Nitrides as alternative materials for localized surface plasmon applications

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Abstract: Optical responses of titanium nitride and zirconium nitride are studied in the visible and near-infrared regions for localized surface plasmon applications. Both materials are found to be promising alternatives to noble metals.
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Localized surface plasmon resonances (LSPR) have been studied intensely for the last few decades. Other than the size and shape, material of the scatterer is also a very important parameter affecting the performance. In fact, the search for alternative materials for plasmonic applications is as old as the history of plasmonics itself [1]. Until recently, noble metals were thought to be the only good plasmonic materials. However, metal nitrides such as titanium nitride (TiN) and zirconium nitride (ZrN) have been recently proposed as good plasmonic materials for many plasmonic and metamaterial applications [2]. LSPR applications of metal nitrides have received less attention due to relatively poor results obtained by formulations within quasistatic limits [3]. In this study, electromagnetic response of titanium nitride and zirconium nitride in the visible and near-infrared spectrum is examined for LSPR applications. Local field enhancement and local heating of spherical nitride particles are found to be very promising when compared to gold (Au) which is one of the most common conventional plasmonic materials.

Quality factor for LSPR applications can be defined in different ways depending on the application requirements. For particles much smaller than the wavelength of incident light, it is possible to use quasistatic approximations. When light scattering with observation points at large distances is considered, well known Mie efficiencies can be employed. In this work, we use a more generalized formulation which provides useful information for arbitrary distances from the surface of a spherical scatterer [4]. Near field intensity efficiency (Q_{NF}) of a scattering sphere can be obtained by integrating the scattered field over an observation sphere at arbitrary distances and converges to the well known scattering efficiency (Q_{sca}) when the distance is taken at infinity. With a generalized formulation, one can avoid the quasistatic and far field approximations, thus make a detailed examination of the scattering mechanisms for the case of nitrides [5].

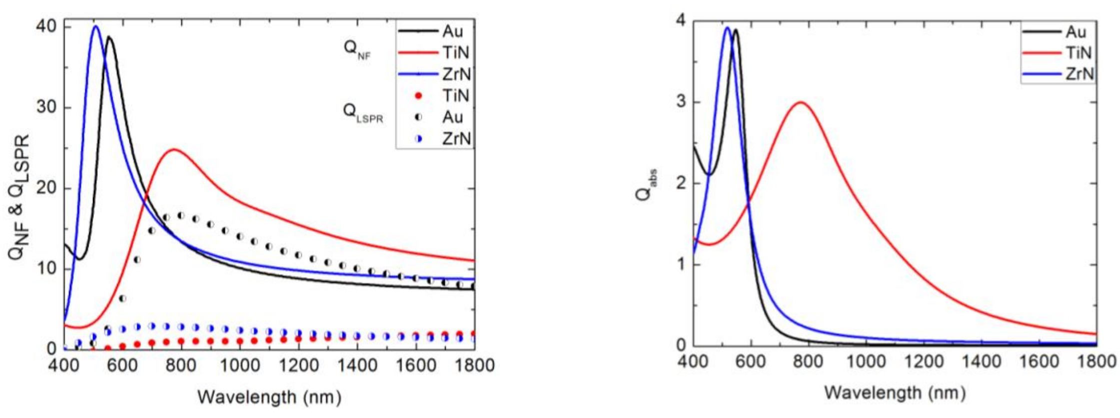

Figure 1: (a) Quasistatic LSPR quality factors and near field intensity efficiencies of Au (r=57 nm), TiN (r=74 nm) and ZrN (r=46 nm) spherical particles. (b) Absorption efficiencies of Au (r=35 nm), TiN (r=55 nm) and ZrN (r=32 nm) particles.

In Fig. 1(a), near field efficiencies of Au, TiN and ZrN are given for spherical particles with dimensions providing the maximum values for each material. Quality factors calculated with quasistatic approximation are also given as a reference for each material. Au provides better efficiencies at short wavelengths when compared to TiN. However, in near infrared region, TiN efficiency values are larger than Au. Since the near infrared region is frequently used for bio-imaging applications due to the transparency of biological specimen at these wavelengths, higher efficiencies obtained with TiN particles are very important. ZrN, on the other hand, provides very similar efficiency results to Au. The spectral position of ZrN peak is blue-shifted and reaches to slightly higher values. These results are contradictory to quasistatic quality factor calculations which estimate a very poor performance from nitrides.

Another application area of particles providing LSPR is the local heating of biological samples by use of the absorption process within the particles. Fig. 1(b) gives the absorption efficiencies of Au, TiN and ZrN spherical particles in water for dimensions providing the highest efficiency values for each material. As expected from the previous experiences with noble metals, Au performs well in the visible region. TiN, on the other hand, provides very good and relatively broader absorption in the near infrared region. Based on the efficiency results, TiN can be considered as a promising material for LSPR applications especially in near-infrared region.

In this talk, the mismatch between quasistatic calculations and near field efficiencies is discussed in detail. Superiority of nitrides at different spectral regions are explained along with the physical mechanisms.

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