# Terahertz sensing and imaging using atomic vapor cells.

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## Topic(s)

"quantum sensing/metrology", "cross-cutting technologies"

## Background

In recent years, Rydberg atoms have emerged as a key contender in a variety of quantum technologies including quantum computing, single photon sources, RF communications and RF sensing [1]. There is particular promise for using Rydberg atoms in metrology where precision spectroscopy allows for SI-traceable standards across the microwave and millimeter wave region [2,3]. At higher frequencies, in the terahertz region of the spectrum, there is a gap between electronic, microwave technologies and photonic, infrared technologies, often referred to as the terahertz gap. In this region, despite the efforts of the last three decades, there are significant issues for producing high power terahertz sources as well as sensitive terahertz detectors. There are also no standard dipole antennas with which to calibrate the fields.

Rydberg-atom-based quantum technologies are beginning to make progress into this ultra-high-frequency, terahertz range and offer prospects for calibrated measurement. In our work, we have been able to demonstrate precision terahertz electrometry at frequencies above 1 terahertz using infrared diode lasers. Using Rydberg electromagnetically induced transparency [5], we are able to measure fields with a sensitivity of ~ 1 V/m for frequencies over 1 THz. In other work, Rydberg atoms in vapor cells have been used to generate milliwatts of narrowband terahertz radiation [4].

There is much interest in using terahertz imaging technology across a wide range of applications including medical diagnostics, security scanning and production-line quality control. However, for many applications, THz imaging has not yet achieved the required speed and sensitivity for real-time analysis and therefore, it remains a long-standing goal to achieve true real-time and full-field terahertz imaging. We have demonstrated high-speed, sensitive and high spatial resolution terahertz imaging, both in the near field [6] and in the far field [7]. The technique involves using atoms, contained within a room temperature vapor cell, to convert difficult to detect terahertz photons into easy to detect optical photons. Images can then be captured at high speed using standard optical cameras. We have been able to achieve unprecedented frames rates in the kilohertz range limited only by our available optical camera.

## Presentation

Here we report on progress in terahertz electrometry and imaging using Rydberg atoms in atomic vapor cells. We show that, using only infra-red diode lasers, we are able to perform precision measurements on atomic rubidium at frequencies above 1 THz. An example spectrum is shown as Fig.1. We achieve an electric field sensitivity of < 3 V/m and a minimum detectable power of 0.03 microWatts at a frequency of 1.06 THz.

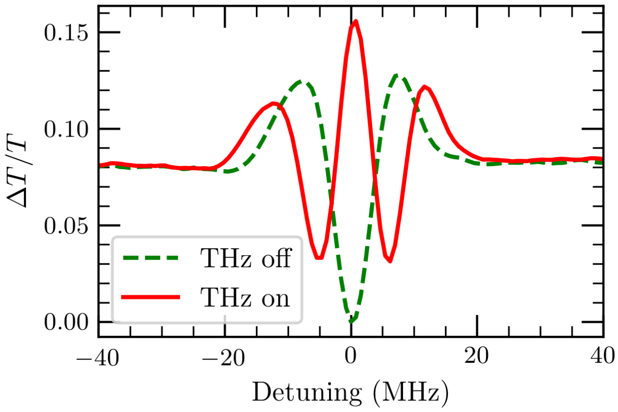


Fig. 1 EIT Spectra without the terahertz field at 1.06 THz allows THz electrometry within a rubidium vapor cell

Furthermore, we present a method for terahertz imaging which uses room-temperature atomic vapor as an efficient terahertz-to-optical convertor, thereby allowing imaging to be collected using standard optical cameras. We demonstrate 2D imaging with near diffraction-limited resolution for a 1 $cm^2$ sensor and frame rates of several kilohertz. The system demonstrates a linear sensitivity scaling at low intensities and we measure a minimum detectable intensity of ~0.1 mW m^-2 for 1 s integration. An image of ‘Ψ’ in the vapour cell is shown as Fig. 2. We expect that with some minor modifications to the setup, frame rates exceeding 50 kHz should be possible.

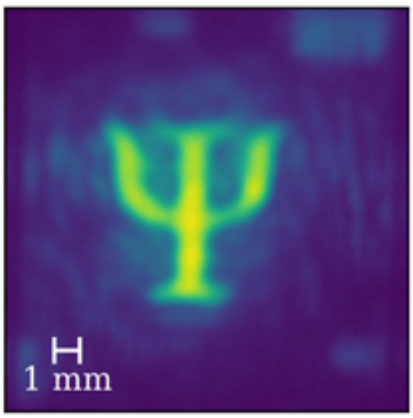


Fig. 2 Terahertz image formed from the optical fluorescence of a cesium vapor contained with a vapor cell. The images have diffraction limited resolution and can be captured in a few milliseconds.

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