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ARTICLE

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SURFACE PLASMON RESONANCE IN TITANIUM NITRIDE IN VISIBLE FREQUENCY RANGE

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This paper aims to report the optical properties of Titanium nitride and its efficient use as substitute to metals in the excitation and propagation of surface plasmon polariton wave with the help of MATLAB simulations.

Introduction

Recent plasmonic applications like metamaterials and optoelectronic devices are limited by use of conventional metals[1]. Gold and silver are the most commonly used as plasmonic material. But these conventional metals suffer very high losses in visible and near infrared (NIR) ranges[2]. Metals have large negative real permittivity[3] which limits the unability of the optical properties of the metals. The integration of new plasmonic materials significantly improves the performance of many existing MM and plasmonic devices.

Transparent conducting oxides (TCOs) are found to be better plasmonic material and substitute to gold and silver in near infrared (NIR) ranges[4-7]. Highly dopped (10^{21} cm^{-3}) TCOs can exhibit metallic properties in near infra-red range but cannot be plasmonic substitute in the visible wavelength range[8]. New plasmonic materials, transition metal nitrides like titanium nitrides and zirconium nitrides can have higher carrier concentration than TCOs in the visible range and they have negative real permittivity i.e. metallic properties. In accordance with that the optical properties of these transition metal nitrides can be tuned and they can be compatible with standard fabrication and integration procedures. They allow greater flexibility in the design of a device and enable it with high performance. These TiN have moderate magnitude of the real part of permittivity, whereas, metals such as gold and silver have very large negative real permittivity in the near-IR and visible ranges, which is a major obstacle in the design and fabrication of efficient devices. So, the transition metal nitrides like TiN have significant advantages over conventional metals for plasmonic and metamaterial designs.

For the excitement of surface plasmons, the metallic conductivity of TiN plays an important role due to its coherent oscillations of free electrons at metal-dielectric interface. According to Drude model[9] plasma frequency (ω_p) is related with permittivity of free space (ε_0) and high frequency dielectric constant (ε_∞) as $\omega_p = \sqrt{ne^2/\mu\varepsilon_0}\ \varepsilon_\infty$ [10]. For high carrier concentration n~ 6.6 $*10^{22}$ cm^{-3} the plasma frequency of TiN exists in visible region, which is close to gold and explains the gold like behavior of TiN. This leads to activate SPs within TiN in the frequencies near visible wavelength region. In this case three phase Kretschmann optical structure (air- TiN –prism (BK7)) is considered. This structure has a potential application in light emitting and waveguide devices[11] and also in sensing applications.

Results and Discussions

The results and analysis are supported by MATLAB simulations. Layer wise three phase model (air/doped metal oxide/substrate) is considered for the simulation. The nature of surface plasmon resonance in TiN, depends on the thickness of the film and angle of incidence of the incident

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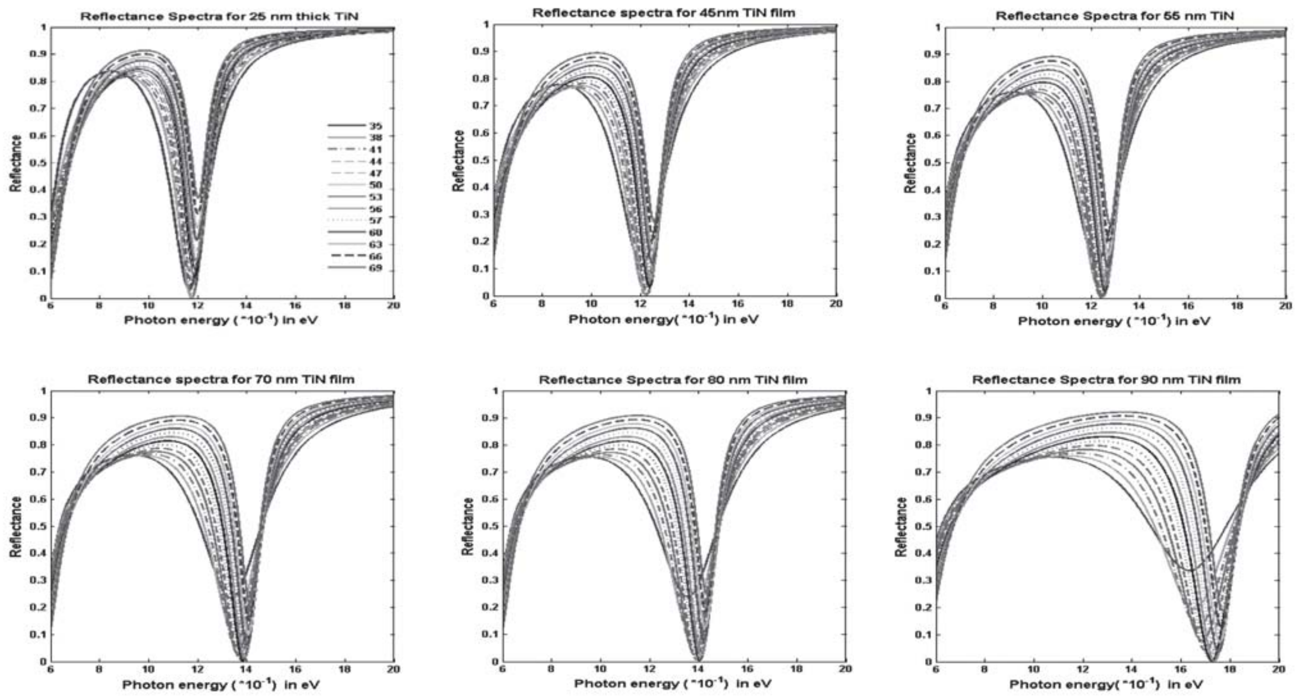

Fig.1. Reflectivity spectra panel for different thickness of the titanium nitride thin film changing with incident angle varying from 25^0 to 71^0

radiation of wavelength 633nm. The variation of the resonance characteristics for several thicknesses as well as angle of incidence for TiN film will be presented in Fig.1.

The Reflectance variation profile for different thickness of the metal nitride thin film with the varational incident angle of the exciting radiation is depicted in Fig. 1. All these Reflectance profiles elaborately support Surface Plasmon Resonance for the range of incident angles considered.

It also depicts that for higher incident angle above 55^0 the probability for absorbance is greater than the reflectance because above this angle, the reflectance detected at the detector end is higher when the exciting radiation is incident on the three phase configuration. From these figures we can get the optimised thickness which shows better response for the Surface Plasmon Resonance phenomenon. These figures confirms that very thin TiN film give better sensitivity for plasmonic applications.

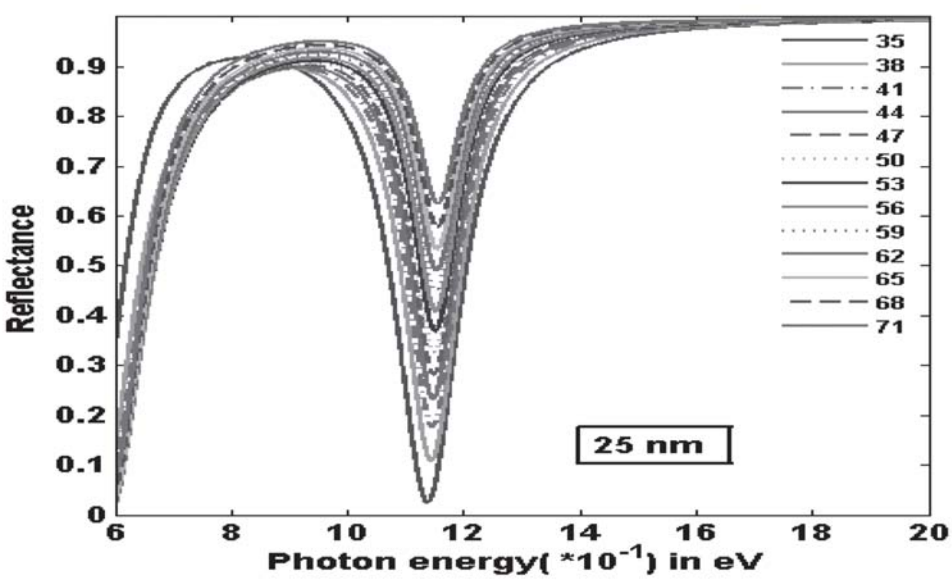

Fig. 2. Reflectance versus incident photon energy for 25nm Titanium nitride

And in Fig. 2. the reflectance spectra of TiN for different energies of the incident radiation with variational angle of incidence is plotted. When the thickness of the metal nitride material is very thin (eg. 25nm) then the Surface Plasmon Resonance takes place at lower angle of incidence. When the exciting electromagnetic radiation is incident on the three-phase configuration at an angle 35^0, then the Reflectivity collected from detector is 2.54%. So, the film behaves as almost transparent. Though the FWHM for this incident angle for 25nm thick film is 0.138eV, which is higher than the value for higher incident angle. When the electromagnetic radiation is incident at higher incident angle the metal nitride film become opaque with higher reflectance and lower absorbance. For 60^{0} angle of incidence 53.7% of the incident light gets absorbed through the thin film layer. When the thickness of the thin film is 55nm then Surface Plasmon Resonance takes place at 37^{0} with almost no reflectivity. So all the exciting radiation gets transmitted over the boundaries of the metal nitrides film. Whereas 100nm thick TiN material shows the resonance at 52^{0} with almost 100% absorbance of the incident light, so no reflection will be detected at the detector end.

Conclusions

Transition metal nitrides are good agreement for Surface Plasmon Resonance in visible frequency range and can be better substitute to gold and silver in plasmonic applications. TiN thin film with optimised thickness excited with optimised angle of incidence give better response for Plasmonics and Metamaterials applications. ❐

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