Continuous Angle Beam Steering Using Spatiotemporal Frequency-Comb Control in Dielectric Metasurfaces

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Abstract: Experimental laser beam steering is demonstrated using light-matter interaction between frequency-comb source and silicon based metasurface. Continuous angular scanning of 25^0 is successfully achieved over a time interval of 10 ps.

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1. Introduction

Laser beam steering is a pivotal component in numerous current and developing applications including LIDAR, laser scanners, and autonomous vehicles. Faster laser scanning is directly related to higher frame rates as well as improved imaging resolution. Rapid beam rotation is typically achieved using optical phased-arrays implemented with liquid crystals or other means of electro-optic spatial light modulators [1]. To further enhance the scanning time over large and continuous angle of view, we present a novel methodology of "Frequency-Arrayed Optics". With this methodology, ultrafast laser beam steering is implemented through light-matter interaction between a silicon-based metasurface and a mode-locked laser with a frequency-comb spectrum (i.e., an equally spaced phased-locked frequency lines).

2. Interaction of Frequency-Comb Source and Phase-Gradient Metasurfaces

Over the past few years, metasurfaces have been used with continuous-wave (CW) lasers to engineer the spatial distribution of light in the far-field leading to successful implementations of light bending [2], meta-lenses [3], meta-holograms [4] and other applications. This is achieved through coherent interference of scattered waves from an array of nano-structured elements that are locally controlling the optical phase-front. These applications require spatial coherence which imposes employment of a monochromatic laser, but this leads only to generation of static optical patterns. Instead, we demonstrate that it is possible to generate dynamic patterns through coherent interference of waves in 4D space-time if CW laser is replaced with a frequency-comb source. In our work, the metasurface is judiciously designed such that the spatial distribution of light generated in the far-field is different for each of the frequency-comb spectral lines. Because the spectral lines are phase-locked, their different optical patterns are constructively interfered at a narrow angle in the far-field leading to directivity of the laser beam. The temporal coherence of the phase-locked spectral components causes the direction of the constructed laser beam to be at a time-dependent rotating angle; and henceforth, beam steering is realized.

3. Experimental Results

Figure 1(a) displays a conceptual schematics of the experimental setup used to implement the dynamic optical beam steering. An ultrafast pulse laser source provides a frequency-comb spectrum. A phase-gradient metasurface is judiciously designed to focus these frequency lines to equidistant locations on the same focal plane. Figure 1(b) provides an SEM image showing part of the metasurface. It is implemented using highly anisotropic Si nano-antennas. They enabled the realization of Pancharatnam-Berry Phase controlled by local geometric orientation of individual antennas. The whole metasurface structure is 8 mm x 4 mm, obtained through large scale fabrication using standard Electron Beam Lithography and Reactive Ion Etching. The focal plane where all the frequency lines are focused acts as a "frequency-arrayed" source. Figure 1(c) demonstrates a conceptual schematic of the light generated from the frequency-arrayed source. In the proposed frequency-arrayed arrangement, different frequency elements induce different spacing between phase-front, and therefore, constructive interference of optical waves causes the direction of light propagation to change as time proceeds. Therefore, this focal plane operates as a frequency-arrayed source where light propagating from different frequencies to the far-field interfere to a narrow beam whose direction θ is time-dependent (Beam Steering Action). A microscope objective is used to map the angle θ to horizontal displacement hitting a streak camera which capture this displacment Vs time. Figure 4(d) displays the streak camera measurement showing angular steering over a continuous range of 25^0 during a time period in the order of 10 ps.

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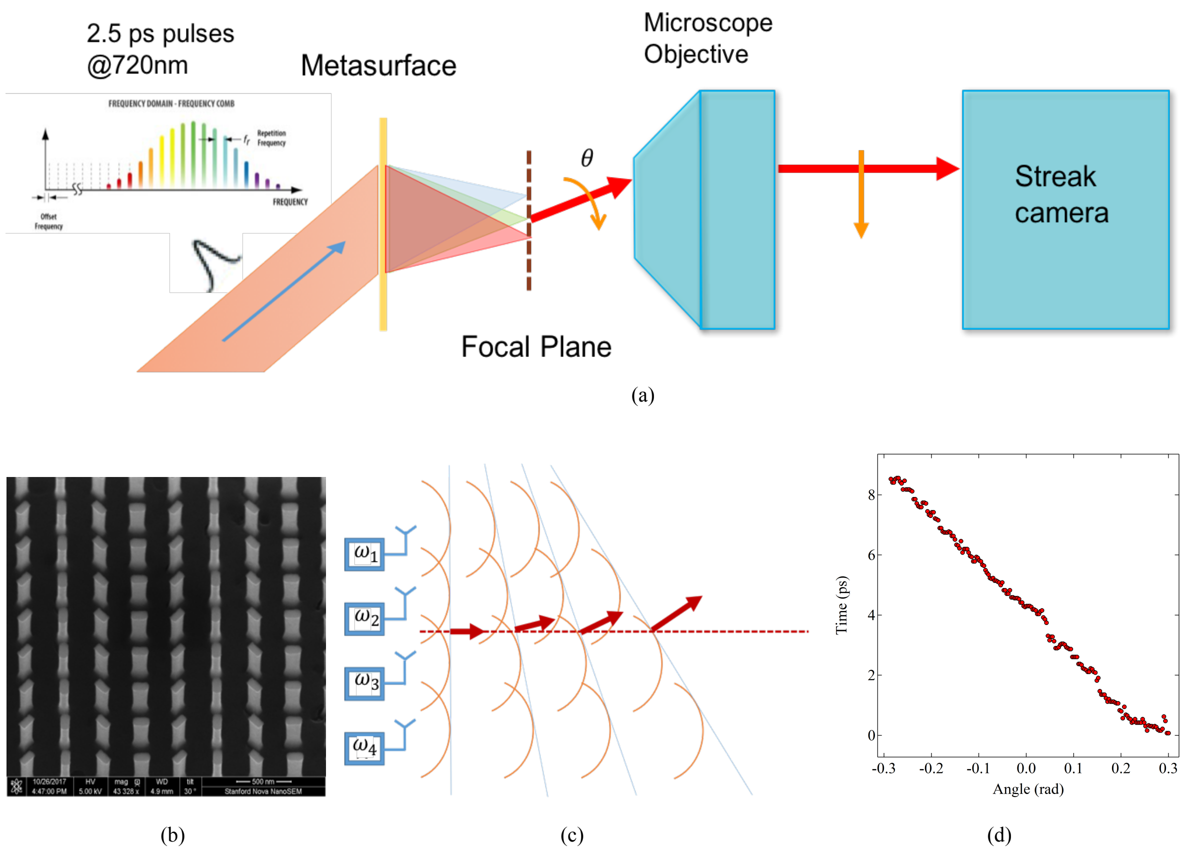

Figure 1: (a) Schematics of experimental Setup consisting of a frequency-comb source (picosecond pulse), silicon-based metasurface, microscope objective and streak camera. (b) SEM image of a section of the fabricated Silicon based metasurface. (c) Conceptual schematic of beam steering using frequency-arrayed source. (d) Experimental measuremt of the streak camera showing the beam steering action.

4. Conclusions

Design and implementation of a dynamic laser beam steering device has been achieved using light-matter interaction between a frequency-comb source and a dielectric metasurface. A new methodology of frequency-arrayed optics is introduced which can be extrapolated towards achieving other 4D spatiotemporal patterns such as axial scanning. The results provide an insight towards integrating the fields of nanophotonics and ultrafast optics to control light with high spatiotemporal accuracy.

5. References

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