論文の内容の要旨

Terahertz Beam Steering Based on Structured Surface Scattering
（構造化表面散乱に基づくテラヘルツ波ビーム制御）

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Being located between conventional radio and light frequencies, the terahertz (THz) regime has been the last frontier in the use of electromagnetic waves. The THz waves hold great potential particularly in sensing, imaging, and wireless communications. Over the last few decades, numerous techniques to generate and detect THz waves have been developed. Among others, the advent of THz time domain spectroscopy has driven intensive studies on material properties in THz frequencies. Besides, the continuous race of increasing carrier oscillation frequencies in semiconductor devices and decreasing laser oscillation frequencies in quantum cascade lasers has been bringing practical THz sources usable at room temperature with a tiny setup.

Nevertheless, there still exists a missing piece to explore the full potential of the THz waves, i.e. THz beam steering. The wavelength of THz waves imposes multiple challenges in free space transmission. On one hand, it is far shorter than a microwave wavelength, hence THz signals must be transmitted via highly directed links to compensate for path losses. Consequently, the free space THz transmission will suffer from line-of-sight problems. On the other hand, the THz wavelength is far longer than an optical wavelength, which makes THz components such as lenses or phase shifters much bulkier than their optical counterparts. These challenges motivate us to develop integrated systems that allow for THz beam steering. Once it is established, it would play key roles in a wide range of applications. For instance, in THz wireless communications, where quasi-optical links rely on directed paths between emitters and receivers, beam steering allows for finding the optimum path automatically even when the emitters or receivers are changing their positions or in movement. In THz sensing or imaging, beam steering devices are usable in place of mechanical scanning stages, and thus dramatically enhance the speed of measurements and the level of system integration. High speed beam

steering could also lead to novel THz methodologies, for example, imaging of moving objects by tracking the targets with THz beams.

In this thesis, the author proposes and demonstrates the steering of THz beams based on the control of surface scattering from artificial structures. Since the THz waves are likely to experience high losses when propagating through media, it is advantageous to implement phase shifting via scattering or reflection from artificial surfaces. In particular, the approach to convert guided waves into collimated or focused radiation is promising for planar, large aperture, and low-loss THz beam steering systems. For this purpose, we first investigate coherent scattering of THz plasmonic surface-waves into free space using structured metal surfaces. We experimentally demonstrate nearly diffraction limited THz focusing with a planar device by incorporating a non-equidistant grating on the waveguide. Next, we propose a programmable reflection grating that allows for electrically controlled steering and focusing of THz radiation. We experimentally demonstrate THz beam steering and focusing over a wide frequency band by the computer controlled grating. Finally, we numerically consider the combination of the two: THz plasmonic surface-wave scattering by a programmable grating, which will lead to fully integrated planar THz beam steering systems. Although the experimental characterization remains as a future work, we demonstrate the steering of 2.4 GHz microwaves based on surface-wave scattering using electronically reconfigurable scatterers.

It should be emphasized that the proposed scheme is independent of the wave generation. Hence, it can be combined with any THz sources regardless of the generation method or the signal intensity. A variety of THz sources such as quantum cascade lasers, photoconductive antennas, or even electrically generated radiation can be used depending on the applications. Thus it will involve a breakthrough for a variety of applications in which free space THz propagation is indispensable such as wireless communications and stand-off imaging.