Non-linear Optical Metamaterials over Multiple Wavelength Ranges for Ultrafast and Secure Communication

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Superheterodyne radio receivers are widely used in RF communication today. It is a method of detecting signal by non-linear mixing it with a wave of a reference frequency. The most significant benefit is that it reduces signals from various frequencies to a fixed intermediate frequency that the following amplifier is optimized for. Moreover, superheterodyne is also compatible with advanced modulation schemes. Therefore, state-of-art radios (including Wi-Fi, cell phone, GPS etc.) use the superheterodyne receiver. Another major development of the radio communication systems is that it's evolved from discrete components to integrated chips. The development of optical communication has been following the pattern of radio communication in the past. It is reasonable to predict that the future optical communication systems will be built on integrated Si photonic chips and signal is coded with advanced modulation schemes and detected by optical superheterodyne receivers.

However, an optical superheterodyne receiver has not been realized. The key reason lies in the nonlinear mixer. In RF range, a power detector is a nonlinear mixer as it responds to E^2 while at optical frequency, a photodetector isn't fast enough to follow the electromagnetic field. Another path is to utilize non-linear materials. However, there is no material that is readily compatible with Si platform.

In this work, we propose to demonstrate metamaterials with high non-linearity at both optical (carrier) and microwave(signal) frequency simultaneously for the first time. The property is crucial for the optical nonlinear mixer. The structures for each frequency range is separately designed and characterized at first and then we'll focus on arrangements that combine the two structures together. Our nonlinear optical structure is shown in Figure 1. The metamaterial is an Ag/SiO2/Ag stack structure which is fabricated by nanoimprint lithography. The 'chevron' structure gives asymmetric electron distribution (Figure 2) which contribute to second-order nonlinearity and the resonance generated by the two metal layers furtherly enhance the effect. The geometry of the structure is optimized for optical communication wavelength of 1.55 um(Figure 3). Characterization has shown strong secondary harmonics generation (Figure 4) which indicates high nonlinearity. Comparing to the optical frequency, the non-linear effect in RF frequency has been well studied and is much easier to realize. Combining the structures at these two wavelength ranges are under investigation and the result will be presented. We predict that the integrated optical mixer based on this work will take a significant leap of Si photonics.

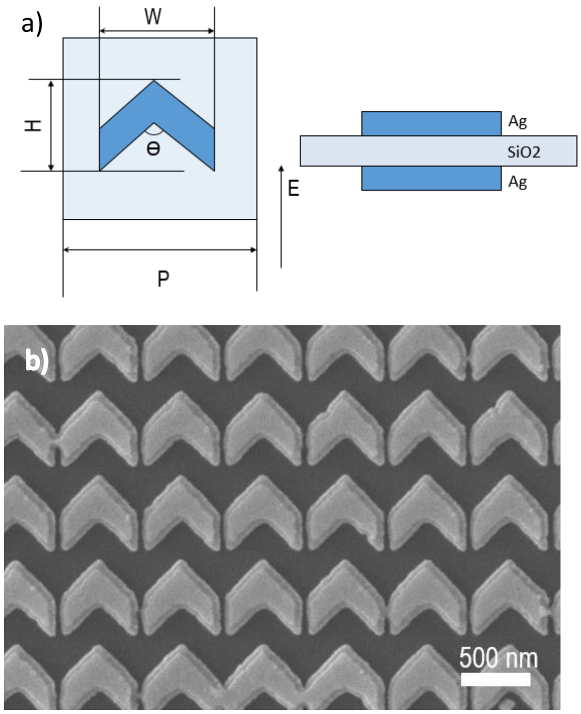

Figure 1. a) The optical metamaterial is a $Ag/SiO_2/Ag$ stack structure and is periodic on the wafer plane. b) SEM image of a sample fabricated by nanoimprint lithography.

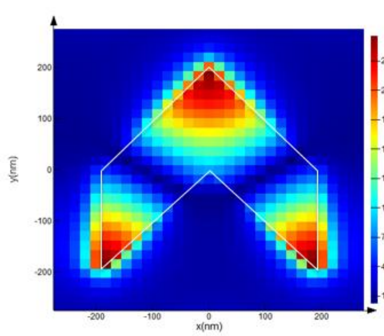

Figure 2. FDTD simulation of the electric field distribution at the plane in the middle of metal layers. While lines indicate the boundary of the structure.

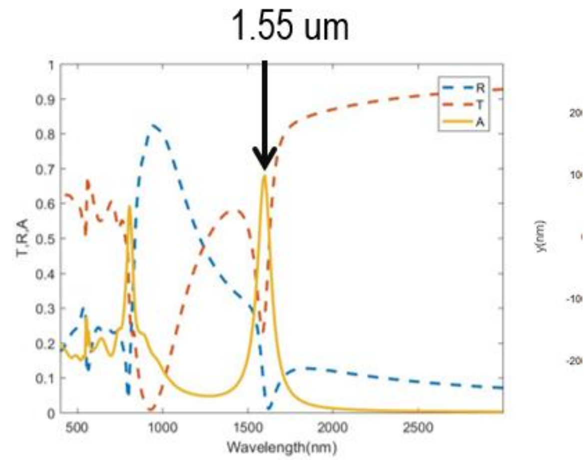

Figure 3. Simulation result of transmission, reflection and absorption of the chevron structure. The structure geometry is optimized for the optical communication wavelength of 1.55 um.

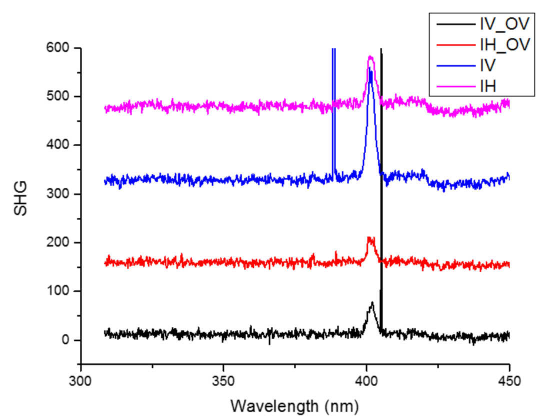

Figure 4. Characterization of nonlinear property of the structure by measuring second harmonic generation. A sample was hit by a pulsed laser with 800 nm wavelength, 200 uW power and 20 um beam diameter.