A Test Bench Device for the Characterization of Metamaterials in the Optical Regime

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Metamaterials (MTMs) have gained lots of interest in recent years due to their many applications including but not limited to the creation of a perfect lens, subwavelength cavity resonators, novel filters, phase conjugation and compensation. Most of these applications have focused mostly in the microwave frequency regime. Currently there is a shift to MTM applications in the optical frequency regime, including novel imaging, optical lithography, propagation enhancements, and waveguide splitting. These materials can be applied in subwavelength resolution devices as well as guiding structures and couplers in the optical regimes and further research is needed for the implementation of these devices in the visible regime. Along with this comes an even stronger drive to characterize their properties. In this paper, a test bench device for the characterization of such MTMs in the optical regime is proposed, designed, and fabricated. Once this initial structure is developed, it can be used as an "optical injector" to characterize novel MTMs in terms of effective material parameters at the optical frequencies and to test a number of the ideas for guiding structures using metamaterials in the visible regime.

The initial testbed structure is composed of multiple layers of gold (Au), titanium (Ti), and a dielectric (SiO_2) utilizing a coupling mechanism composed of a prism coupler (GaP) to couple the light into a waveguide filled with the material that is to be characterized within this testbed device. Coupling of light into a device is a significant problem in the optical regime. In this paper, the Kretschmann configuration is implemented achieving Attenuated Total Reflection (ATR) (F. Kaneko, T. Sato, M. Terakado, H. Hatakeyama, K. Shinbo, K. Kato, T. Wakamatsu, *Proceedings of the 7th International Conference on Properties and Applications of Dielectric Materials*, pp. 53-56, 2003). This configuration has the advantages of being easier to fabricate (compared to periodic grating on the surface of the substrate) and eliminates the air gap, necessary in other configurations (e.g. Otto) which is difficult to achieve at fabrication in a uniform and consistent way. The gold (Au) material is chosen to take advantage of the plasmon resonances in the optical regime. In this case, it also represents an epsilon negative (ENG) material. An Argon-Ion laser at 514 nm is used to excite the structure since the attenuation constant of Au is close to a minimum at 514 nm.

The type of dielectric, the thicknesses of the layers, as well as the details of the coupling mechanisms will be provided by a computational electromagnetics model based on the Finite Difference Time Domain (FDTD) method. The proposed device will be characterized in terms of losses, confinement factors, and the plasmon mechanisms within the ENG materials. Results of the computational model will be validated through experimental results of the performance of the designed structures. Once the initial design is validated, the testbed device will be used to characterize novel metamaterials synthesized to perform at optical frequencies. The performance of the designs will be quantified through transmission, confinement factor, and loss measurements and design iterations will be made accordingly.