Efficient Terahertz-Range Beam Control Using Flat Optics

by

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Contents

Abstract

The terahertz range, which spans 0.1 to 10 THz of the electromagnetic spectrum, has significant potential for numerous diverse uses including high-volume short-range communications, non-invasive and non-destructive sub-dermal medical imaging, and safe imaging of personnel and postal items for security applications. These capabilities are identified due to the unique properties of terahertz radiation; terahertz waves are of high carrier frequency relative to conventional wireless communications, are able to transmit through dry, non-polar substances, and yet are non-ionising. However, owing to factors including a lack of available power and significant atmospheric attenuation, it is challenging to maintain sufficient signal power over a realistic propagation distance for terahertz waves. For this reason, the terahertz range is presently lacking in practical applications, and hence it occupies an under-utilised portion of the electromagnetic spectrum. As unused spectrum is a valuable resource, the development of technologies to exploit the terahertz range is a highly desirable goal.

Beam-control techniques—the capacity to shape and steer electromagnetic radiation—can prevent radiated power from being lost to undesired directions. Thus, techniques of this variety have the capacity to address the aforementioned obstacles to the realisation of practical terahertz technologies. This thesis is therefore centred around the development of terahertz beam-control devices that satisfy two criteria. Firstly, the beam manipulation operation must be highly efficient, as much of the motivation of this work is to mitigate the constraints upon power. Secondly, planar devices are preferable, as this is a requirement for compact systems. With these restrictions in mind, various techniques are explored for their viability in future applications of terahertz technology, including various forms of metallic and dielectric resonators, 3D printing, and composite materials with effective properties. The advantages and drawbacks of each approach are evaluated.

Statement of Originality

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Signed Date

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Conventions

Typesetting

This thesis it typeset using the LaTeX2e software. Vim build 7.4 was used as an effective interface to LaTeX.

Referencing

Harvard style is employed for referencing and citation in this thesis.

System of units

The units comply with the international system of units recommended in an Australian standard: AS ISO 1000-1998 (Standards Australia Committee ME/71, Quantities, Units and Conversions 1998).

Spelling

Australian English spelling is adopted, as defined by the Macquarie English Dictionary (Delbridge 2001).

Terminology

Where applicable, recent terminology is employed for this thesis, in accordance with that which is seen to be used most frequently in the interested academic community. For instance, the frequency range in which these investigations are undertaken could validly be classified as either the sub-mm or the terahertz range, but most recent work at similar frequencies employs the latter terminology, and hence this is adopted for this thesis.

Publications

Journal publications

Chang-C.-C.,* **Headland-D.**,* Abbott-D., Withayachumnankul-W., and Chen-H.-T. (2017). Demonstration of a highly efficient terahertz flat lens employing tri-layer metasurfaces, *Optics Letters*, **42**(9) pp. 1867–1870.
*These authors contributed equally to this work.

DH performed unit-cell modelling, array-level design and modelling, experimentation, and lead the writing and publication of the manuscript.

Headland-D., Niu-T., Carrasco-E., Abbott-D., Sriram-S., Bhaskaran-M., Fumeaux-C., and Withayachumnankul-W. (2017). Terahertz reflectarrays and nonuniform metasurfaces (**Invited for special issue on Terahertz Photonics**), *IEEE Journal of Selected Topics in Quantum Electronics*, **23**(4), art. no. 8500918.

DH lead the writing of the manuscript of this review article.

Headland-D., Withayachumnankul-W., Webb-M., Ebendorff-Heidepriem-H., Luiten-A., and Abbott-D. (2016). Analysis of 3D-printed metal for rapid-prototyped reflective terahertz optics, *Optics Express*, **24**(15), pp. 17384–17396.

DH performed design and modelling of the devices in this work, conducted all experiments and analysis, and lead the writing of the article.

Headland-D., Carrasco-E., Nirantar-S., Withayachumnankul-W., Gutruf-P., Schwarz-J., Abbott-D., Bhaskaran-M., Sriram-S., Perruisseau-Carrier-J., and Fumeaux-C. (2016). Dielectric resonator reflectarray as high-efficiency nonuniform terahertz metasurface, *ACS Photonics*, **3**(6), pp. 1019–1026.

DH performed modelling of the device presented in this work, conducted all experiments and analysis, and lead the writing of the article.

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DH conducted all experiments and analysis, and lead the writing of the article.

CHENG-Y. Z., WITHAYACHUMNANKUL-W., UPADHYAY-A., **HEADLAND-D.**, NIE-Y., GONG-R. Z., BHASKARAN-M., SRIRAM-S., AND ABBOTT-D. (2015). Ultrabroadband plasmonic absorber for terahertz waves, *Advanced Optical Materials*, **3**(3), pp. 376–380.

DH performed modelling and analysis.

NIU-T., UPADHYAY-A., WITHAYACHUMNANKUL-W., **HEADLAND-D.**, ABBOTT-D., BHASKARAN-M., SRIRAM-S., AND FUMEAUX-C. (2015). Polarization-dependent thin-film wire-grid reflectarray for terahertz waves, *Applied Physics Letters*, **107**(3), art. no. 031111.

DH conducted experiments.

CHENG-Y. Z., WITHAYACHUMNANKUL-W., UPADHYAY-A., **HEADLAND-D.**, NIE-Y., GONG-R. Z., BHASKARAN-M., SRIRAM-S., AND ABBOTT-D. (2014). Ultrabroadband reflective polarization convertor for terahertz waves, *Applied Physics Letters*, **105**(18), art. no. 181111.

DH conducted experiments.

Conference publications

CARRASCO-E., **HEADLAND-D.**, NIRANTAR-S., WITHAYACHUMNANKUL-W., GUTRUF-P., SCHWARZ-J., ABBOTT-D., BHASKARAN-M., SRIRAM-S., AND FUMEAUX-C. (2017). Demonstration of a high-efficiency reflectarray antenna at 1 THz based on dielectric resonators (**Finalist for a best paper award**), *11th European Conference on Antennas and Propagations*, Paris, France, pp. 3335–3337.

HEADLAND-D., CARRASCO-E., NIRANTAR-S., GUTRUF-P., SCHWARZ-J., ABBOTT-D., BHASKARAN-M., SRIRAM-S., PERRUISSEAU-CARRIER-J., FUMEAUX-C., AND WITHAYACHUMNANKUL-W. (2016). Efficient terahertz reflectarray based on dielectric resonator antennas, *41st International Conference on Infrared, Millimeter, and Terahertz Waves*, Copenhagen, Denmark.

HEADLAND-D., NIRANTAR-S., GUTRUF-P., ABBOTT-D., BHASKARAN-M., FUMEAUX-C., SRIRAM-S., AND WITHAYACHUMNANKUL-W. (2016). Fabrication of micro-scale single-crystal silicon structures for efficient terahertz magnetic mirror, *41st International Conference on Infrared, Millimeter, and Terahertz Waves*, Copenhagen, Denmark, DOI: 10.1109/IRMMW-THz.2016.7758654.

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WITHAYACHUMNANKUL-W., **HEADLAND-D.**, SRIRAM-S., BHASKARAN-M., AND FUMEAUX-C. (2016). Silicon terahertz resonators, *2nd Australian Microwave Symposium*, Adelaide, Australia, pp. 27–28, DOI: 10.1109/AUSMS.2016.7593477.

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HEADLAND-D., THURGOOD-P., STAVREVSKI-D., WITHAYACHUMNANKUL-W., ABBOTT-D., BHASKARAN-M., AND SRIRAM-S. (2015). Modified elastomeric polymers for loss reduction in the terahertz range, *40th International Conference on Infrared, Millimeter, and Terahertz waves*, Hong Kong, DOI: 10.1109/IRMMW-THz.2015.7327610.

HEADLAND-D., WITHAYACHUMNANKUL-W., WEBB-M., UPADHYAY-A., BHASKARAN-M., SRIRAM-S., AND ABBOTT-D. (2014). Dielectric hole lattice for terahertz diffractive optics with high transmission, *39th International Conference on Infrared, Millimeter, and Terahertz Waves*, Tucson, USA, DOI: 10.1109/IRMMW-THz.2014.6956000.

CHENG-Y. Z., WITHAYACHUMNANKUL-W., UPADHYAY-A., **HEADLAND-D.**, NIE-Y., GONG-R. Z., BHASKARAN-M., SRIRAM-S., AND ABBOTT-D. (2014). Broadband terahertz reflective linear polarization convertor, *39th International Conference on Infrared, Millimeter, and Terahertz Waves*, Tucson, USA, DOI: 10.1109/IRMMW-THz.2014.6956188.

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List of Figures

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