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## **Interaction between viral particles and structured metal surface under surface plasmon propagation**

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**Abstract.** The new method for decontamination of biological liquids (blood or blood plasma, for instance) from viruses is proposed. The method is based on the efficient attraction between nanoparticles and nanostructured surface, under which the surface plasmon-polaritons propagate.

**Keywords:** nanoparticle, virus, local-field enhancement, surface plasmon-polariton.

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### **1. Introduction**

A virus is a small “semi-living” particle that is infectious agent able to replicate only inside living cells of organisms [1, 2]. The struggle against viruses has become up to date the most important problem of the living sciences. The characteristic dimensions of viruses are about few tens of nanometers. For example, the dimensions of adenoviruses are close to 70...90 nm, the dimension of AIDS virus reaches 100...120 nm, and dimensions of herpes viruses are approximately 170 nm. It means that the viruses are the objects of nanophysics, specifically, near-field physics [3-5]. As viruses are organic supramolecular structure, from the electrodynamics viewpoint it is characterized both by linear and nonlinear responses. Then, it should actively interact with the surfaces, especially, with the nanostructured ones. As it is well known [6], interaction between nanoparticles and nanostructured surfaces is related with local fields. The effect of local-field enhancement is a characteristic phenomena of nano-optics [7]. The local-field enhancement can, for example, lead to amplification of interaction between the surface and the nanoparticle. This amplification can be observed for nanoparticles with dimensions close to

characteristic linear dimensions of nanostructures at the surface. Then, the possibility for selective adsorption of nanoparticles (with the above linear dimensions) arises. This possibility is the main idea of using the nanostructured surface under special condition to rectify biological liquids (for example, blood) from the nanocomponents, including viruses. To clarify the idea, let us consider a system consisting of the metal surface at which the regular very long cylinders are situated. At this complicated surface, the surface plasmon-polaritons can be excited (Fig. 1). Due to interaction between the localized near the cylinders plasmons and surface plasmon-polaritons, the very complicated distribution of local field (along the OX) will be formed. This local-field distribution is schematically shown by the insert in Fig. 1. If one would suppose that some small nanoparticles, the linear dimensions of which are close to or smaller than the diameter of these cylinders, will be adsorbed at the surface, one should take into account that adsorption will occur at the surface with periodically changed local field. Then, it can be realized the situation when the nanoparticles will adsorbed at the surface mainly within domains of strong local field. The interaction potential (its attractive part) between the nanoparticle and surface can be evaluated as [8]

$$U(\mathbf{r}, l) = -\frac{\hbar}{4\pi^2} \int_0^\infty d\omega \text{cth}(\hbar\omega/2kT) \times \quad (1)$$

$$\times \text{Im} \left[ \chi_{ij}^{(p)}(\omega) I_{ij}(\mathbf{0}, l, l, \omega) e^{-i\mathbf{k}\mathbf{r}} \right],$$

where  $\chi_{ij}^{(p)}(\omega)$  is the effective susceptibility of the single nanoparticle,  $I_{ij}(\mathbf{r}-\mathbf{r}', l, l, \omega)$  – indirect part of electrodynamic Green function for the substrate, and  $\mathbf{k}$  – wave vector of the surface periodic structure. Then, supposing that the nanoparticles are shaped as ellipsoidal particles, the effective susceptibility  $\chi_{ij}^{(p)}(\omega)$  can be written in the form [9, 10]

$$X_{ij}(\omega) = \chi(\omega) \frac{1}{\varepsilon_m + \chi(\omega)L_i} \delta_{ij},$$

where

$$L_i = \frac{a_x a_y a_z}{2} \int_0^\infty \frac{ds}{(s+a_i^2) \sqrt{(s+a_x^2)(s+a_y^2)(s+a_z^2)}}, \quad (3)$$

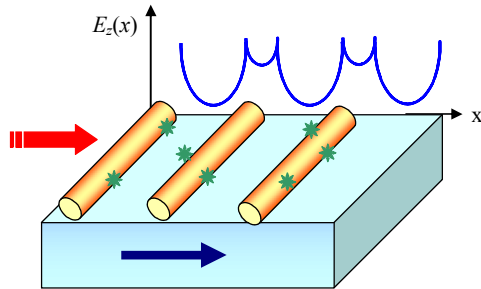
are depolarization factors,  $a_x, a_y, a_z$  mean the semi-axes of ellipsoid,  $\varepsilon_m$  is the dielectric permittivity of the medium where the particle is embedded. The electrodynamic properties of the surface with the periodic structure can be described with the Green function  $I_{ij}(\mathbf{r}-\mathbf{r}', l, l, \omega)$ . The Green function in the so-called  $\mathbf{k}$ -p representation can be written in the form [11]

$$I_{ik}(\mathbf{k}, z, z', \omega) = L_{ij}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega) G_{jk}^{(0)}(\mathbf{k}, d, z', \omega), \quad (4)$$

where  $G_{jk}^{(0)}(\mathbf{k}, z, z', \omega)$  is the electrodynamic Green function of the upper semi-infinite medium, and  $L_{ij}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega)$  is the local-field factor [3]. The local-field factor has the form

$$L_{ij}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega) = \Omega_{ij}^{-1}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega), \quad (5)$$

$$\Omega_{ij}^{-1}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega) = \left[ \varphi_{ij}^{-1}(\mathbf{k}, z, \omega) - a^2 n^2 G_{ji}(\mathbf{k}, z, \omega) \times \right. \\ \left. \times \chi_{il'}^{(+)}(\omega) \varphi_{l'm}(\mathbf{k} + \mathbf{G}, z, \omega) G_{mi'}(\mathbf{k} + \mathbf{G}, z, \omega) \chi_{i'l}^{(-)}(\omega) - \right. \\ \left. - a^2 n^2 G_{ji}(\mathbf{k}, z, \omega) \chi_{il'}^{(-)}(\omega) \varphi_{l'm}(\mathbf{k} - \mathbf{G}, z, \omega) \times \right. \\ \left. \times G_{mi'}(\mathbf{k} - \mathbf{G}, z, \omega) \chi_{i'l}^{(+)}(\omega) \right].$$



**Fig. 1.** Sketch of the system under consideration. The line qualitatively shows a spatial distribution of the interaction potential along the  $x$ -axis.

The next designations were used here:  $\mathbf{G}$  is a smallest vector of the reciprocal 2D lattice,

$$\varphi_{nk}(\mathbf{k} \pm \mathbf{G}, z, \omega) = \left[ \delta_{kn} - an G_{kj}(\mathbf{k} \pm \mathbf{G}, z, \omega) \chi_{jn}^{(0)}(\omega) \right]^{-1} \quad (6)$$

$$\varphi_{nk}(\mathbf{k}, z, \omega) = \left[ \delta_{kn} - an G_{kj}(\mathbf{k}, z, \omega) \chi_{jn}^{(0)}(\omega) \right]^{-1}, \quad (7)$$

$$\int_V d\mathbf{r} \chi_{jl}(\mathbf{r}, \omega) = \chi_{jl}^{(0)}(\omega) \quad \text{and}$$

$$\int_V d\mathbf{r} e^{\pm i\mathbf{G}\mathbf{r}} \chi_{jl}(\mathbf{r}, \omega) = \chi_{jl}^{(\pm)}(\omega)$$

are the averaged effective susceptibilities of the nanocylinders,  $\chi_{jl}(\mathbf{r}, \omega)$  is the effective susceptibility of a single nanocylinder at the surface which dielectric properties are written by the Green function  $G_{ij}(\mathbf{k}, z, z', \omega)$ . All the Green functions  $G_{ij}(\mathbf{k}, z, z', \omega)$  in Eqs. (5-7) are taken with  $z' = d$ , where  $d$  is the radius of the nanocylinder. As the local-field factor  $L_{ij}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega)$  relates the local field  $E_i(\mathbf{k}, z, \omega)$  and external long-range field  $E_i^{(0)}(\mathbf{k}, z, \omega)$ , one can see that the strong local-field domains are determined by high values of local-field factor. Then, from Eqs. (1) and (4) one can see that domains of strong local fields correspond to the strong interaction energy between the nanoparticle and surface. The surface wave excitation and propagation means that the real part of determinant for the matrix  $\Omega_{ij}(\mathbf{k}, \mathbf{k} \pm \mathbf{G}, z, \omega)$  becomes equal to zero. So, it should be expected that small nanoparticles will be better adsorbed at the surface domain of the strong local field. On the other hand, it is well known that the strong local fields are formed at the edge of the nano-stripe structures at the surface, along which the surface electromagnetic waves propagate [12, 13]. If the nanostripes are situated alongside each other and not so far (several tens of nanometers), the small nanoparticles (like viruses) can be adsorbed at the edges of the stripes (at the edges of the nanocylinders). If one assumes that the blood, in which for instance AIDS viruses are presented, flows along the surface shown in Fig. 1, these viruses can be adsorbed by the structured surface, but blood organelles having larger linear dimensions could not be efficiently adsorbed at this surface.

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