Highly-efficient All-dielectric Huygens' Surfaces Holograms

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300 word summary:

Optical metasurfaces have developed as a breakthrough concept for advanced wave-front. Key to these "designer metasurfaces" is that they provide full 2π phase coverage and that their local phase can be precisely controlled. However, reflection and/or absorption losses as well as low polarization-conversion efficiencies pose a fundamental obstacle for achieving high transmission efficiencies that are required for practical applications.

Here, we demonstrate the first holographic metasurface utilizing the concept of all-dielectric Huygens' surfaces thereby achieving record transmission efficiencies of approximately 82% at 1477nm wavelength. Our low-loss Huygens' surface is realized by two-dimensional subwavelength arrays of silicon nanodisks with both electric and magnetic dipole resonances designed to function as near-ideal Huygens' particles. This allows us to realize a full 2π coverage that lack dissipative losses and also suppress unwanted reflections without relying on cross-polarization schemes that suffer from polarization-conversion losses.

We effectively generate a hologram showing the letters 'hv'. In order to design the arrangement of the pixels in the metasurfaces, we calculate the phase mask required for a hologram generating the letters 'hv' in the hologram plane. In the next step the phase mask is fabricated on a back-side polished SOI wafer by electron-beam lithography followed by a reactive-ion etching process. Then, we measure the phase of the generated hologram using a home-built Mach-Zehnder interferometer and perform a phase retrieval process to compare the experimental phase with the designed phase. Finally, we record the holographic image in the hologram plane and demonstrate that the device functionality is completely polarization insensitive with a transmission efficiency of 82%, in contrast to all the earlier works utilizing geometric phase.

500word abstract:

Optical metasurfaces have developed as a breakthrough concept for advanced wave-front. Key to these "designer metasurfaces"[1] is that they provide full 2π phase coverage and that their local phase can be precisely controlled. The local control of phase, amplitude and polarization on an optically thin plane will lead to a new class of flat optical components in the areas of integrated optics, flat displays, energy harvesting and mid-infrared photonics, with increased performance and functionality. However, reflection and/or absorption losses as well as low polarization-conversion efficiencies pose a fundamental obstacle for achieving high transmission efficiencies that are required for practical applications.
A promising way to overcome these limitations is the use of metamaterial Huygens' surfaces [2-4], i.e., reflection-less surfaces that can also provide full 2π phase coverage in transmission. Plasmonic implementations of Huygens' surfaces for microwave [2] and the mid-infrared spectral range [3], where the intrinsic losses of the metals are negligible, have been suggested, however, these designs cannot be transferred to near-infrared or even visible frequencies because of the high dissipative losses of plasmonic structures at optical frequencies.

Here, we demonstrate the first holographic metasurface utilizing the concept of all-dielectric Huygens' surfaces thereby achieving record transmission efficiencies of approximately 82% at 1477nm wavelength. Our low-loss Huygens' surface is realized by two-dimensional subwavelength arrays of loss-less silicon nanodisks with both electric and magnetic dipole resonances [4]. By controlling the intrinsic properties of the resonances, i.e. their relative electric and magnetic polarizabilities, quality factors and spectral position, we can design silicon nanodisks to behave as near-ideal Huygens' particles. This allows us to realize all-dielectric Huygens' surfaces providing full 2π coverage that lack dissipative losses and also suppress unwanted reflections without relying on cross-polarization schemes that additionally suffer from polarization-conversion losses.
We now use such Huygens' surfaces in order to create a highly-efficient phase masks for the generation of optical holograms. By varying only one geometrical parameter, namely the lattice periodicity that can be controlled easily during the fabrication process we can effectively generate arbitrary hologram images from a 4-level phase discretization. In order to design the arrangement of the pixels in the metasurfaces, we calculate the phase mask required for a hologram generating the letters 'hv' in the hologram plane. In the next step the Huygens' hologram is fabricated on a back-side polished SOI wafer by electron-beam lithography followed by a reactive-ion etching process. Then, we measure the phase of the generated hologram using a home-built Mach-Zehnder interferometer and perform a phase retrieval process to compare the experimental phase with the designed phase. Finally, we record the holographic image in the hologram plane and demonstrate that the device functionality is completely polarization insensitive with a transmission efficiency of 82%, in contrast to all the earlier works utilizing geometric phase.

References

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