Plasmonic nanosensor in the diagnosis and treatment of cancer

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Abstract

We present a novel method based on silver nanoparticle-generated transient photothermal vapour nanobubbles. These intracellular plasmonic nanobubbles are effective in the diagnosis (by optical scattering) and treatment (by mechanical, nonthermal and selective destruction of target cells) of cancerous cells. Theoretical simulation of fused silica rod SPR sensors and optical fiber SPR sensors was carried out. Then these nanosensors were designed, fabricated and their sensitivities were measured experimentally. We introduce the nanosensors and describe how its size and environment can be harnessed to detect and treat cancer cells.

1. Introduction

Surface Plasmon Resonance (SPR) is one of the most promising optical techniques that find applications in diverse fields. SPR is a century-old technique dating back to the finding of Wood's anomaly seen in for the reflected light from diffraction gratings. Later, it was investigated in 1957 by the pioneering work of Ritchie. First sensing application of SPR technique was reported in 1983.

Recent developments have greatly improved the sensitivity of SPR sensors based on metal nanoparticle. In this paper, we describe how the combination of photothermal properties of plasmonic nanoparticles with those of transient vapor bubbles can be used to diagnose and treat cancer in a single method, making the treatment shorter and more efficient.

2. SPR sensing technique

A metal-dielectric interface supports charge density oscillations along the interface which are called Surface Plasma Oscillations. The quantum of these oscillations is called Surface Plasmon. The propagation constant K_{sp} of the Surface Plasmon Wave propagating along the metal-dielectric interface is given by,

$$K_{sp} = \left(\frac{\omega}{c}\right)\sqrt{\frac{\varepsilon_m \varepsilon_s}{\varepsilon_m + \varepsilon_s}} \qquad (1)$$

where ε_m and ε_s are dielectric constants of metal and the dielectric medium respectively, ω is frequency of incident light and c is the velocity of light.

The Propagation Constant K_s of light wave with frequency ω propagating through the dielectric medium is given by,

$$K_s = \left(\frac{\omega}{c}\right)\sqrt{\varepsilon_s} \tag{2}$$

Since $\varepsilon_m < 0$ (for metal) and $\varepsilon_s > 0$ (for dielectric), for a given frequency, $K_{sp} > K_s$. To excite surface plasmons, two propagation wave-vectors should be equal. So, the direct light cannot excite surface plasmons at a metal-dielectric interface. To excite surface plasmons, the momentum and hence the wave vector of the exciting light in dielectric medium should be increased. This can be done if instead of direct light, Evanescent Wave is used to excite surface plasmons.

The propagation constant of the Evanescent Wave at prism-air interface is given by,

$$K_{ev} = \left(\frac{\omega}{c}\right)\sin\theta\sqrt{\varepsilon_g} \tag{3}$$

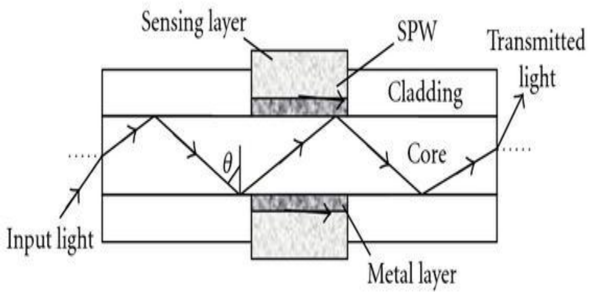
where ε_g represents the dielectric constant of material of the fused silica rod or optical fiber and θ is angle of incidence of the beam.

Increase in the dielectric constant of the prism increases K_{ev} and hence this can be made equal to K_{sp} to satisfy the Surface plasmon resonance condition. Thus the resonance condition for surface plasmon resonance is,

$$\left(\frac{\omega}{c}\right)\sin\theta_{res}\sqrt{\varepsilon_p} = \left(\frac{\omega}{c}\right)\sqrt{\frac{\varepsilon_m\varepsilon_s}{\varepsilon_m + \varepsilon_s}} \tag{4}$$

The excitation of surface plasmons at metal/dielectric interface results in transfer of energy from incident light to surface plasmons which reduces the intensity of reflected light. If the intensity of reflected light is measured as a function of angle of incidence θ for fixed values of frequency, metal layer thickness and dielectric layer thickness, then a sharp dip is observed at resonance angle θ_{res}.

Then, theoretical simulation of SPR angles was carried out in MATLAB for nine different wavelengths of Ar-ion laser. After this, nanosensors were developed by coating Ag particles on fused silca glassrod. To design an SPR-based fiber optic nanosensor, the silicon cladding from the middle of the fiber was removed and the unclad core was coated with metal layer.



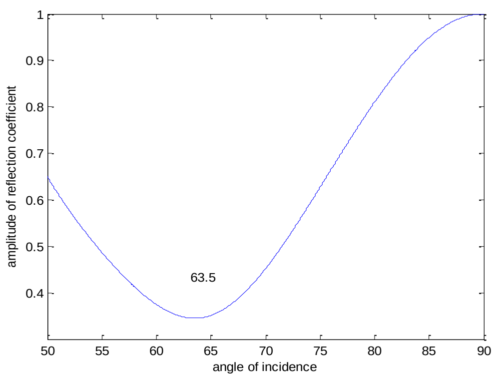


Fig. 1: (Left) Schematic diagram of a fiber optic based SPR sensor, (Right) A SPR resonance curve (Hor. axis- Angles of incidence, Ver. axis - Reflection coefficient) obtained by theoretical simulation in MATLAB.

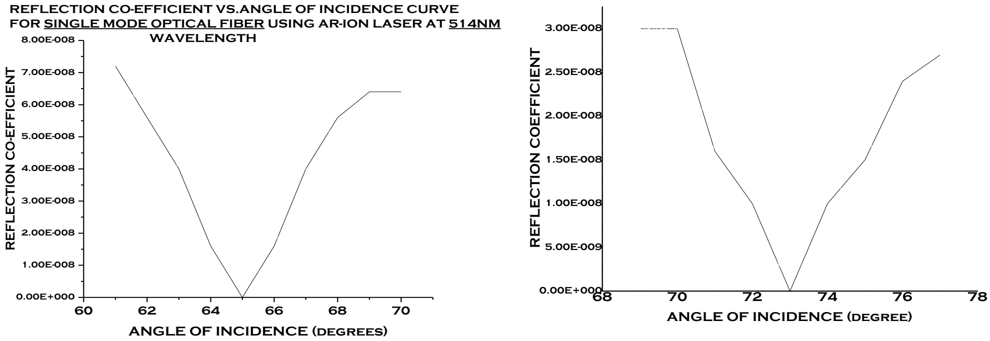


Fig. 2: (Left) An experimental SPR resonance curve for 514nm of Ar-ion laser in single mode fiber with air (r.i. 1.0003) as dielectric showing resonance at 64.5 degree, (Right) SPR curve with same fiber at 514nm but this time with turpine oil (r.i. 1.47) as dielectric showing resonance at 73 degrees.

3. Application of Plasmonic nanosensors to diagnose and treat cancer

Next, we generated Plasmonic nanobubbles (PNB) by interacting optical radiation with nanoparticles coated on the nanosensors. When a plasmonic nanoparticle is activated by a laser pulse, it acts a heat source and generates a transient PNB in its surrounding environment. PNBs of nanometer-scale size and nanosecond-scale duration are well suited as diagnostic probes by scattering light from the probe laser. In addition, PNBs provide localized therapeutic action through a mechanical, non-thermal impact due to their rapid expansion and collapse, thereby disrupting the cell membrane

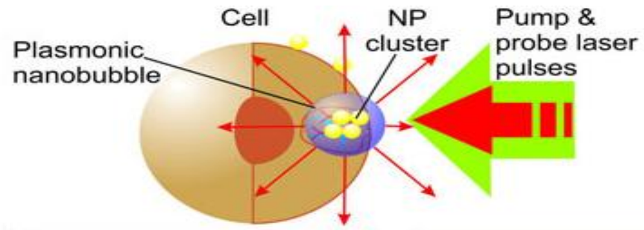


Fig. 3: Illustration of how plasmonic nanobubble acts

4. Conclusion

To summarise, PNB's provide an efficient technique to diagnose and treat cancer-without any use of chemicals and relying only on nanoscale phenomena of light and heat which are natural to living systems.

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