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Synthesis and characterization of titanium nitride thin films for enhancement and localization of optical fields

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ABSTRACT

Emerging plasmonic materials are an essential driving factor of the ongoing progress towards the empowering of photonic devices functionalities and performance improvement. Transition metal nitrides, being refractory metals with tunable optical properties, are prominent representatives of alternative plasmonic materials. Recent intensive examination of linear and nonlinear optical parameters of metal nitrides has revealed TiN to be a promising media for metal-based optics. Another distinctive feature of TiN is its Raman activity. In contrast to Raman-silent metals, TiN-based structures enable nonlinear light frequency conversion not only to even and odd harmonics, but also to Raman-shifted modes. Moreover, the threshold of the underlying stimulated Raman scattering (SRS) effect in these structures could be greatly reduced by appropriate geometry and material design. Here we experimentally investigate the effect of structure and composition of TiN on its optical properties, such as dielectric permittivity and third-order Raman susceptibility. A special attention is given to synthesis and characterization of TiN thin films suitable for plasmon-assisted localization and amplification of optical signals.

1. Introduction

Plasmonic excitations provide unprecedented abilities on control of electromagnetic fields and boosting light-mater interaction. Structures supporting surface plasmon polaritons (SPP) form the basis for transformation optics [1], metamaterials and metasurfaces [2,3], enhanced spectroscopies [4], nano-imaging [5], bio-sensorics [6], to name a few. Further progress towards development of innovative photonic devices is associated with nonlinear plasmonics [7,8]. This relatively new field is intended to harness the diversity of nonlinear optical effects for empowering photonic devices functionalities. However, conventional plasmonic materials are unsuitable for metal-based nonlinear optics due to low photo-induced damage threshold [9]. There is a growing demand for plasmonic media with high melting point, mechanical and chemical stability.

Recently, a new class of alternative plasmonic materials – transition metal nitrides – has been suggested to improve the performance of plasmon-assisted devices [10]. It has been demonstrated that titanium nitride (TiN) has large figure-of-merit (FOM) of plasmon resonance in visible and infra-red ranges as well as capable to withstand the light intensities required for nonlinear optical regime. These properties make TiN attractive for applications in nonlinear plasmonics [11]. Another distinctive feature of TiN is its Raman activity. Surface plasmon wave, excited at the interface between TiN and some dielectric, experience inelastic scattering on phonons within a TiN lattice. This process leads to SPP excitation at Stokes and anti-Stokes frequencies. These localized waves can interact with each other through the third-order nonlinearity. The above effect is analogues to well-known stimulated Raman scattering (SRS) of high-intensity free-space waves in the Raman-active media [12]. The efficiency of this process can be quite large, with up to 50% of the power of the incident light being converted into one of possible Stokes waves. Thus, in contrast to Raman-silent plasmonic materials, TiN-based structures enable nonlinear light frequency conversion not only to even and odd harmonics, but also to Raman-shifted modes. Moreover, that generated signal exists in the form of localized wave because its frequency remains within plasmon excitation spectra. In order to detect the nonlinear Raman response in the far field an out-coupling of enhanced signal from the metal surface is required. Thus, TiN is the promising material from the perspective of amplification of localized optical signals.

In this work we investigate the effect of structure and composition of synthesized TiN thin films on its linear and nonlinear optical

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