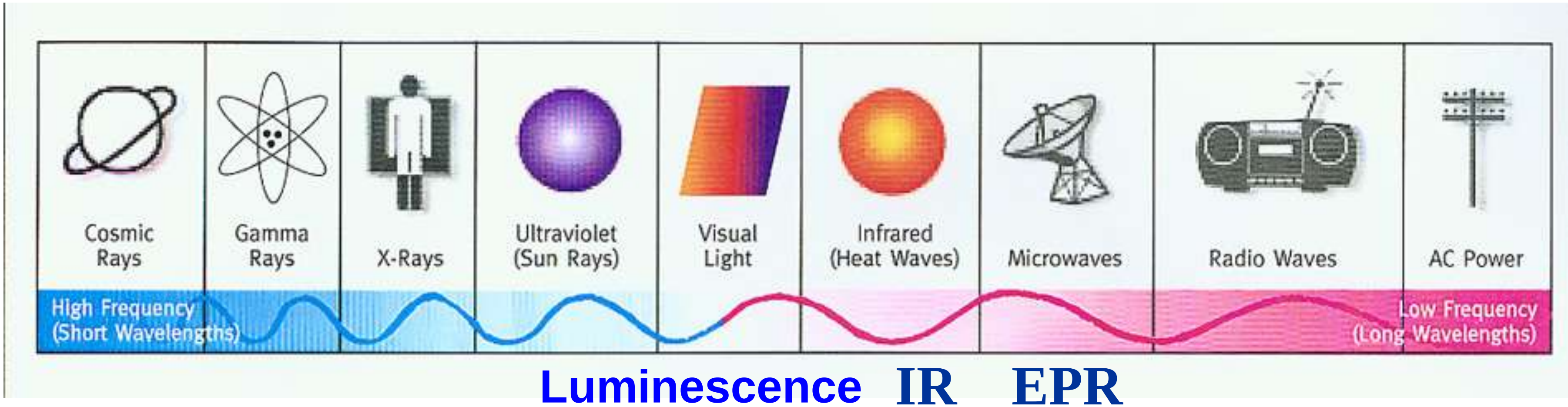






Introduction in spectroscopy

frequency ranges of electromagnetic waves

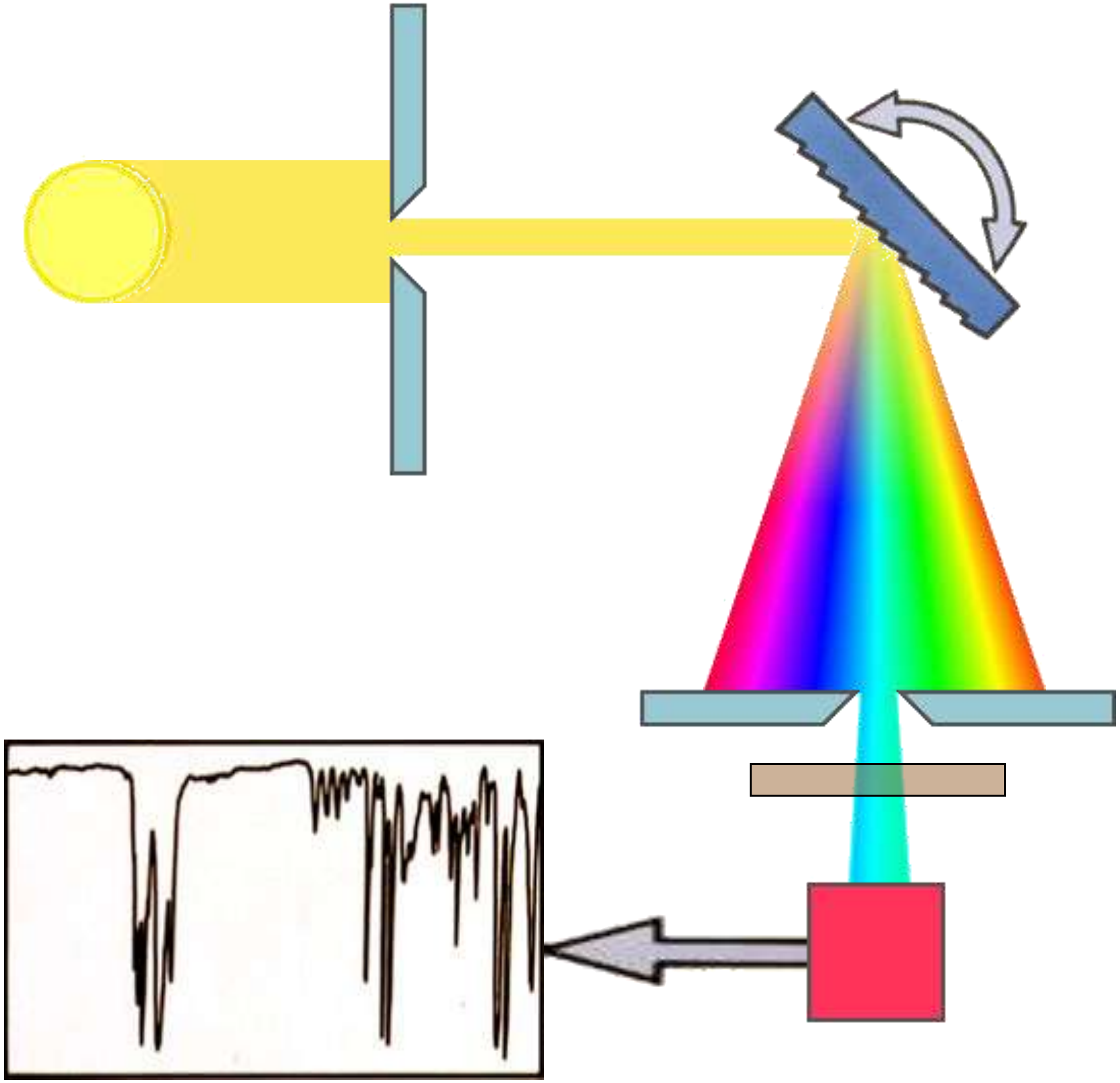


Luminescence **IR** **EPR**

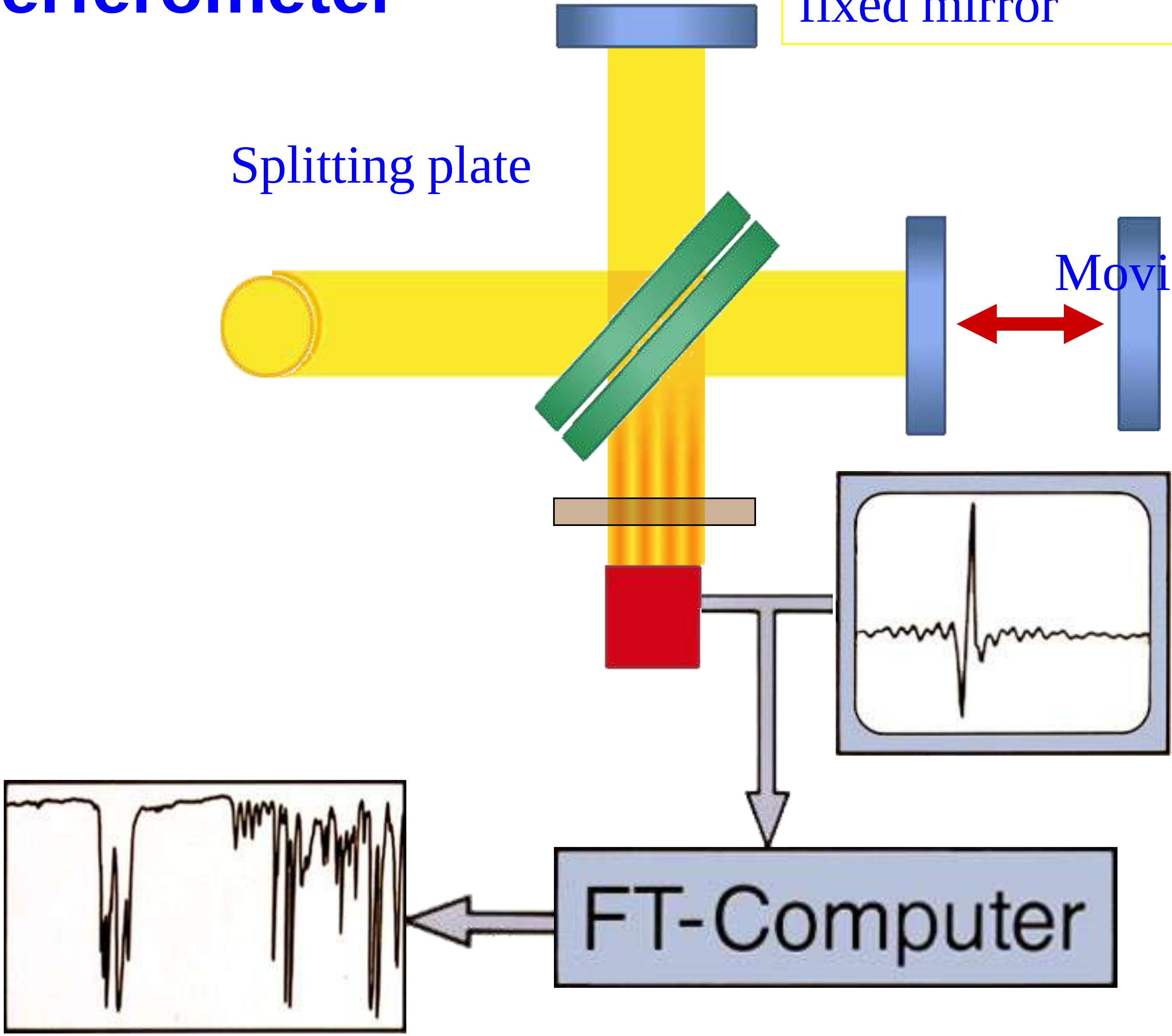
NMR

Raman

Dispersive spectrometer (monochromator)



Interferometer



fixed mirror

Splitting plate

Moving mirror

FT-Computer

History of the Surface Enhanced Spectroscopy (Surface Enhanced Infra Red Absorption-SEIRA)

- **1980 p. –** The first registration of SEIRA effect by Harstain (*Harstain A., Kirtley J., Tsang J. // Phys Rev Lett. – Vol.45. – 1980. – P.201-209*).
- **1983 p. –** Theoretical explanation the surface enhanced optical signals and physical process near rough metal surface ,(Kosobukin V.A.. // *Surface: physics, chemistry, mechanics. – Vol. 12.- 1983.-P.5-20).*
- **1991 p. –** The effect was named as SEIRA by Osawa and Ikeda *(M. Osawa, M. Ikeda // J. Phys. Chem.- Vol. 95.-1991. -P. 9914-9919).*
- **2001 p. – the first our department publication on application of the SEIRA for study of DNA from tumor cells** *(G.I..Dovbeshko, O.P.Gnatyuk, V.I.Chegel,Yu.M.Shirshov, // Biophysical bulletin.- Vol.528, №2(9).-2001. - C.93-99).*
- **2003** – Ataka K., Heberle J. Electrochemically induced surface-enhanced infrared difference absorption (SEIDA) spectroscopy of protein monolayer// J Am Chem Soc. 125.
- **2005 p.** *–review on SEIRA by Ricardo Aroca and Concha Domingo with 5 citations of our publications* **.** *(R. Aroca, C. Domingo. Surface-enhanced Infrared Spectroscopy // Focal point. – Vol.58. – 2005.-P.324-338).*

History of the Surface Enhanced Spectroscopy

(SERS- Surface Enhanced Raman Scattering)

1. Fleischmann, M.; PJ Hendra and AJ McQuillan (15 May 1974). "Raman Spectra of Pyridine Adsorbed at a Silver Electrode". *Chemical Physics Letters* **26** (2): 163–166.
2. Jeanmaire, David L.; Richard P. van Duyne (1977). "Surface Raman Electrochemistry Part I. Heterocyclic, Aromatic and Aliphatic Amines Adsorbed on the Anodized Silver Electrode". *Journal of Electroanalytical Chemistry* **84**: 1–20.
3. ***Emelyanov V.I. Koroteev N.I. Effect of giant Raman Scattering by molecules adsorbed at the metal surface*** // Uspehi fizycheskih nauk. – 1981. – V.135, №2. – P.345-361.
4. ***Cheng P., Furtaka T. Giant Raman Scattering*** M.: Mir, 1984. – 408p.
5. ***Kneipp K., Kneipp H., Itzkan I., Dasari R., Feil M.*** Surface-enhanced Raman scattering and biophysics // J. Phys.: Condensed Matter. – 2002. – Vol.14. – P.R597-R624.
6. *Galina Dovbeshko, Olena Fesenko, Konstyantyn Yakovkin, Sirena Bertrione, Alessandro Damin, Domenica Scarano, Adriano Zecchina and Elena Obraztsova* **The poly-A interaction and interfaces with carbon nanotubes.** // Molecular Crystals Liquid Crystals. – 2008. – Vol 496, №345331. – pp. 170-185.

History of the Surface Enhanced Spectroscopy (Surface Enhanced Fluorescence - SEF)

- Lakowicz J.R., Shen B., Gryczynski Z., D'Auria S, Gryczynski I. Intrinsic fluorescence from DNA can be enhanced by metallic particles, Biochemical and Biophysical Research Communications. 286 (2001) 875-879
- G. Dovbeshko, O. Goncharuk, O. Pavlovich, O. Fesenko, O. Gnatiuk, V. Gorchev, S.Karachin, New strategy to study of embryonic cells on the basis of effect of plasmonic enhancement, Nanobiophysics: fundamental and applied aspects" 5-8 October, 2009, Kharkov, Ukraine. P.91.
- G.I. Dovbeshko, O.M.Fesenko, V.V. Boyko, V.F. Gorchev, S.O. Karakhin, N.Ya. Gridina, V.S. Gorelik, V.N. Moiseenko, Novel photoluminescence enhancing substrates for image formation of biological objects, Ukr.Phys.Zurn,v.57,N.7, 2012, 732-738

The theoretical basis of the effect of IR enhancement

The theoretical interpretation of the effect is connected with enhancement of external electric field due to excitation of local plasmon vibrations at essential curvature of rough surface or on metal particles. In such systems, according to Kosobukin, the electric field in the point of space *r* could be presented as :

$$\boldsymbol{E(r,t) = \exp(-i\omega t)[E0(\omega) + E1(r,\omega)]},$$ where $\boldsymbol{\omega}$ - frequency, $\boldsymbol{t}$ - time. **(1)**

The additional term $\boldsymbol{E_1(r,\omega)}$ is connected with excitation of local (surface) plasmon vibrations. The enhancement of the external field can be presented as:

$$\boldsymbol{E_\alpha(r,\omega) = g_{\alpha\beta}(r,\omega) E_{0\beta}(\omega)}\ , \ \mathbf{(2)}$$

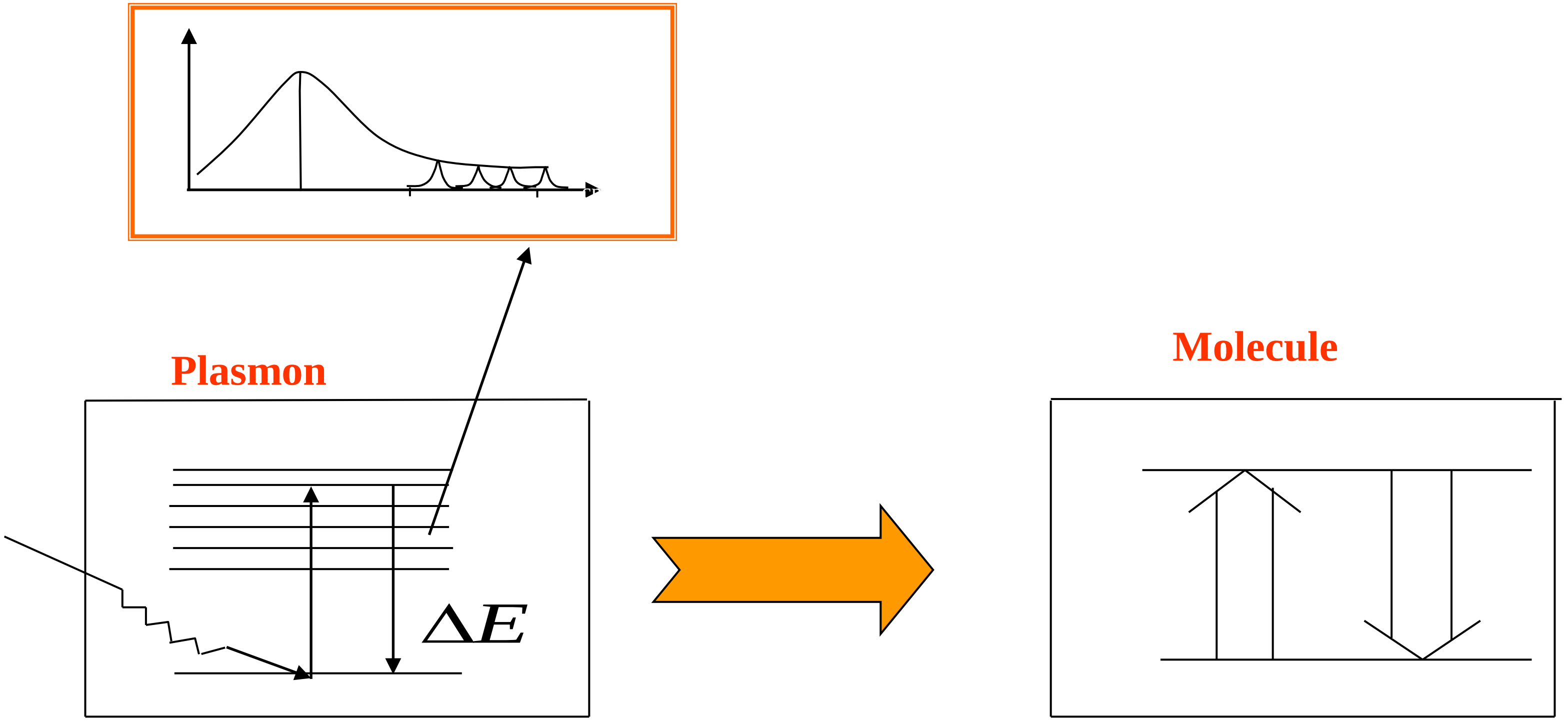
where $g_{\alpha\beta}(\mathbf{r},\omega))$ is coefficient of the enhancement.

The effective cross-section of the process of light interaction with a molecule adsorbed on metal surface could be expressed as:

$$\boldsymbol{\sigma_\alpha(r,\omega) = \quad |<f|H(r,\omega)|i>|^2 \delta[h(\omega-\omega_{fi})] \sim \sigma_\alpha(0)|g(r,\omega)|^2|h(r)|^2},$$

where $\sigma_\alpha(0)$ - cross-section in the absence of metal $\boldsymbol{(d = d_0, E = E_0)}$; $\boldsymbol{i \to f}$ – optical transition from $\boldsymbol{i}$ (with the energy ε_i) to $\boldsymbol{f}$ state; $\boldsymbol{cE_0^2/8\pi}$ - density of an incident energy flux, $\boldsymbol{c}$ – light velocity; $\boldsymbol{<f/H(r,\omega)/i>}$ - matrix elements of Hamiltonian of molecule interaction with a field; $\boldsymbol{h(r)}$ – enhancement coefficient of dipole moment of adsorbed molecule.

SEIRA mechanism



- The explanation of the effect includes several mechanisms :
- i)the increase of the electromagnetic field near rough metal surface or island metal films,
- ii)the increase of the dipole transition moment of the adsorbed molecules, etc.

Dovbeshko G.I., Fesenko O.M., Chegel V.I., Shirshov Y.M. "Enhancement of optical transition near rough metal surface", Semiconductor physics, quantum electronics and optoelectronics, v.7, №4, 2004, p.215-225).

SEIRA enhancement factor

The effective cross-section of the process of light interaction with a molecule adsorbed on metal surface could be expressed:

$$\sigma_\alpha(r,\omega) = |\langle f|H(r,\omega)|i\rangle|^2 \delta[h(\omega-\omega_{fi})] \sim \sigma_\alpha(0)\ |g(r,\omega)|^2 |h(r)|^2$$

$\sigma_\alpha(0)$ – cross-section for free molecule ($E = E_0$);
$g(r,\omega)$ –coefficient of the enhancement for electric field; $h(r)$ – coefficient of the enhancement for dipole moment of adsorbed molecule

- Calculated enhancement factor:

$$g_{роз} = \varepsilon_м'(\omega)/\varepsilon_м''(\omega)$$

- Experimental enhancement factor:

$$g_{екс} = I_м(\omega)/I_{CaF_2}(\omega)$$

Factor of enhancement in surface enhanced spectroscopy

- Surface enhanced infrared absorption (SEIRA)(g=10-500)
- Surface enhanced Raman spectroscopy (SERS) (g=10-1000000)
- Metal enhanced fluorescence (MEF) (g=10-100)
- Optical imaging with better contrast and resolution

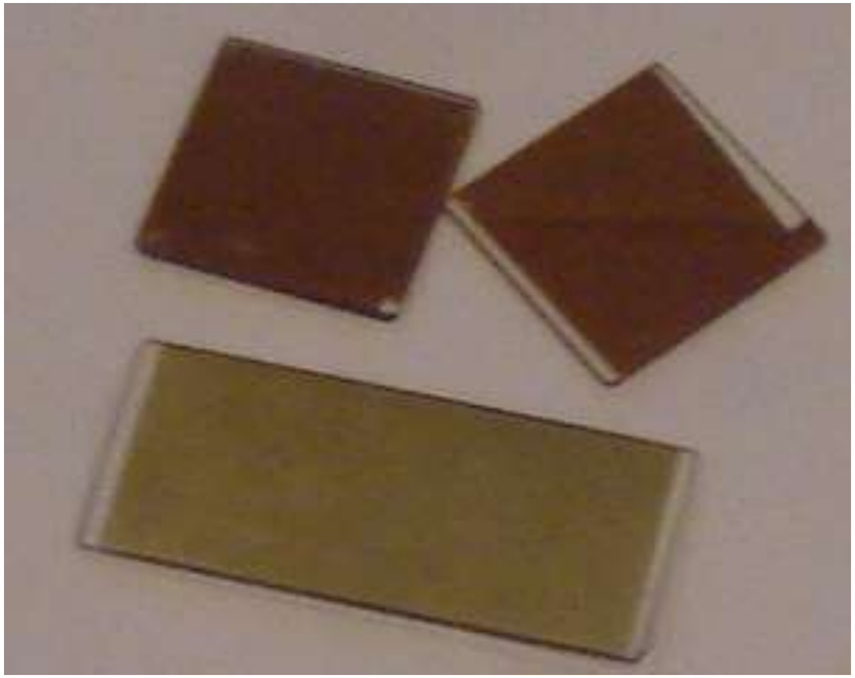
Factors which influences the enhancement in SEIRA effect

Type and morphology of metal or dielectric substrate, position of plasmon or phonon resonances

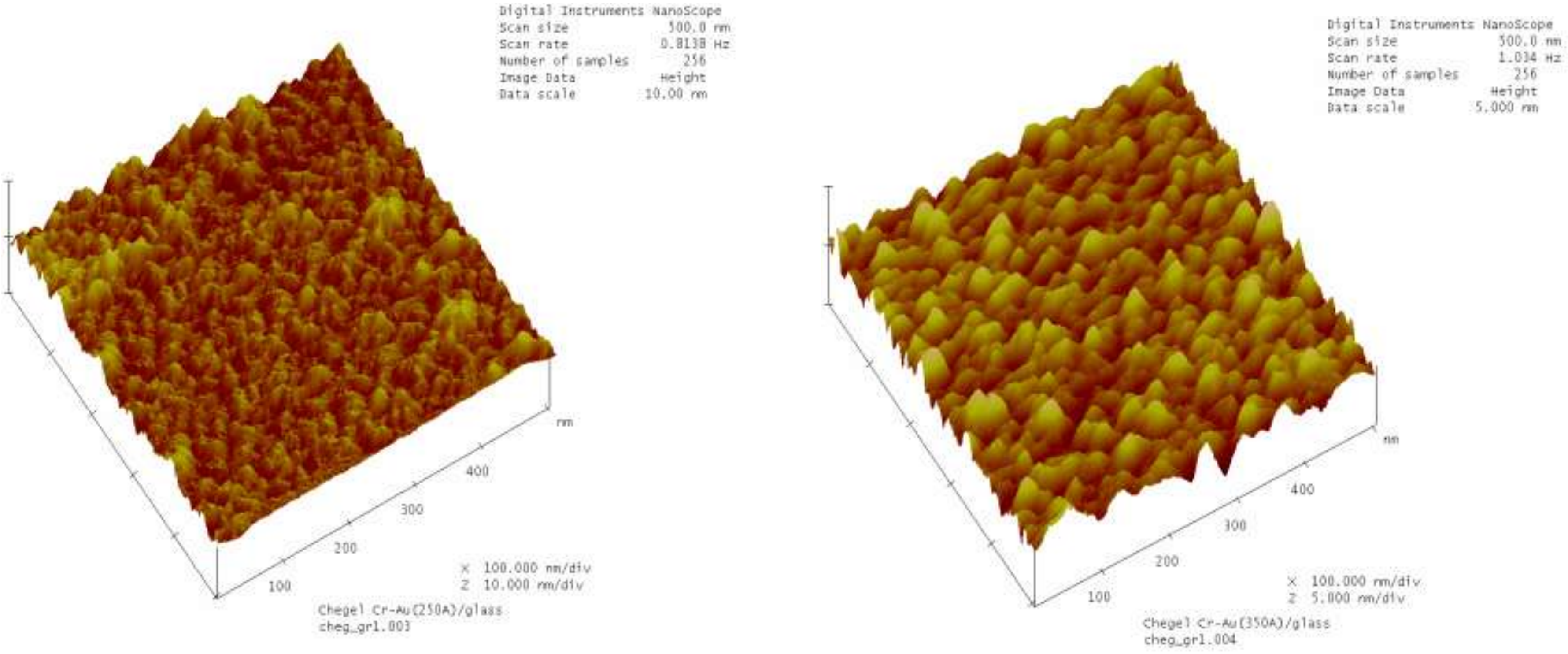
Geometry of the experiment

Type of interaction between molecules and substrates, composition of the adsorbed molecules

Images of gold home-made SEIRA substrates

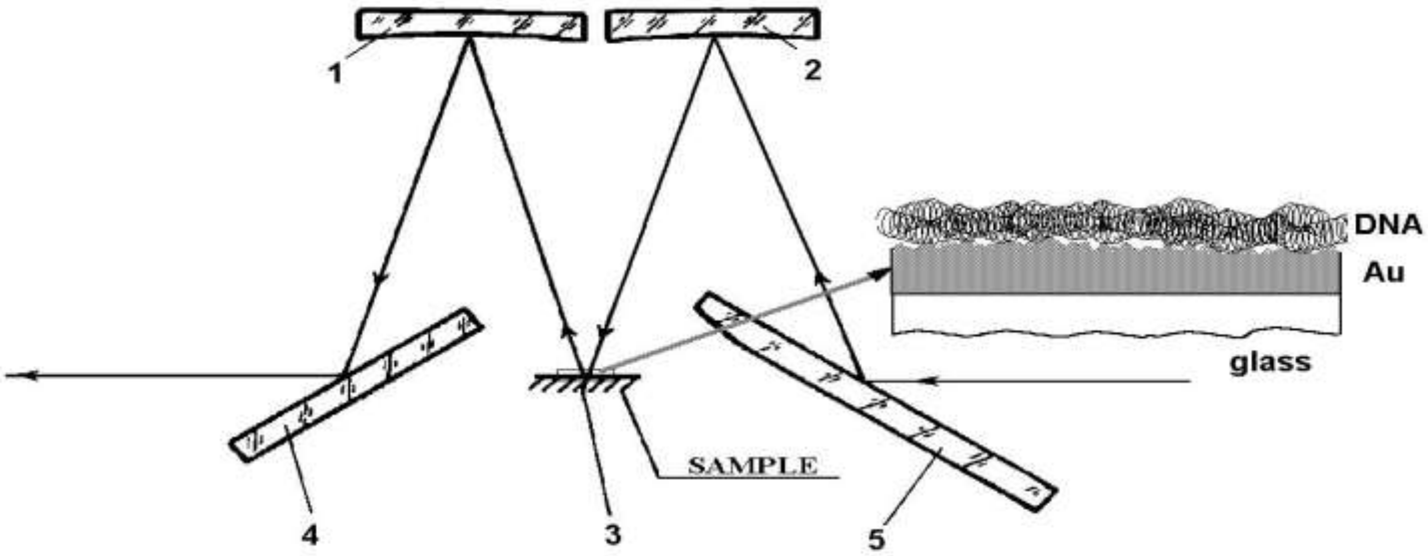


AFM - images of gold surface of home-made SEIRA substrates



AFM images of gold films with 250 (a) and 350 Å (b) thickness and 30 A roughness on SiO2 substrate

Enhancement of optical signal of molecules on rough metal surface



Geometry of experiment

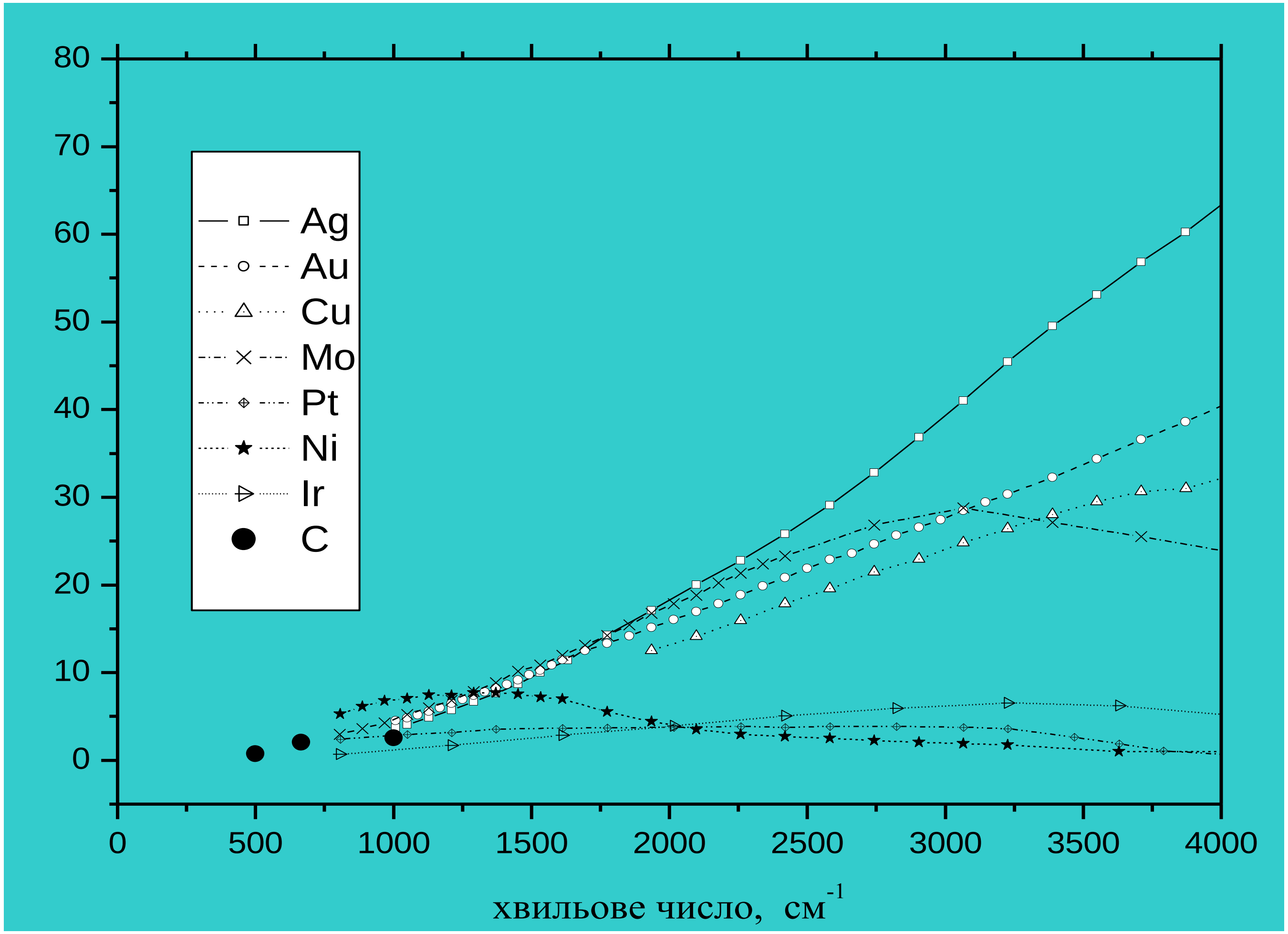
G.I. Dovbeshko, V.I. Chegel, N.Y. Gridina, O.P. Repnytska, Y.M. Shirsh
Tryndiak, I.M. Todor, G.I. Solyanik, Surface enhanced infrared absorpti
nucleic acids from tumour cells: an FTIR reflectance study, Biospectro

The advantages of the SEIRA in reflectance mode

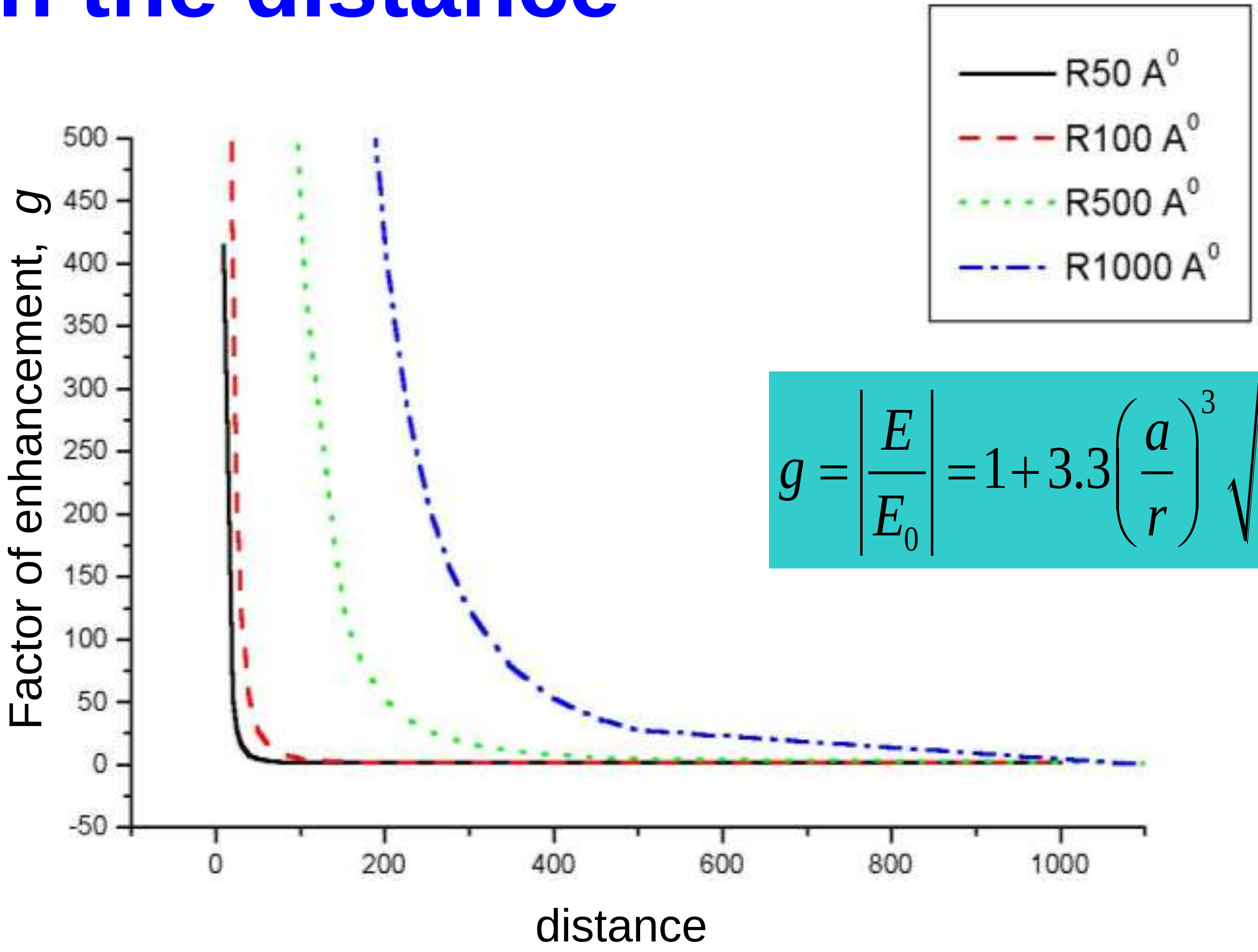
- We used home-made rough Au metal substrates produced by thermal vacuum evaporation Au onto glass supports. Numerous experiments on SEIRA of p-NBA in transmittance and ATR modes were reported in the literature, and one of the distinctive features of the present work is the fact that we used a reflectance mode with an incident beam of 16.5° close to normal to the surface. This angle, which must be less than 20°, was chosen to forbid the beam to enter the glass support, thus enhancing the possibility and sensitivity of registering SEIRA effects (the same holds also for the surface-enhanced Raman spectroscopy experiments).
- Another point is the use of home-made rough gold substrates which give possibility to register larger number of the bands in comparison with other SEIRA experiments due to surface morphology.

Jaroslaw J. Panek, Aneta Jezierska, Aleksander Koll, ***Galina Dovbeshko, Olena Fesenko,*** *p-Nitrobenzoic acid adsorption on nanostructured Au surface investigated by combined experimental and computational approaches, ChemPhysChem // 12, p.1 – 12.*

Dependence of enhancement factor on the type of metal



Dependence of enhancement factor on the distance



$$g = \left|\frac{E}{E_0}\right| = 1 + 3.3\left(\frac{a}{r}\right)^3 \sqrt{\frac{\varepsilon'^2 - 2\varepsilon' + 1 + 2\varepsilon''}{\varepsilon'^2 - 4\varepsilon' + 4 + \varepsilon''^2}}$$

The advantages of the SEIRA

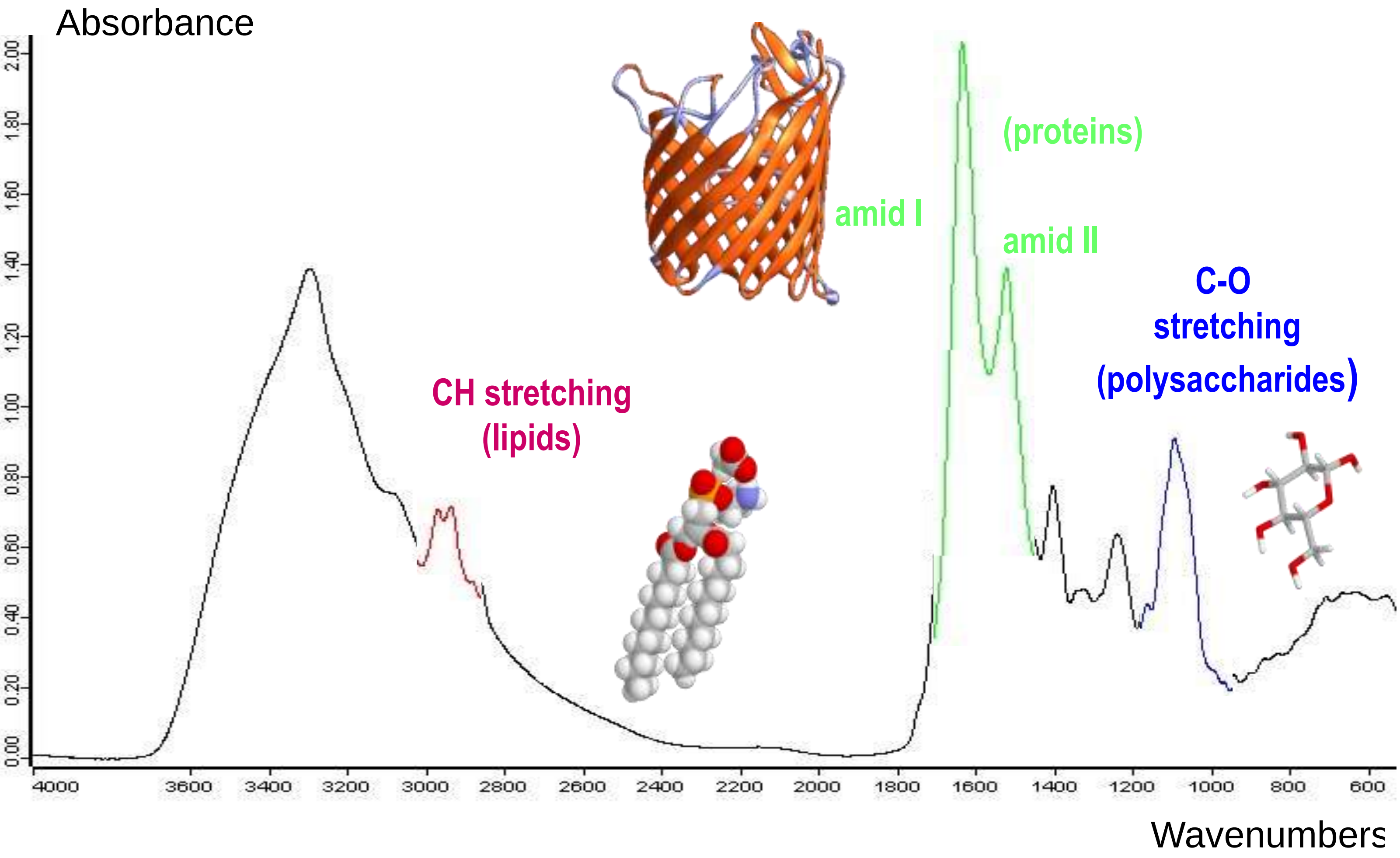
- Enhancement of absorption by 3-200 times
- The reflected light is preferentially polarised in the plane of incidence due to geometry of experiment and thin film
- It is possible to determine molecular orientation in oriented samples.

$$I \sim \left| \frac{d\vec{\mu}}{dQ} \right|^2 \cdot \left| \vec{E} \right|^2 \cos^2 \alpha$$

Selected publications on spectroscopy of biological polymers

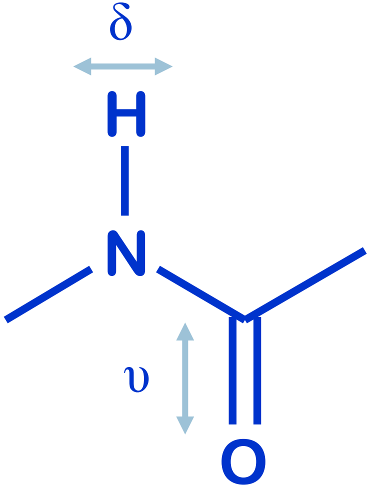
- The SEIRA spectroscopy data of nucleic acids and phospholipids from sensitive- and drug-resistant rat tumours / Chekhun V. F., Solyanik G. I., Kulik G.I., Tryndiak V.P., Todor I.N., ***Dovbeshko G.I.***, Repnytska O.P. // Journal of Experimental Clinical Cancer Research. – 2002. – Vol.21, №4. – P.599-607.
- DNA interaction with single-walled carbon nanotubes: a SEIRA study / ***Dovbeshko G.I.***, Repnytska O.P., Obraztsova E.D., Shtogun Y.V. // Chemical Physics Letters. – 2003. – Vol. 372. – P.432 – 437.
- Structural organisation of nucleic acids from tumour cells / Repnytska O.P., ***Dovbeshko G.I.,*** Tryndiak V.P., Todor I.M. and Kosenkov D.V. // Faraday Discuss. – 2004. – Vol.126. – P.61 – 76.
- G. Dovbeshko, O. Fesenko, K. Yakovkin, S. Bertrione, A. Damin, D. Scarano, A. Zecchina, E. Obraztsova. The poly-A interaction and interfaces with carbon nanotubes. // *Molecular Crystals Liquid Crystals.* – 2008. – Vol 496, №345331. – pp. 170-185.
- G. Dovbeshko, O. Fesenko, O. Gnatyk, Ya. Shtogun, L. Woods, S. Bertarione, A. Damin, D. Scarano, A. Zecchina. Nucleic acid interaction and interfaces with single-walled carbon nanotubes. In Book “Carbon Nanotubes” / Edited by Jose M/Marulanda, 2010, In-Teh. P. 697-720.
- H.Arakawa, G.Dovbeshko S.Diamantoglou, Heidar-Ali Tajmir Riahi. Oxovanadium Ions Bind Transfer RNA at Multiple Sites,DNA and cell biology. – Vol. 29, №8, 2010.

The main absorption bands of proteins, DNA, lipids and characteristic frequencies of different molecular groups

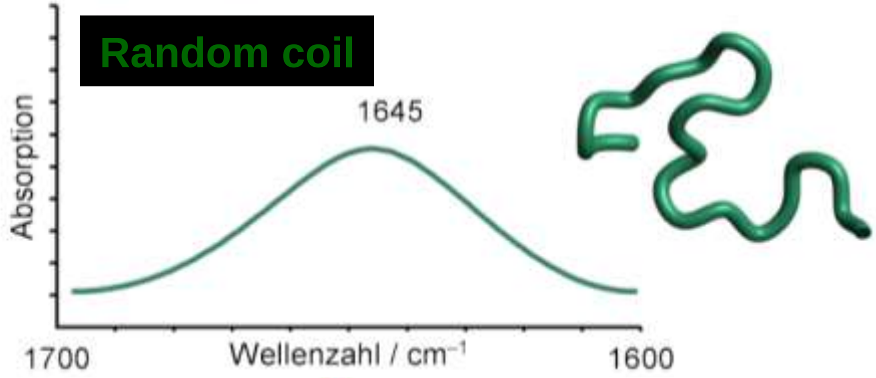


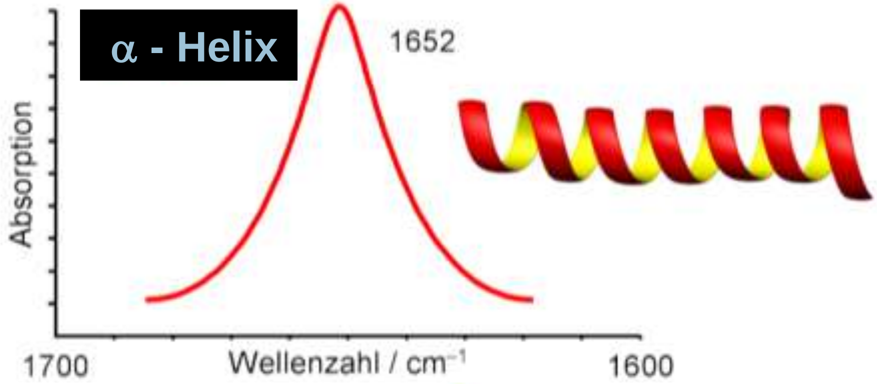
Secondary Structure Determination in proteins

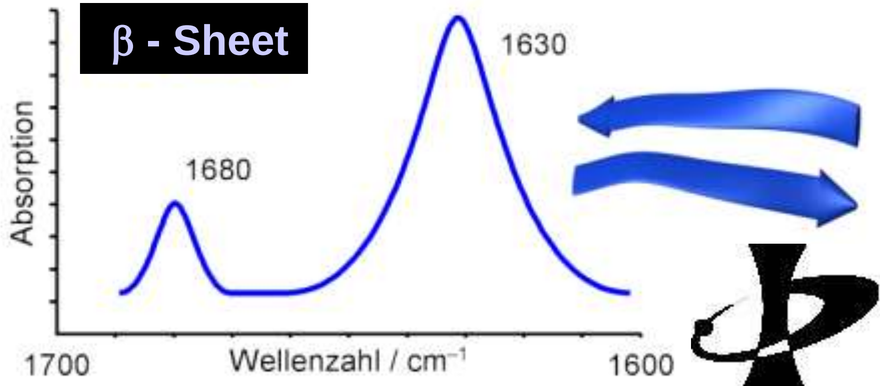
- Amid I :
- C=O Stretching vibration



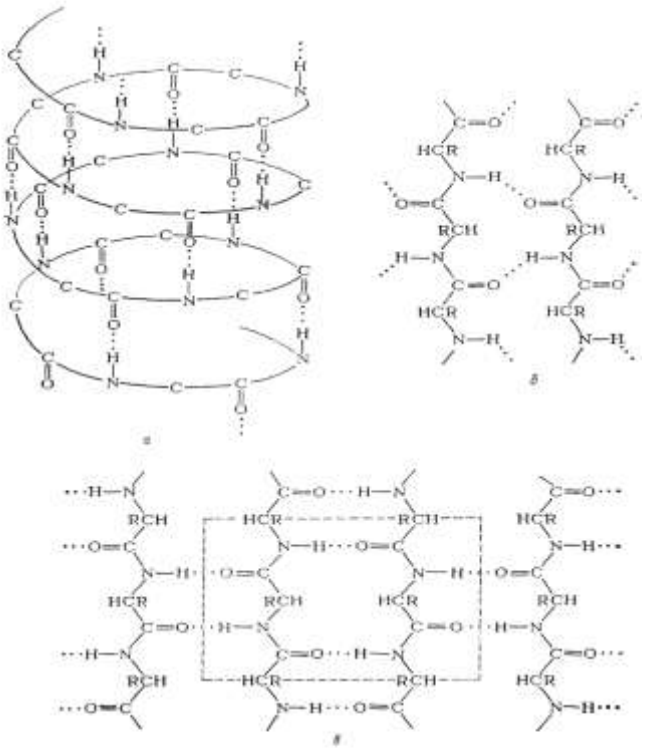
- Amid I - band reveals secondary structure-information







Conformation analysis of proteins

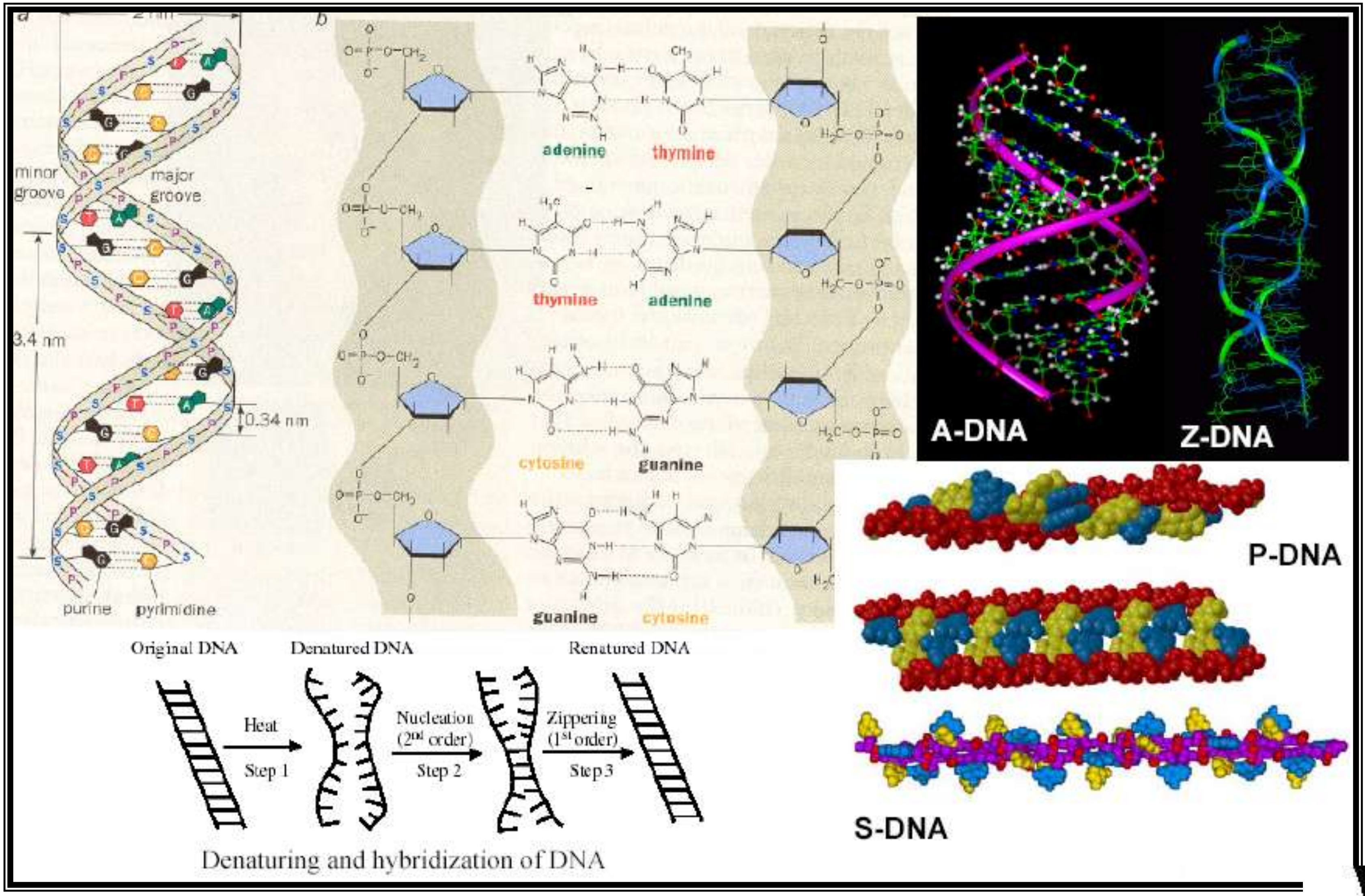


Conformation of polypeptides chain:
(a) - α-helix; (b) - parallel β-form;
(c) - antyparallel β-form.

Secondary structure	Amid I, cm^{-1}	
	Mean value	Maximum
α-helix	1654	1648-1657
β-form	1633	1623-1641
	1684	1674-1695
Turns	1672	1664-1686
Disorder structure	1654	1642-1657

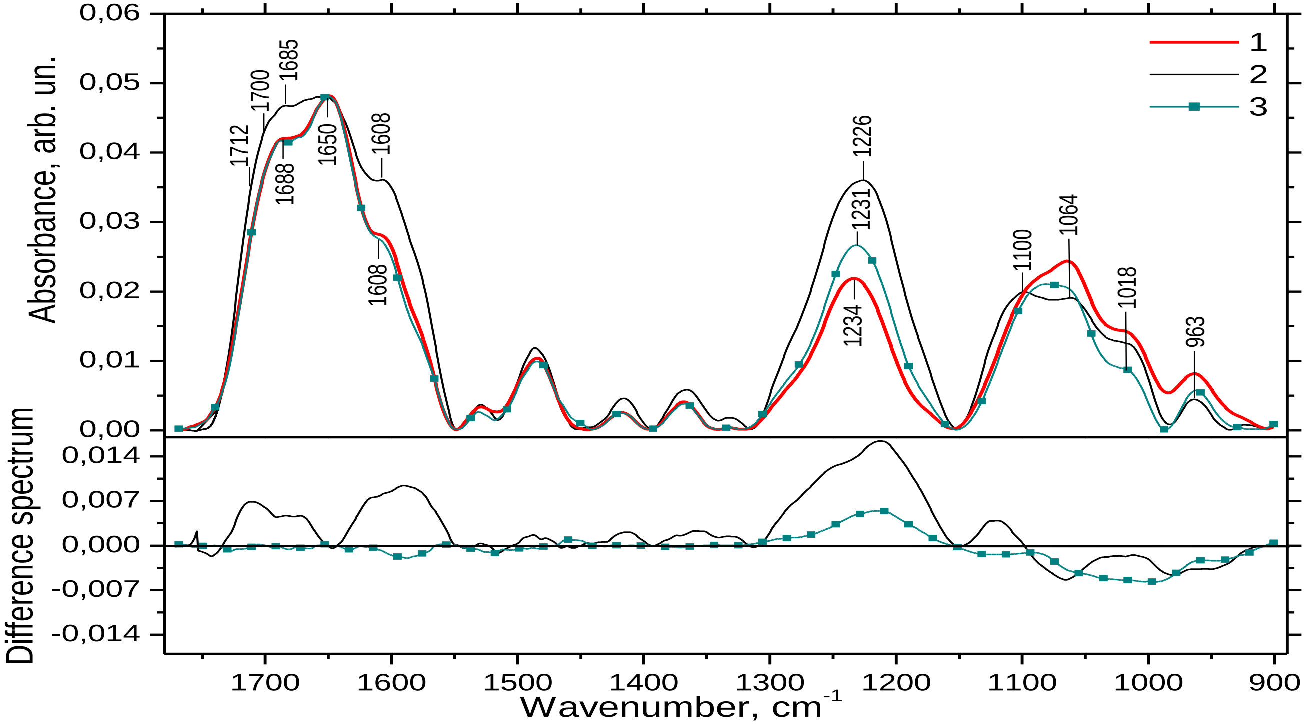
1. Сузи Г. ИК спектры биологических молекул и модельных соединений // Структура и стабильность биологических макромолекул / Сузи Г.; под ред. М. В. Волькенштейна. – М.: Мир, 1973. – С. 487–537.
2. Goormaghtigh E. Determination of soluble and membrane protein structure by Fourier transform infrared spectroscopy / Goormaghtigh E., Cabiaux V., Ruysschaert J.-M. // Subcell. Biochem. – 1994. – Vol. 23. – P. 405–450.

Different DNA conformations and their structure



Denaturing and hybridization of DNA

DNA interaction with carbon nanotubes probed by SEIRA



G.I. Dovbeshko, O.P. Repnytska, E.D. Obraztsova, Y.V. Shtogun. DNA interaction with single-walled carbon nanotubes: a SEIRA study. Chemical Physics Letters 2003; 372: 432-437

Carbon nanotubes enhance the vibration modes of sugars

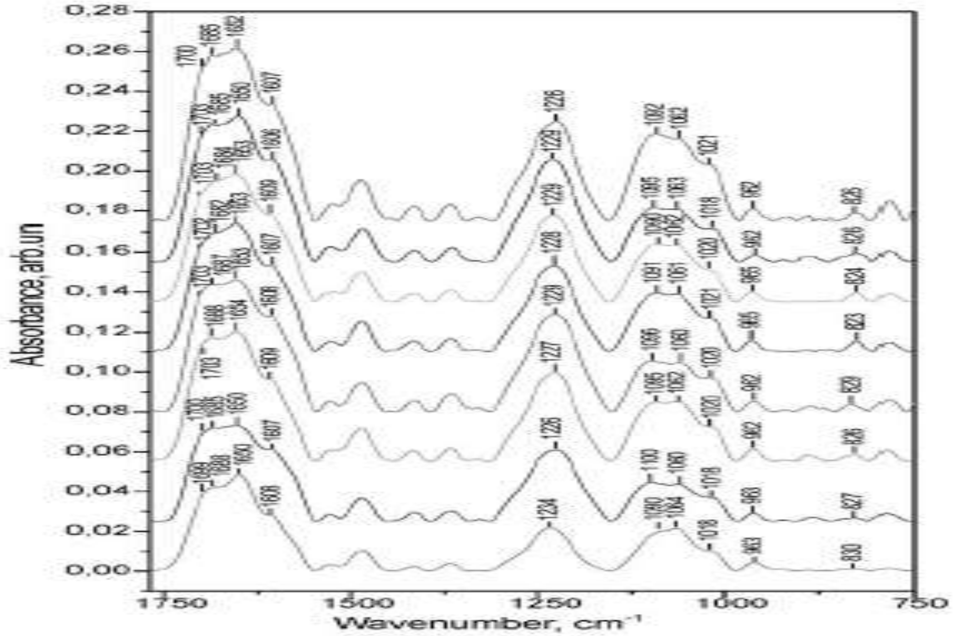
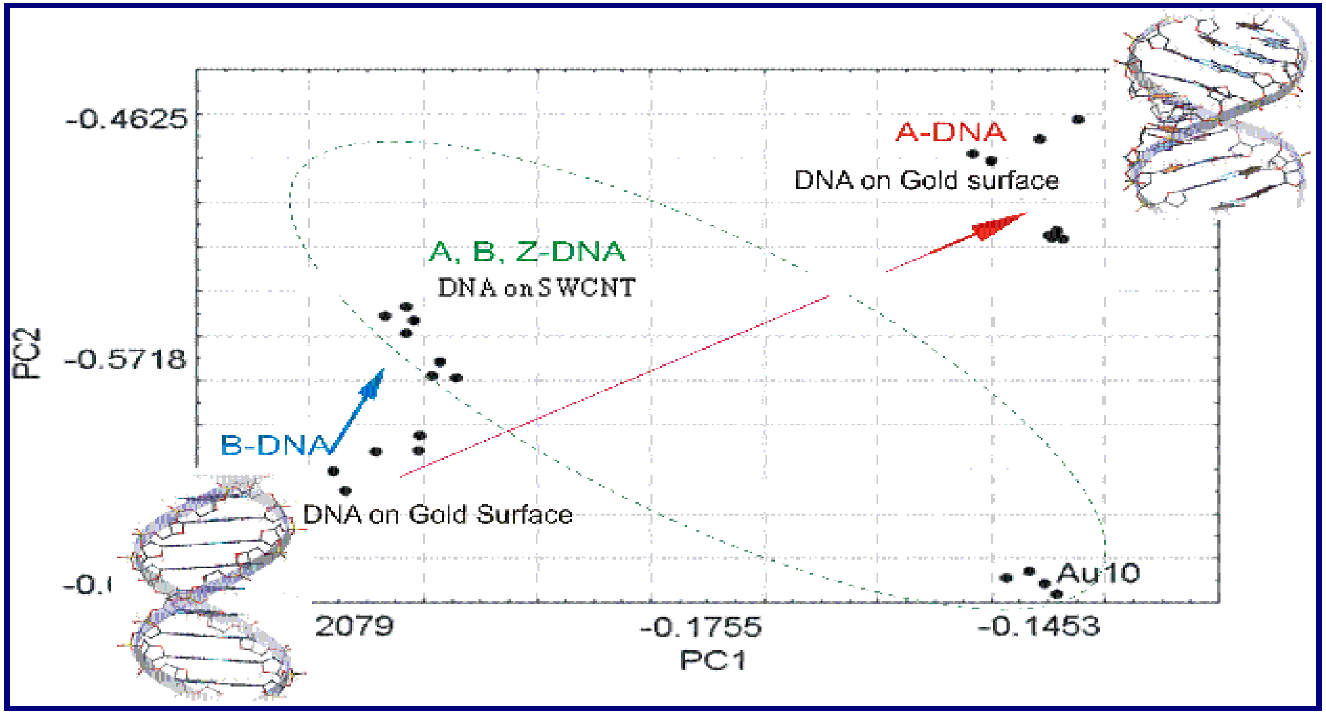


Fig. 2. SEIRA spectra of different parts of the DNA-SWCNT sample in comparison with the reference denaturated DNA (bottom spectra).

g=4-8

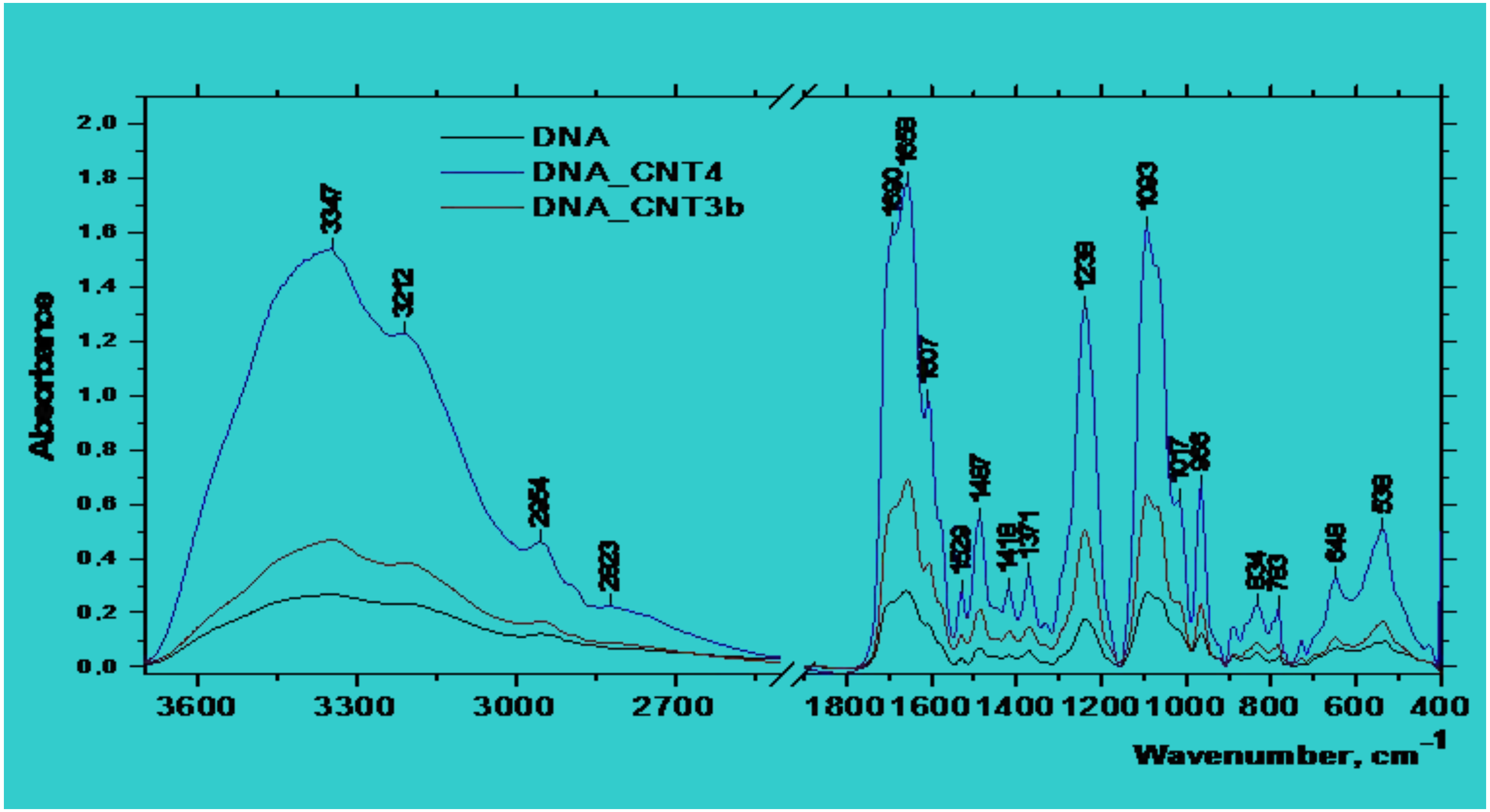
G.I. Dovbeshko, O.P. Repnytska, E.D. Obraztsova, Y.V. Shtogun. DNA interaction with single-walled carbon nanotubes: a SEIRA study Chemical Physics Letters 2003; 372: 432-437

Principal component analysis for determination DNA conformation



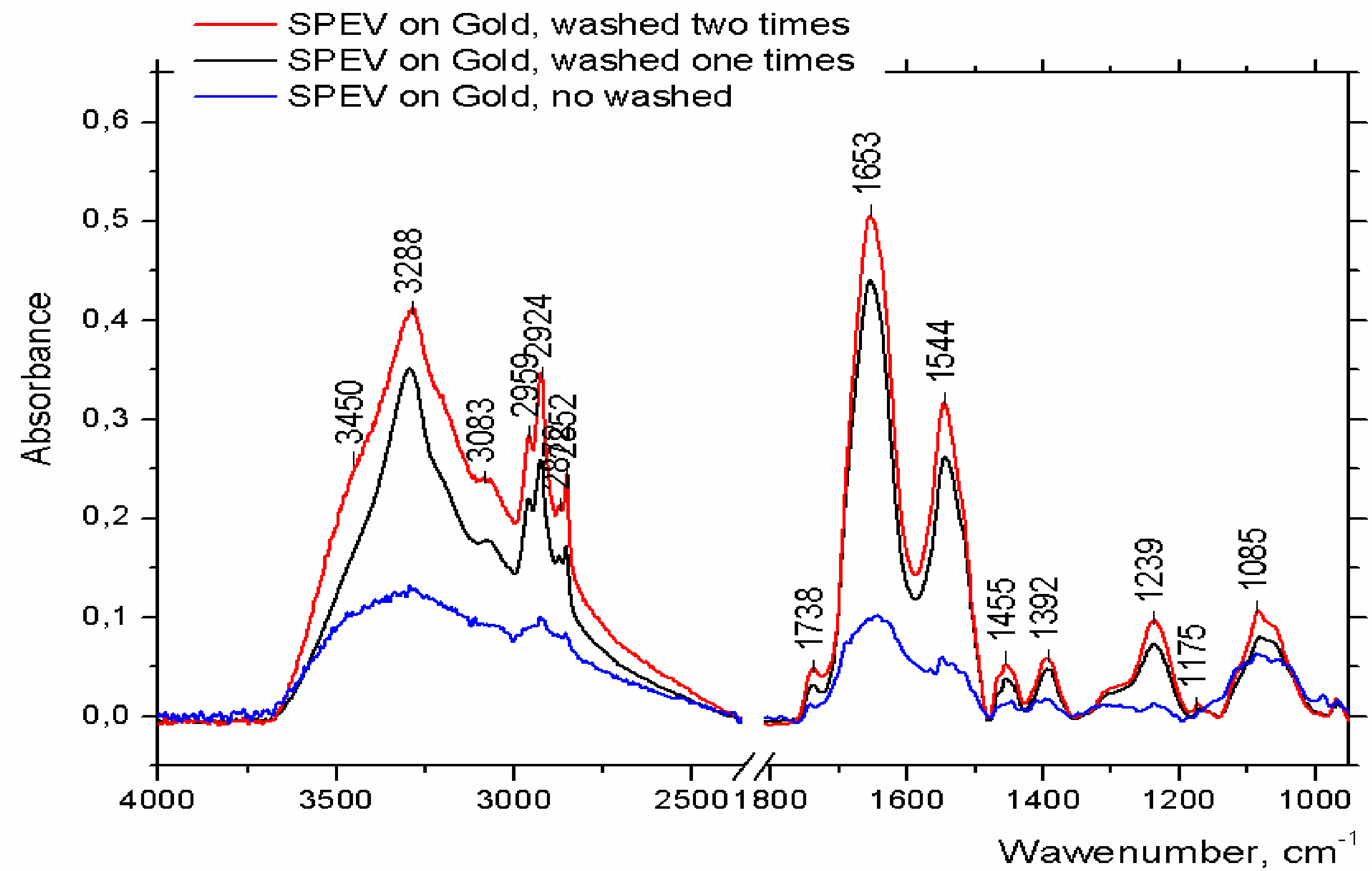
Principal component analysis of free DNA in A and B forms; A and B DNA on gold and DNA with SWCNT on gold, each SEIRA spectr presented by 1 point at the PC plane

FTIR spectra of free film consisting from DNA adsorbed on the carbon nanotubes



g=8-10

SEIRA spectra of SPEV cells

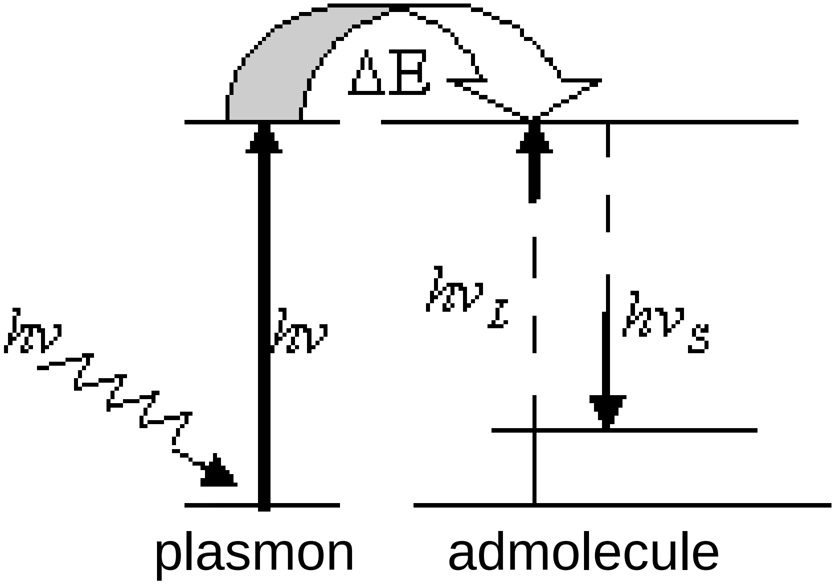


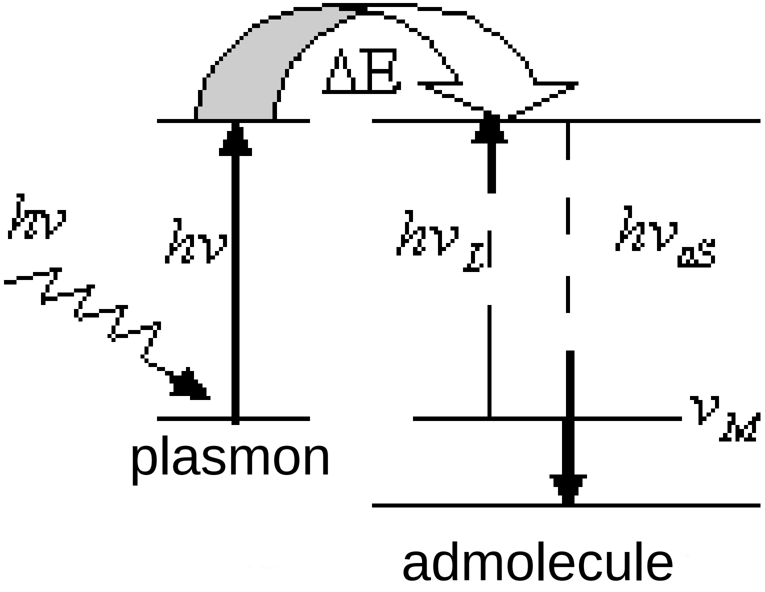
In the process of cell deposition from the suspension on the gold support, the cells did not cover the substrate by monolayer, as usually they form thick layer. In this case the spectrum from the thick layer is not good due to IR saturation for separated bands. As it was seen on top curve, the more intensive spectra are registered after double washing. In last case the cells are placed separately one from another and it was confirmed by confocal microscopy.

g=6-30

SERS method

Schematic diagrams of SERS





Probing Molecules with Photonic Crystals:SERS and SEIRA

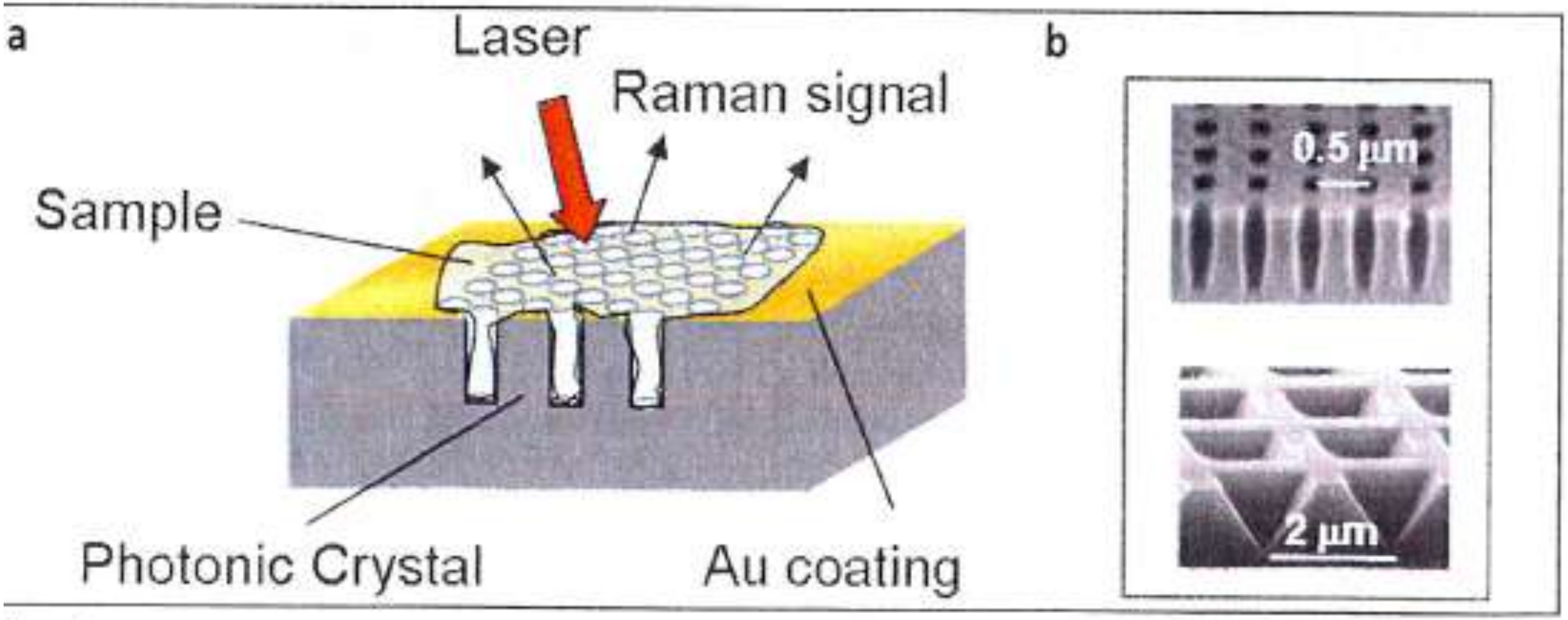


Figure 1:

(a) Schematic of a gold-coated photonic crystal SERS substrate. (b) SEM images of two photonic crystals with different voids shapes and dimensions.

Caterina Netti, John R.Lincoln,Microscopy and Analysis,19 (6):17-19 (EU),2005

Old CD-disks could be used as SEIRA and SERS substrate

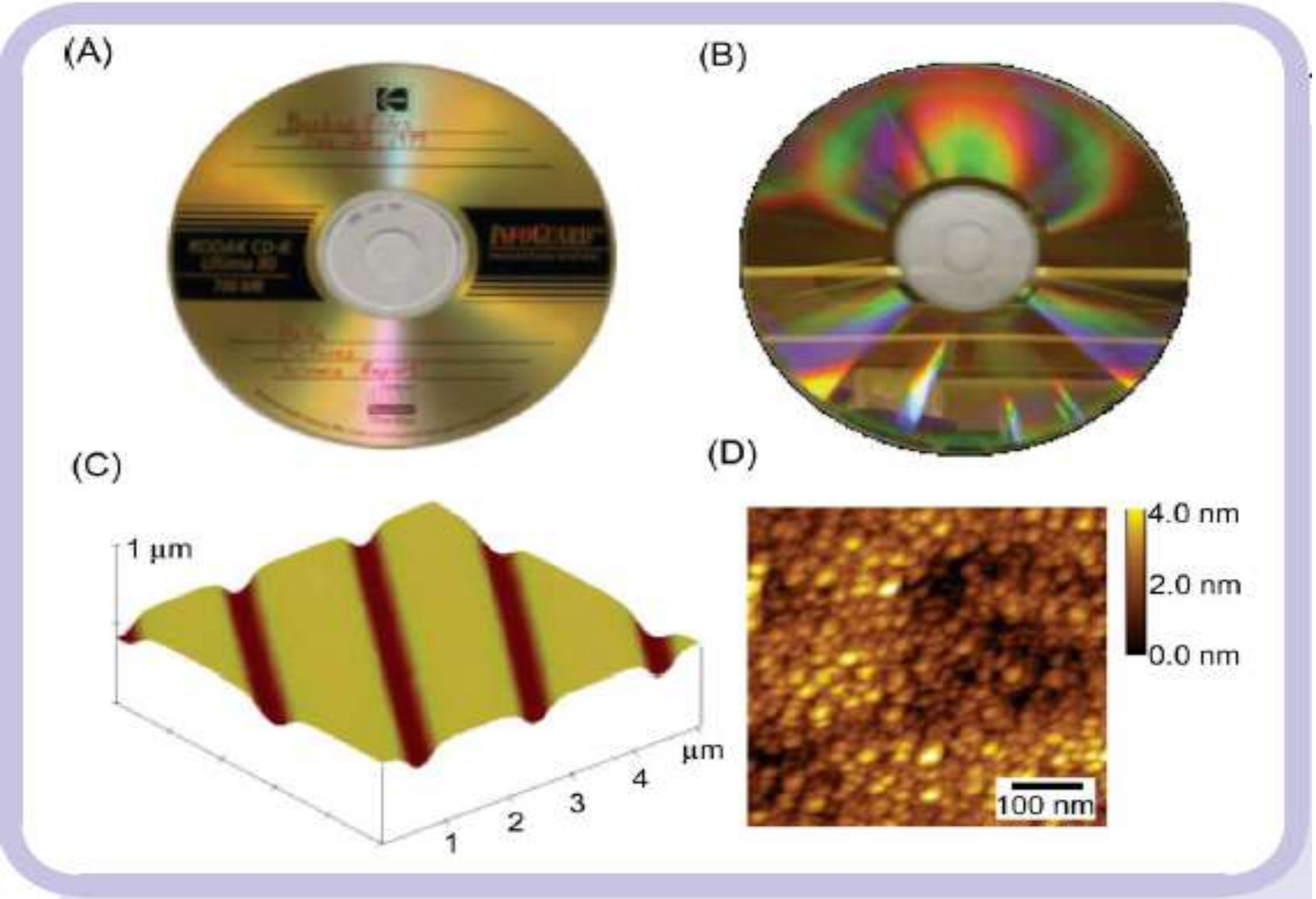
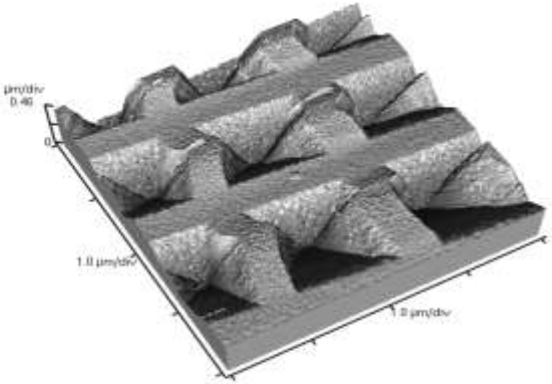
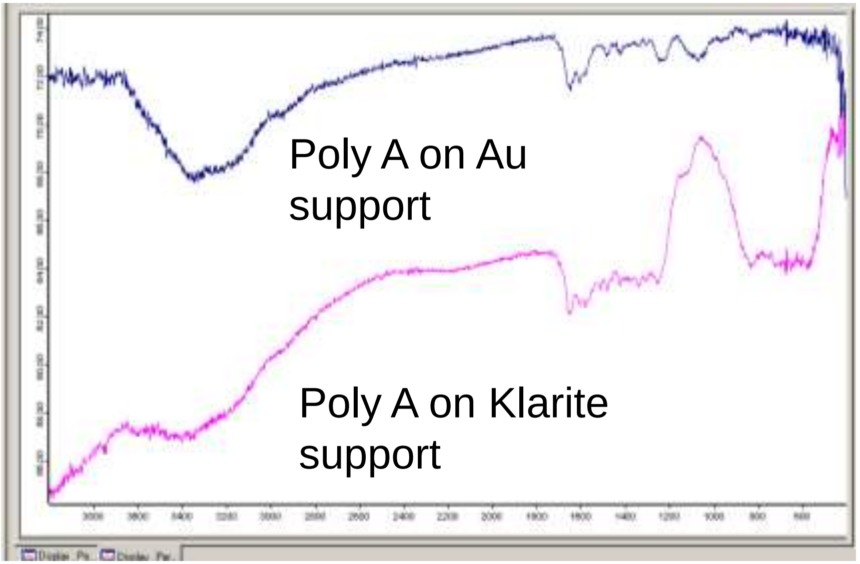


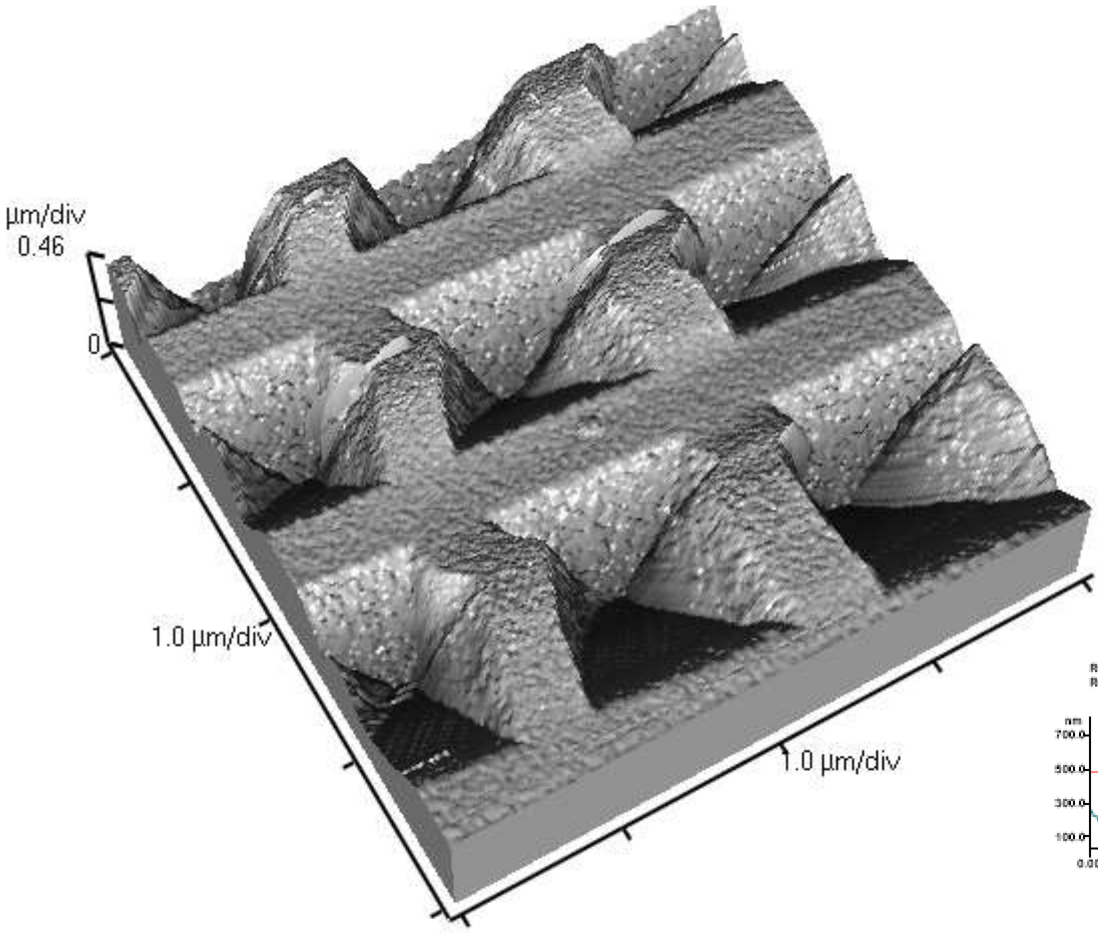
Fig. 3 Photos of CD-Rs before (A) and after (B) removal of the polymer layer, and atomic force microscope (AFM) images of the CD-R gold substrates ($5 \times 5\ \mu m^2$, C, and $500 \times 500\ nm^2$, D).

Klarite Surface Enhanced Raman substrates could be used for SEIRA

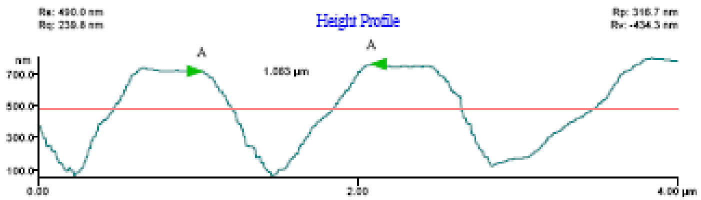




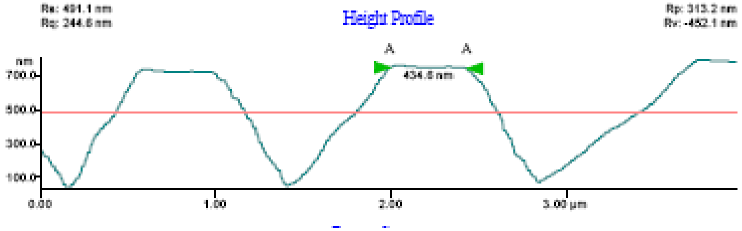
Klarite support



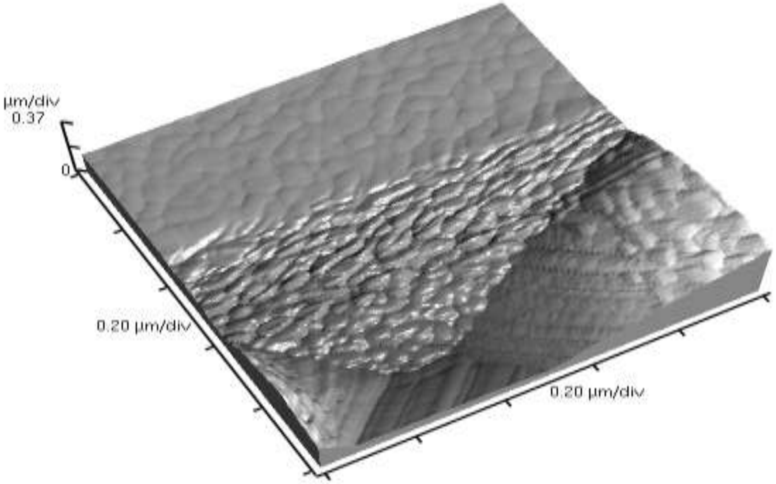
d = 1,040 µm

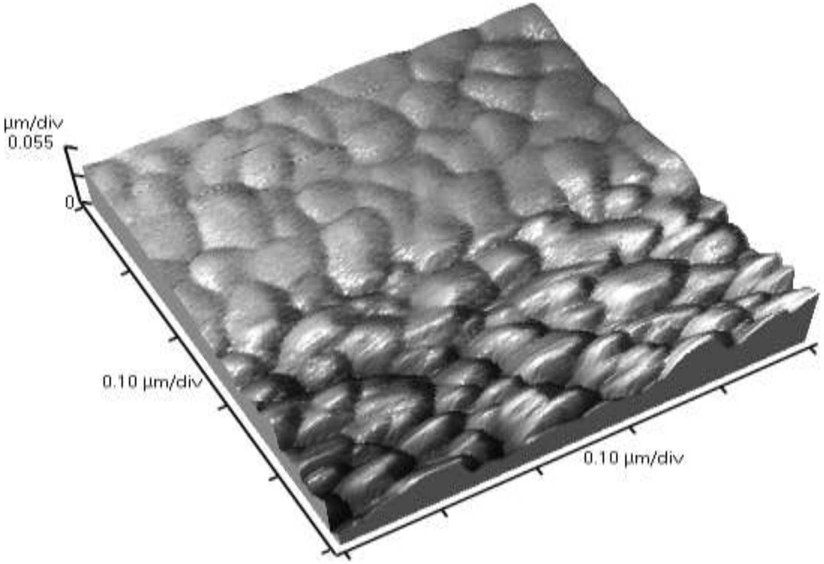


d = 434,6 nm

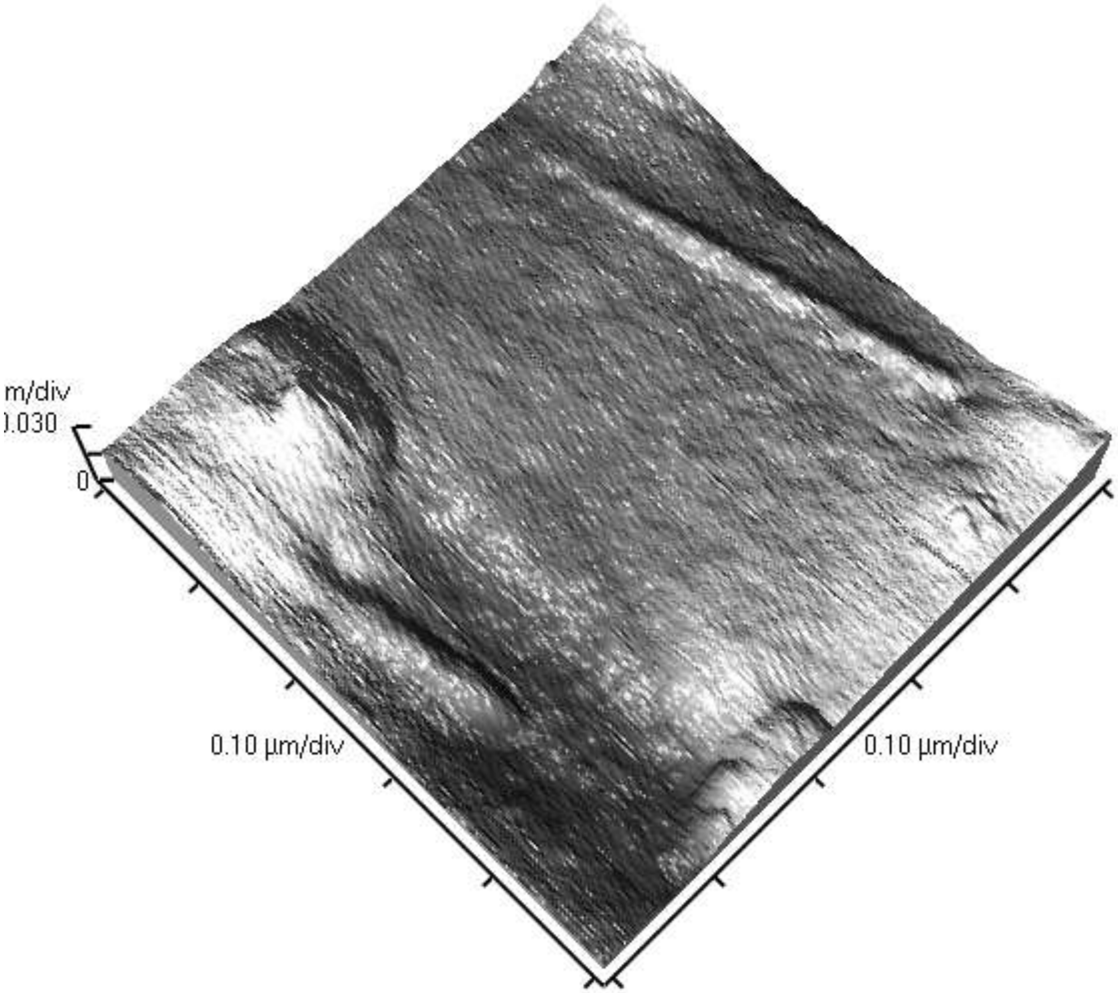


Substructure of Klarite substrate

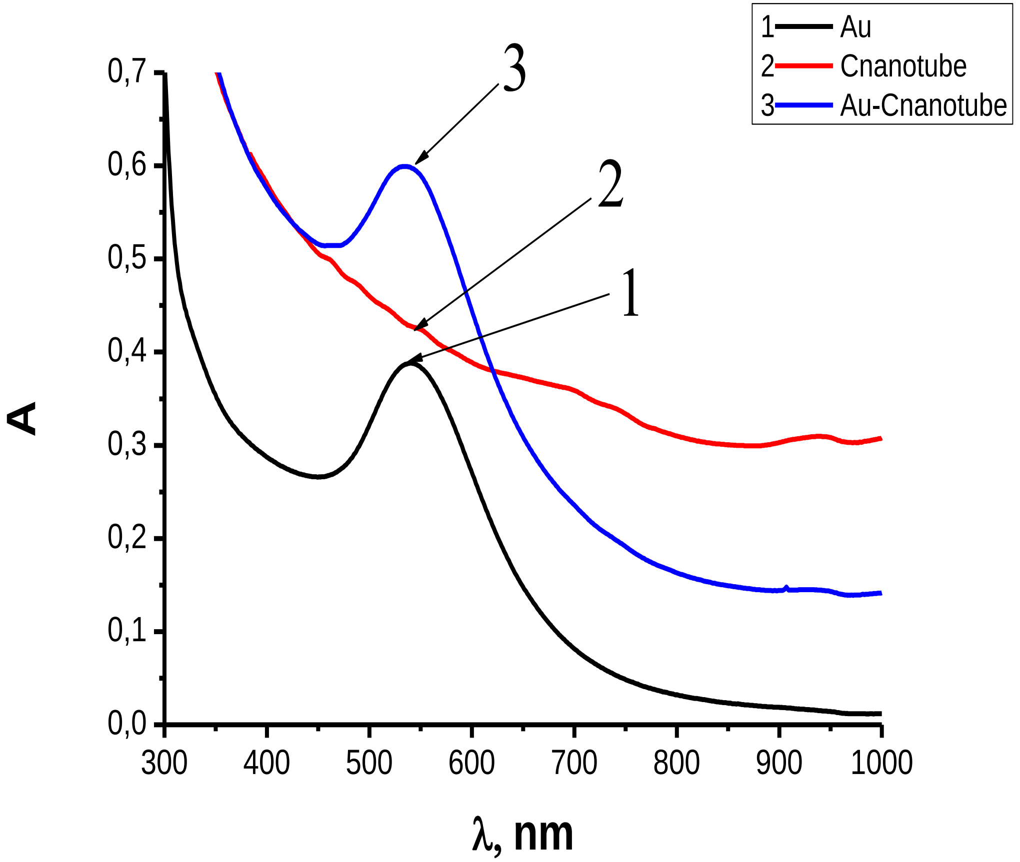




CM-AFM images of PolyA/SWCNT on Klarite

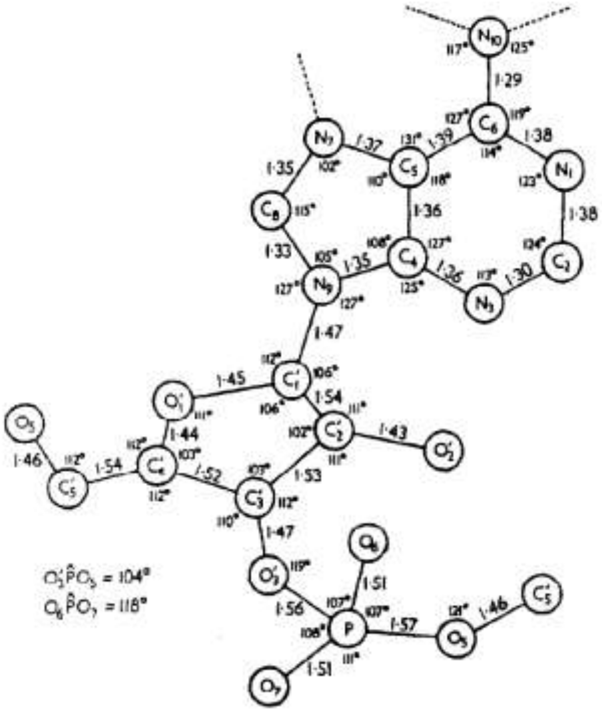


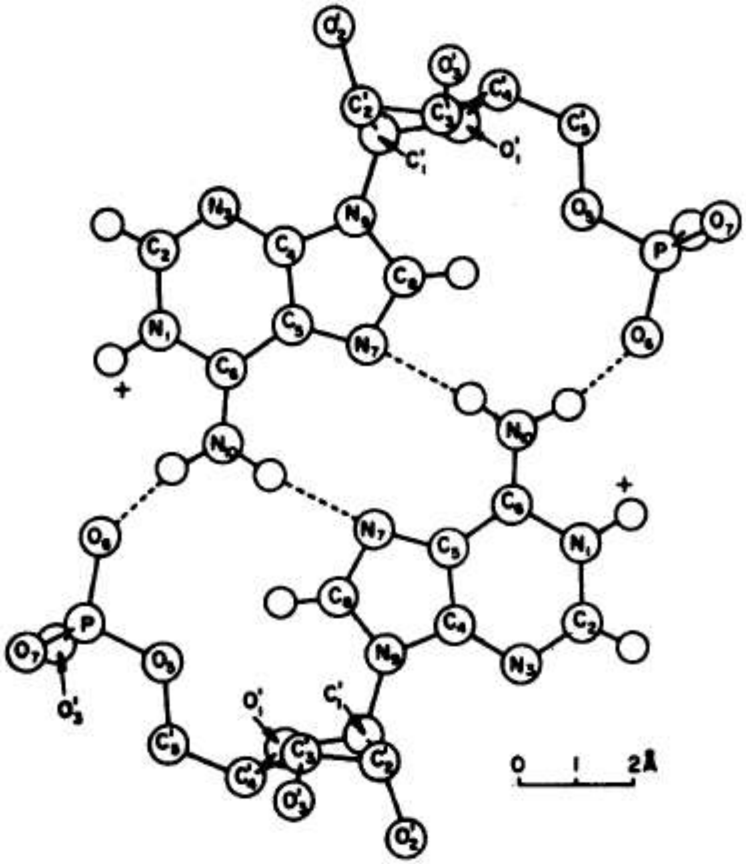
Plasmon vibrations in Au and Au-SWCNT



Poly-A enhanced by single walled carbon nanorubes

Single strand of Poly A (left) and double strand of Poly A (right)

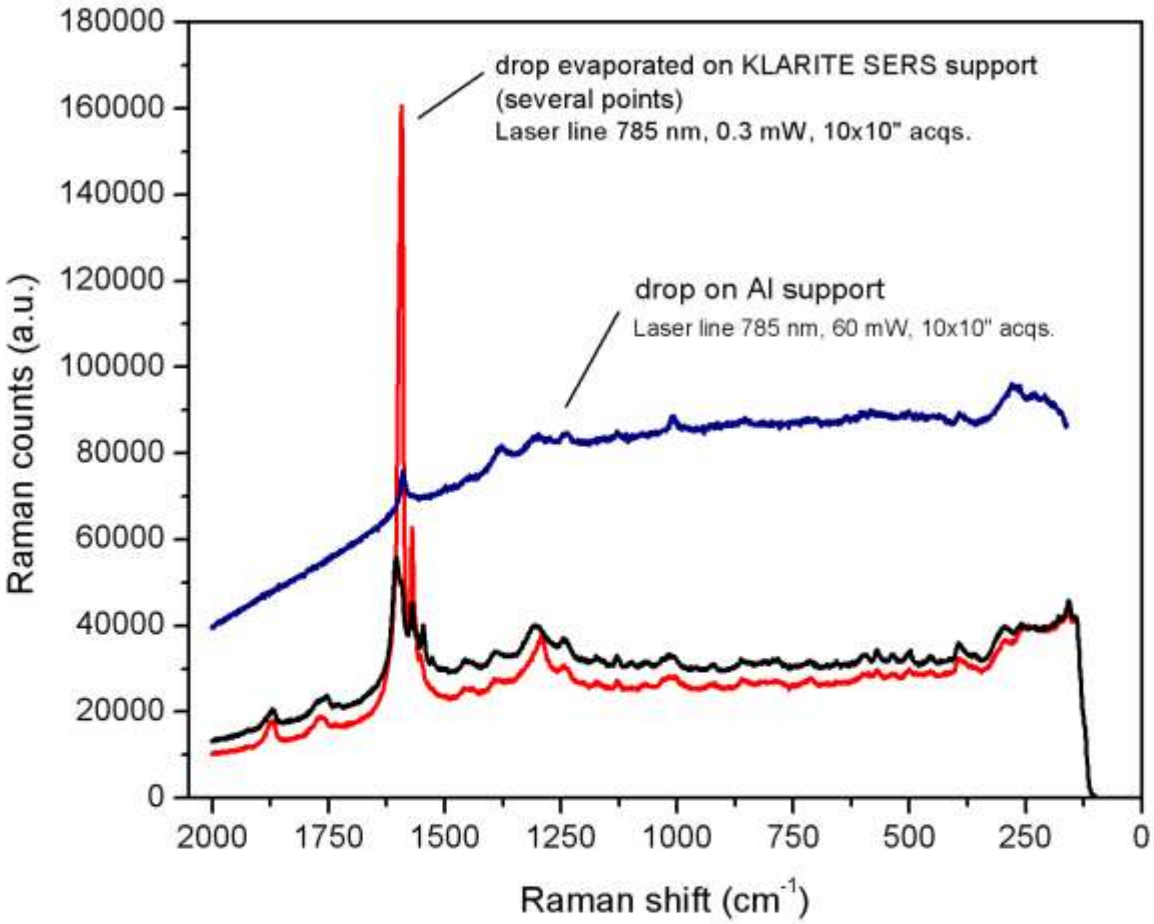




Nanotubes in solution of poly-A before and after centrifugation

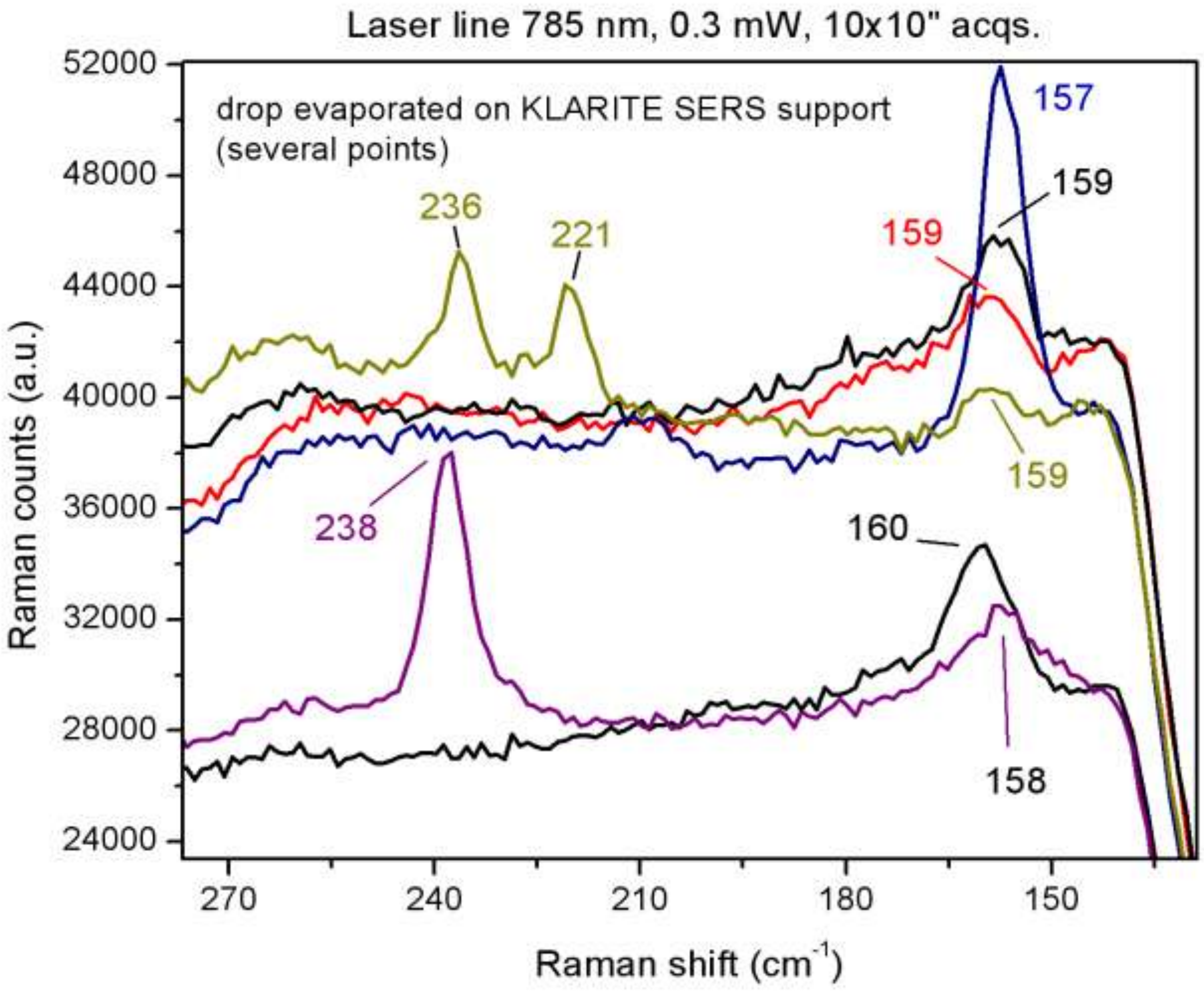
Poly-A with nanotubes after centrifugation

SERS of poly-A with carbon nanotube



$g=10^5$

SERS of poly-A with carbon nanotube



Diameter of nanotubes derived from SERS of individual nanotubes

ν, cm^{-1}	264	238	220	210	162	158
D, nm	0,94	1,04	1,13	1,18	1,53	1,57

$$\nu\ (cm^{-1}) = \frac{248}{D_6\ (nm)};$$

Diameter of nanotubes derived from RS of the bungle

ν, cm^{-1}	177	169	162	156	148	136
D, nm	1,26	1,32	1,38	1,43	1,51	1,65

$$\nu\ (cm^{-1}) = \frac{223.75}{D_1\ (nm)};$$

- **Surface enhanced fluorescence**

Basis of the enhancement for optical signals

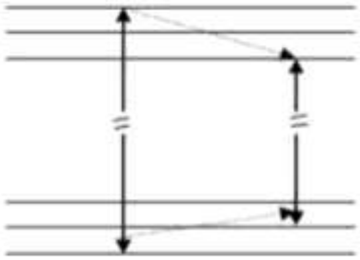
The basis is an enhancement of optical signals from cells adsorbed on the nanostructured metal surface or incubated with nanoparticles. The first conditions for optical signal enhancement on the border of 2 medium (1 - cell, 2 - nanoparticle) is the followings:

$$\varepsilon_2'(\varpi) < 0\,,\ \varepsilon_1'(\varpi) < 0 \ \text{for}\ \varpi_1 < \varpi < \varpi_2\,,\ \frac{\left|\varepsilon_2'(\varpi)\right|}{\varepsilon_2''(\varpi)} >> 1$$

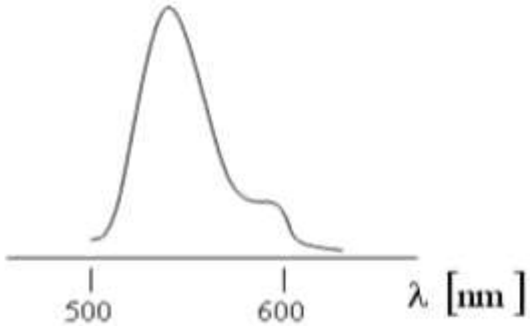
The second condition is en increase the polarizability of the molecules (cell components) induced by nanoparticles.

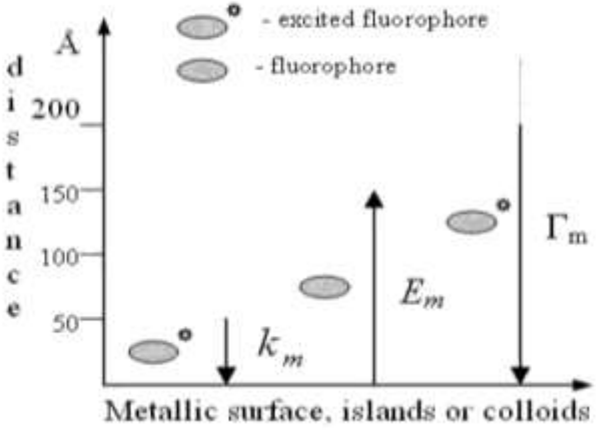
1. G.I. Dovbeshko, O.M. Fesenko, Yu.M. Shirshov, V.I. Chegel. The enhancement of optical processes near rough surface of metals. Semiconductor Physics, Quantum Electronics & Optoelectronics. 2004. V. 7, N 4. P. 411-424.
2. Dovbeshko G.I., Chegel V.I., Paschuk O.P., Shirshov Yu.M, Nazarova A., Kosenkov D., Fesenko O. Biological Molecule Conformations Probed and Enhanced by Metal and Carbon Nanostructures // Fronties of Multifunctional Integrated Nanosystems, Ed.: E. Buzaneva, P. Scharff, Kluwer Academic Publishers. – 2004. – P.447-466
3. Dovbeshko G., Fesenko O., Nazarova A. Effect of nanostructured metal surface on SEIRA spectra of albumin and nucleic acids // Journal of Physical Studies.–2006.– Vol.10, №2. – P.127-134.

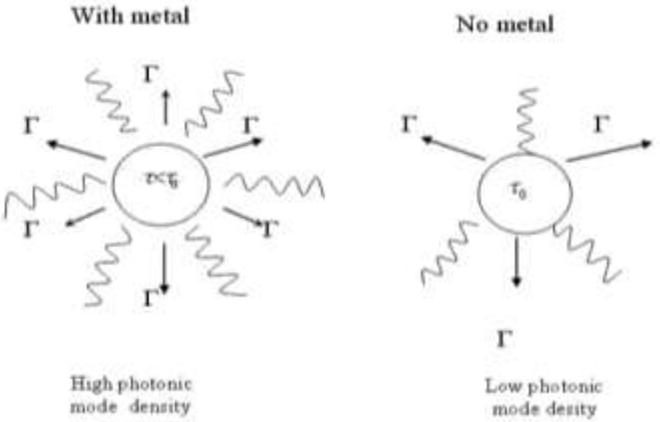
Metal-enhanced fluorescence



Schematic diagram of fluorescence.



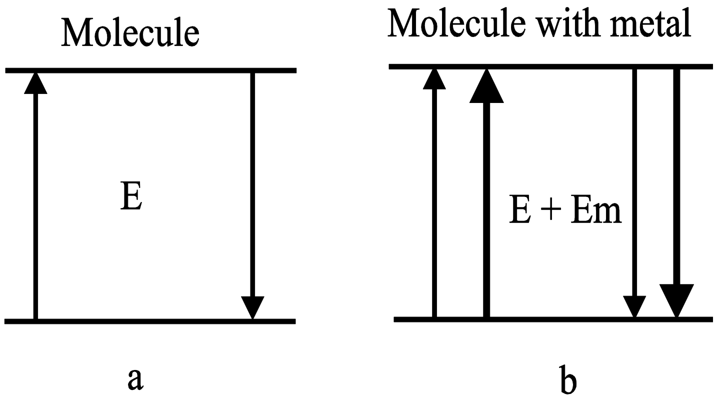


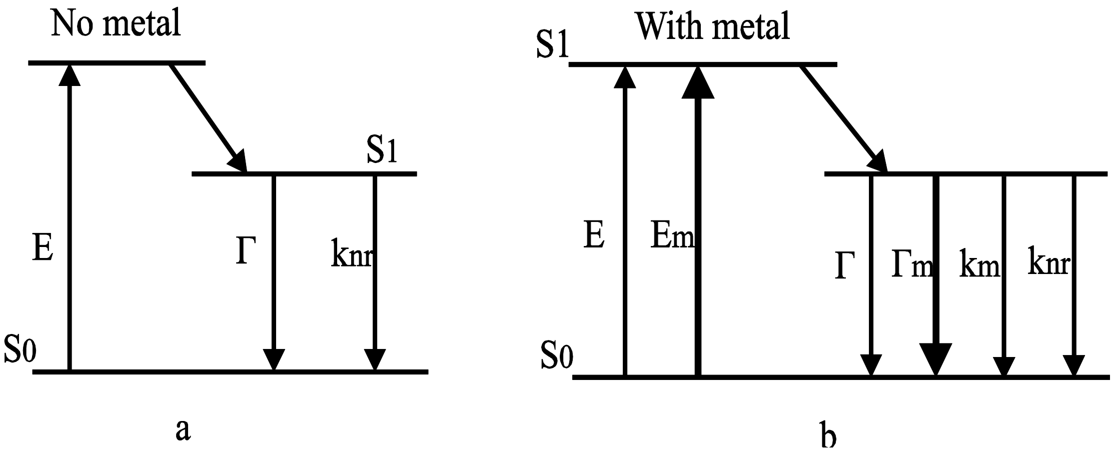


Predicted distance dependences for a metal surface on the transition of fluorophore. The metallic surface can cause Forsterlike quenching with a rate, *km*, can concentrate the incident field, *Em*, and can increase the radiative decay rate, Γ*m*.

High and low photonic mode densities in the presence and absence of metal, respectively

Metal-enhanced fluorescence





Scheme of classical Jablonski diagram for the PL of the molecule in free space and the modified form in the presence of metallic surface: E – incident field, Em – concentrated by metal the incident field, Γ – radiative or emission decay rate, Γm – radiative decay rate in the presence of metal, $k$nr and km– nonradiative decay rate represents all the other rate processes returning the molecule to the ground state without emission without and with metal, accordingly.

1. ***Lakowicz, Analist. 2oo8. 133. 1308-1346***
2. ***G.I. Dovbeshko, O.M. Fesenko, Yu.M. Shirshov, V.I. Chegel. The enhancement of optical processes near rough surface of metals. Semiconductor Physics, Quantum Electronics & Optoelectronics. 2004. V. 7, N 4. P. 411-424.***

Metal-enhanced fluorescence

The quantum yield, Q_0, of a fluorophore shows a competition between radiative decay and nonradiative processes:

$$Q_0 = \frac{\Gamma}{\Gamma + k_{nr} + k_q}$$

The fluorescence lifetime, or decay time, is the average time for an ensemble of fluorescent molecules to remain in the S_1 state:

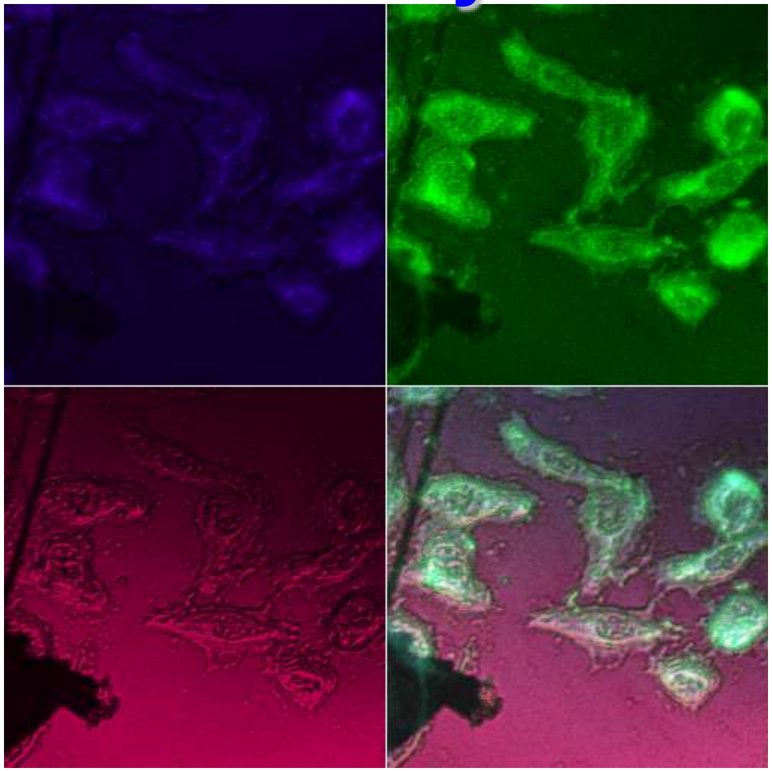
$$\tau_0 = \frac{1}{\Gamma + k_{nr} + k_q}$$

When fluorophores are placed at suitable distances from metallic particles or surface, fluorophores can undergo modifications of their radiative decay rates, Γ_m , where an increase in Γ_m results in an increase in fluorescence intensity, Q_m, and reduction in lifetime τ_m, which is converse to the free-space condition in which both change in unison

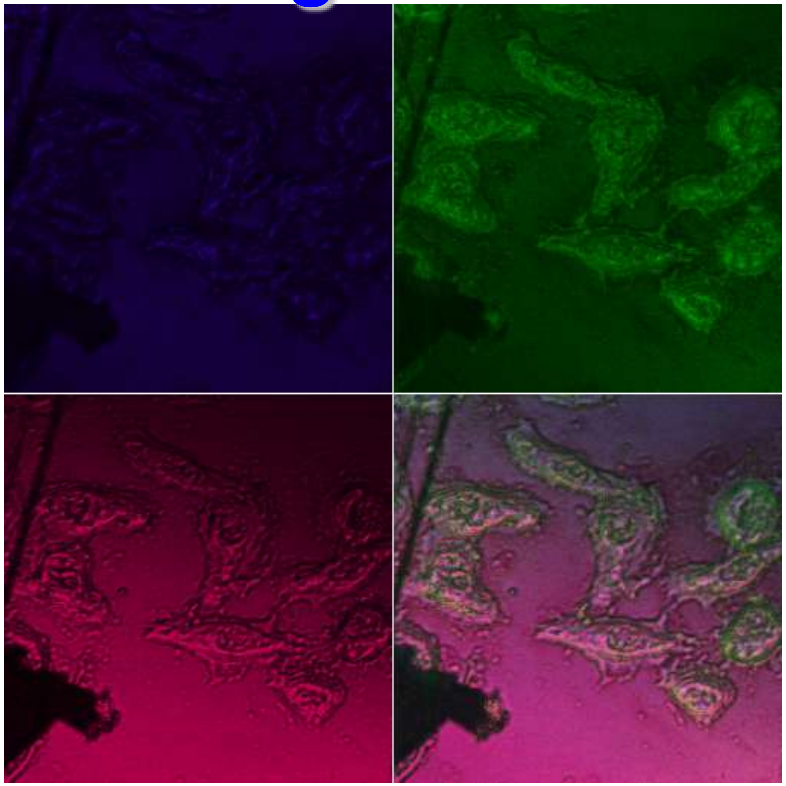
$$Q_m = \frac{\Gamma + \Gamma_m}{\Gamma + \Gamma_m + k_{nr} + k_q},$$

$$\tau_m = \frac{1}{\Gamma + \Gamma_m + k_{nr} + k}.$$

Confocal microscopy image of cells enhanced by nanostructured gold surface



Images of SPEV cells excited by three lasers via long pass filters LP 420, LP 505 and LP 650.



Images of SPEV cells excited by three lasers and registered via band pass filters of BP 420-480, BP 505-530 and LP 650.

Confocal microscopy image of fibroblasts and SPEV cells on home-made gold support

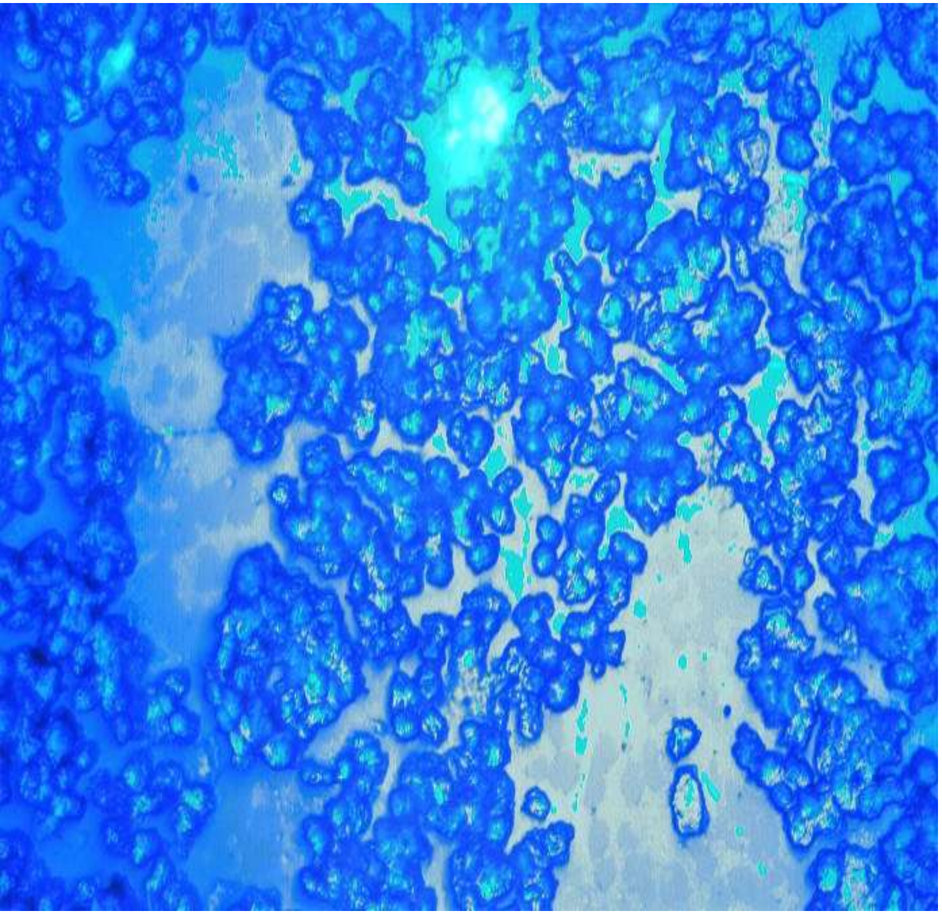


Image of fibroblasts on gold support excited by UV lamp

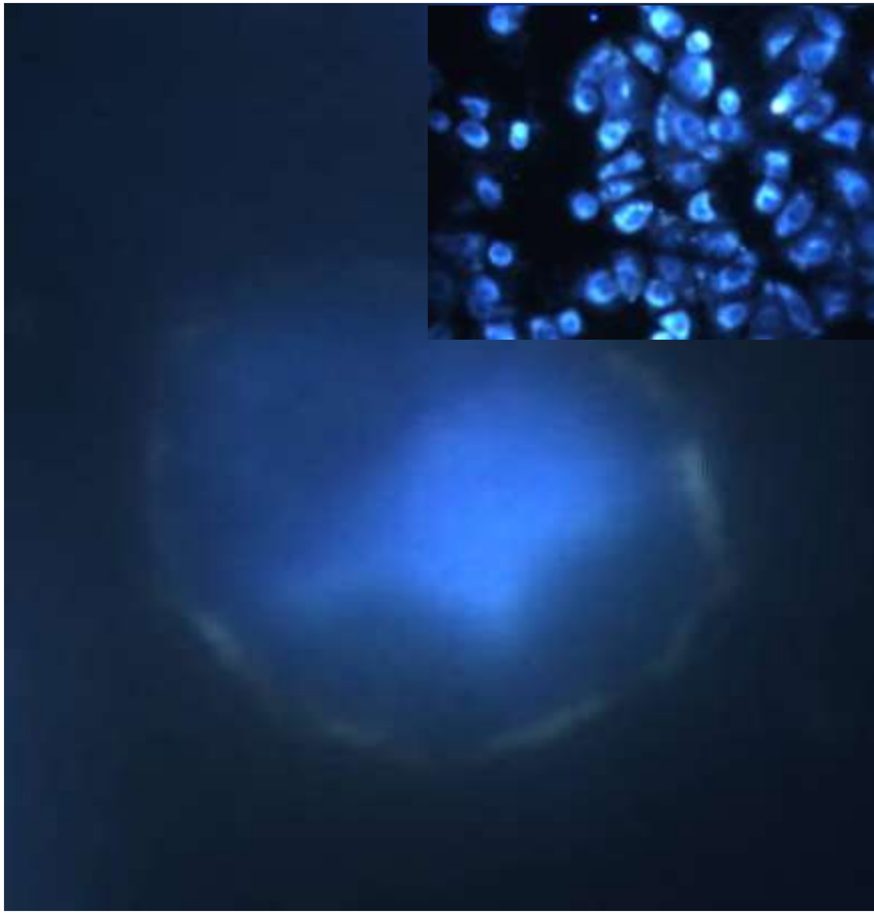
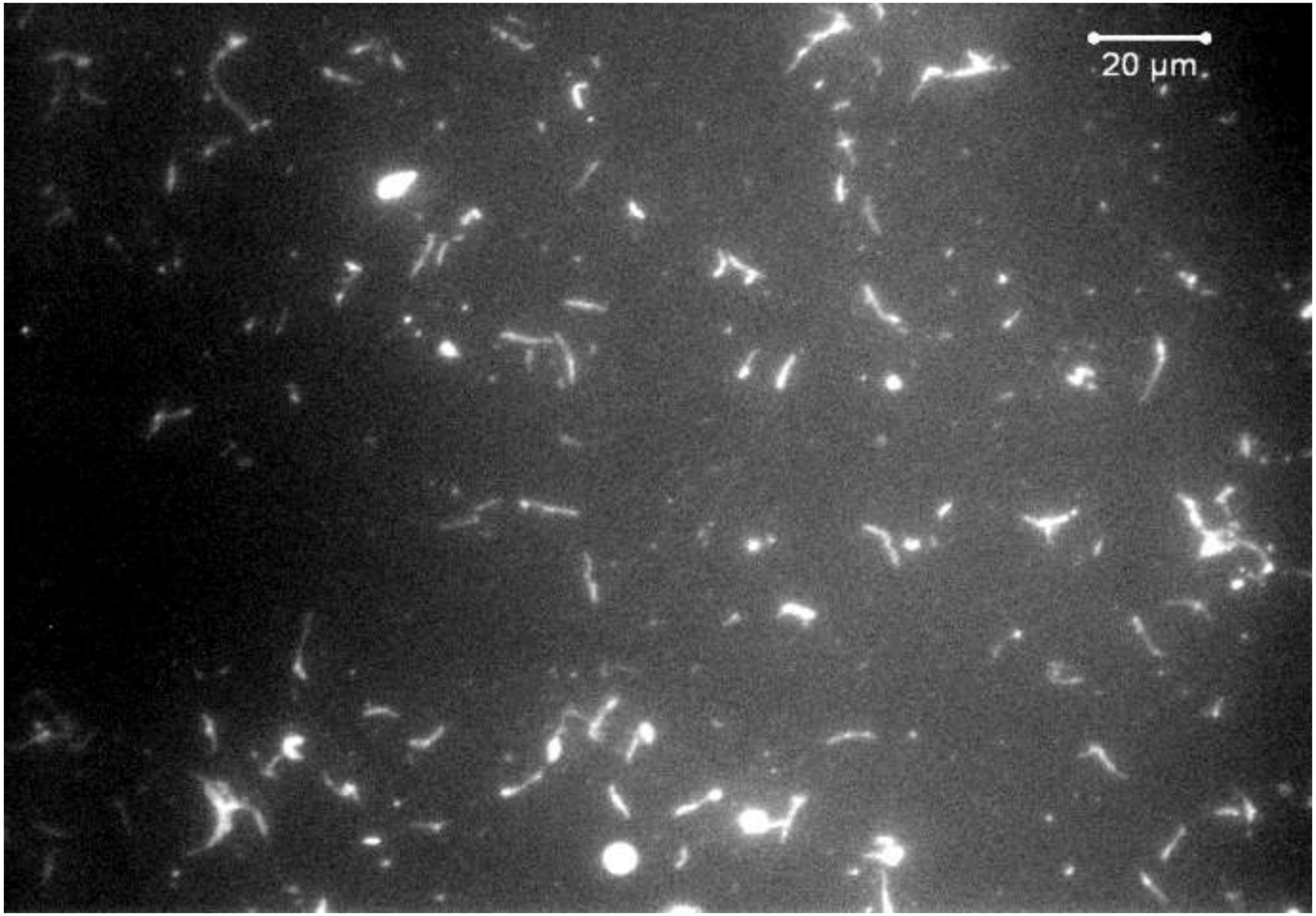


Image of the SPEV cells cultivated on gold support excited by UV lamp

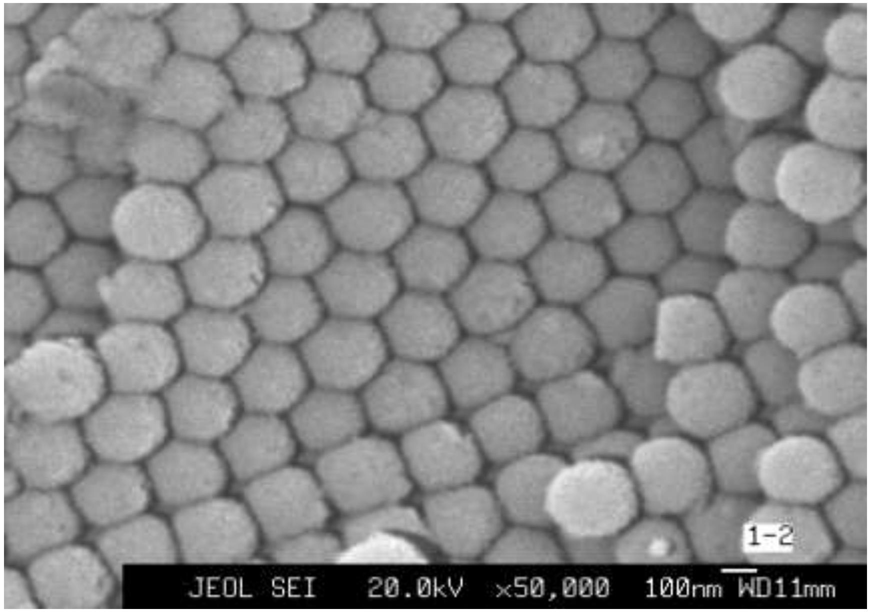
Imaging of DNA on nanostructured gold support with confocal microscopy

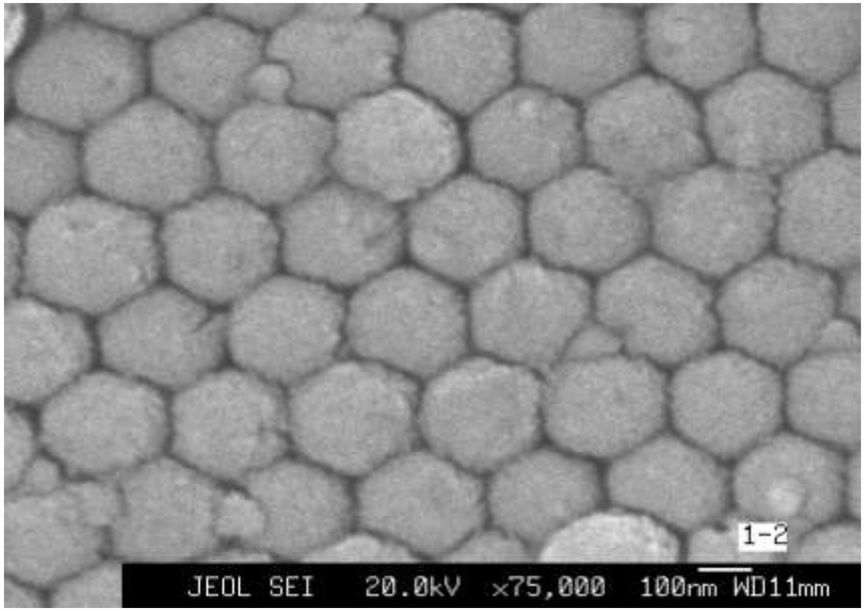
a)



Photonic Crystals

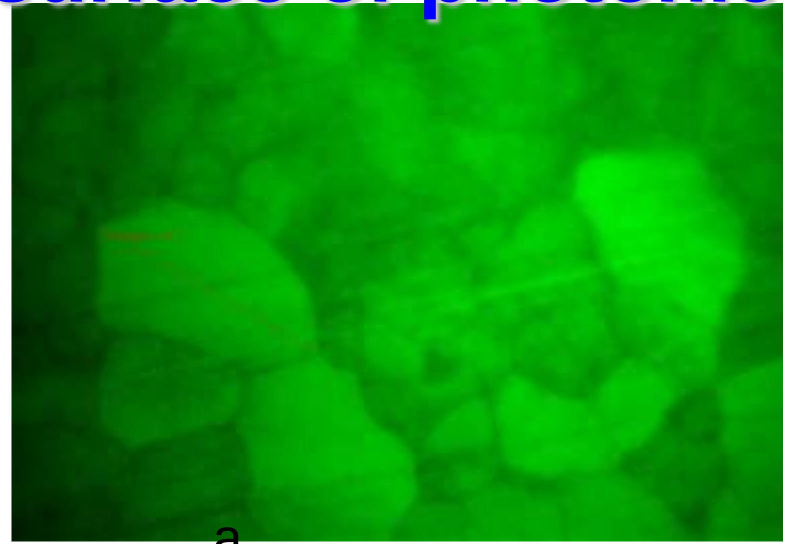
- Microstructure of synthetic opal (SEM images in SEI mode)





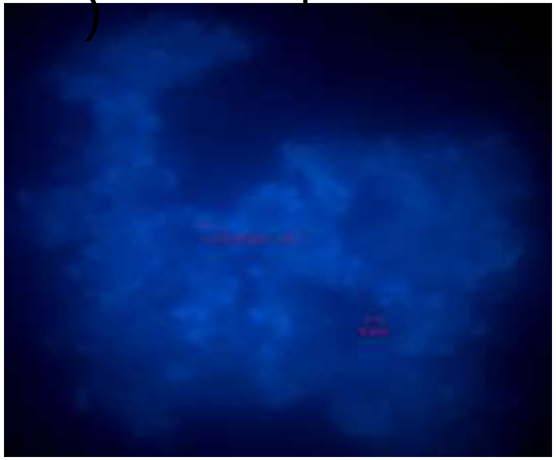
V. Boyko, G. Dovbeshko, O. Fesenko, V. Gorelik, V. Moiseyenko, V. Romanyuk, T. Shvetsc, P. Vodolazkyy. *New Optical Properties of Synthetic Opals Infiltrated by DNA // Mol. Cryst. Liq. Cryst., Vol. 535: pp. 30–41, 2011*

Optical imaging of photonic crystal and DNA at the surface of photonic crystal



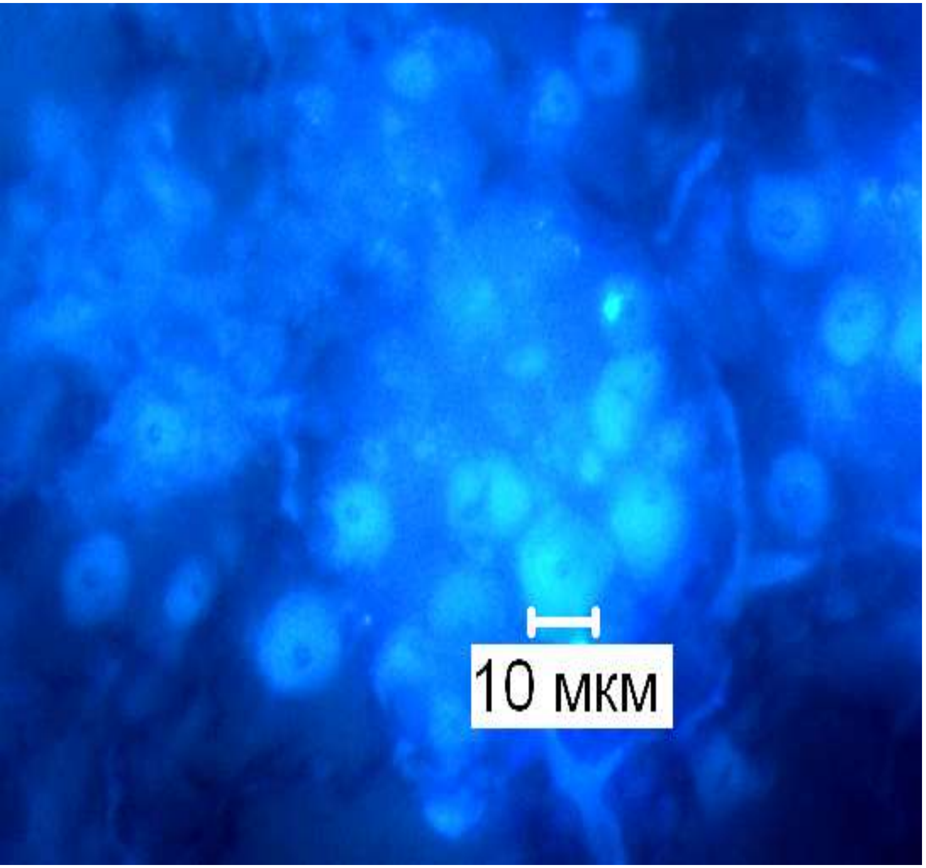
a)

Photonic crystal via confocal microscope

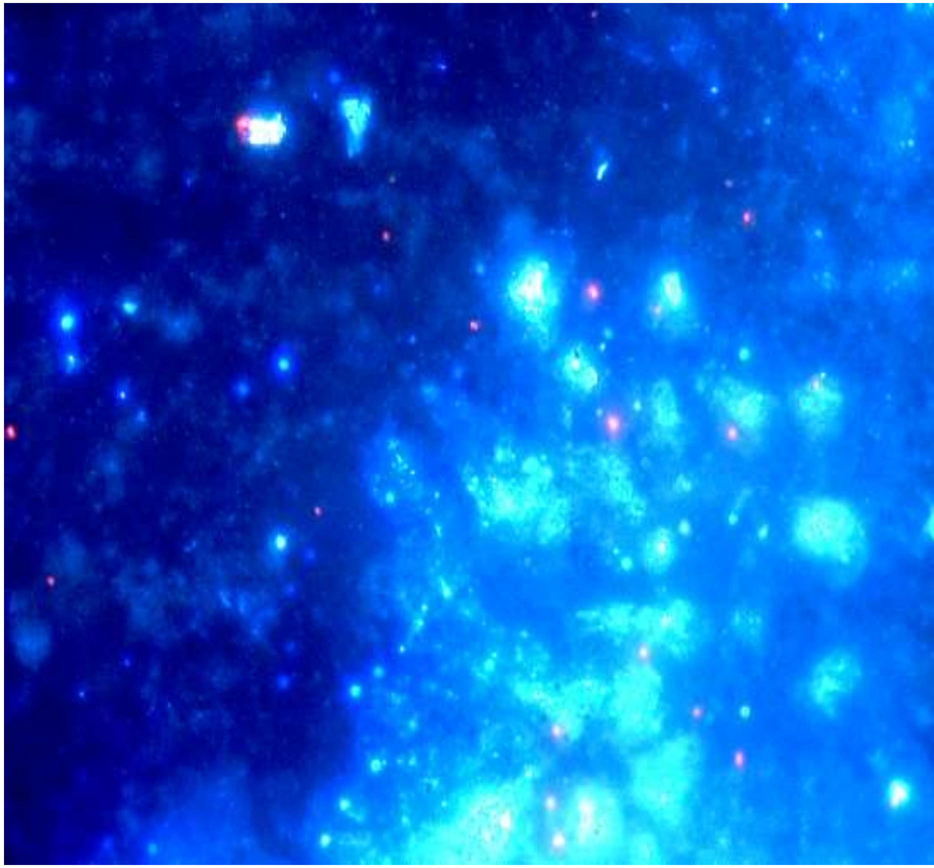


DNA at the surface of photonic crystal via confocal microscope

Optical imaging of blood cells on the surface of PC



erythrocytes



blood cells

- G.I. Dovbeshko, O.M.Fesenko, V.V. Boyko, V.F. Gorchev, S.O. Karakhin, N.Ya. Gridina, V.S. Gorelik, V. Moiseenko, Novel photoluminescence enhancing substrates for image formation of biological objects, Ukr.Phys.Zurn.v.57,N.7, 2012, 732-738

Acknowlegements

A.Zecchina, D.Scorano, A.Damin, S.Bertioni, F.Chesano,
Centre of Excellence
of Nanostructured Interfaces and Surfaces,Turin, Italy

Acknowledgement

- Ukrainian-Russian project (2012-2013гг),
- NTSU № 5525 (2012-2013),
- Ukrainian-Germany project № M366 (2011-2012)
- Nanotwinning Project (2011-2013)

for financial support.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- Thanks for your attention
- All propositions, please, send to e-mail: gd@iop.kiev.ua