ment is approximately f/2, so scattered photons whose propagation has been diverted by less than ~14° are still collected by the lens. These photons have traveled a slightly longer path through the material, and are therefore delayed somewhat.

For these samples, the product of the wave vector and the mean free path l_{tr} is never less than ~20, so these data represent only the weak scattering regime. However, we can also fabricate strongly scattering samples, using 0.5 mm cubes of high-resistivity silicon, (n = 3.42). With these samples, it is possible to more closely approach the Ioffe-Regel criterion, $k \cdot l_{tr} \sim 1$. These data demonstrate the possibility of using THz time-domain spectroscopy for light localization measurements.

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JMC2 **4:00 pm**

Powder Detection Using THz Imaging

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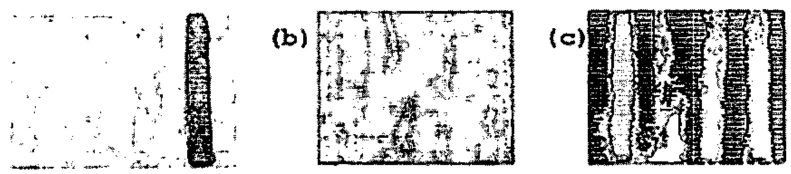
The non-destructive scanning of mail envelopes and packages is a topic of intense current interest. A large number of techniques are under investigation for the rapid screening of mail to detect illegal and/or harmful substances such as explosives, illicit drugs and bioterrorism substances such as the Anthrax causing bacterium Bacillus anthracis. Terahertz imaging has a number of important advantages in this application setting. Firstly paper, plastics, cardboard and many other packaging materials are largely transparent to THz radiation. Additionally, the coherent detection of THz pulses provides frequency-dependent, phase sensitive measurements of the response of the sample. This information may one day lead to a reliable method for the detection of specific substances in mail.

The chirped probe beam THz imaging system (CPTI) encodes the time varying THz information directly onto a chirped probe beam.[1] The chirped probe beam can be thought of as an optical pulse with a continuous frequency distribution, which is linear function of pulse delay. Therefore, the information at certain time is encoded at a corresponding frequency. By dispersing the probe beam in the frequency domain, the encoded information can be extracted.[2] The full THz waveform is measured simultaneously, thereby CPTI can dramatically accelerate the imaging speed.



JMC2 **Fig. 1.** The powders used to demonstrate THz imaging. Figure (a) shows the piece of paper containing samples of salt, baking soda, flour and seasoning (from left to right). Figure (b) shows the THz image at a frequency of 0.3 THz. Figure (c) shows the results of classifying the THz data as described in the text. The image consists of five shades of gray. From darkest to lightest they correspond to paper, salt, baking soda, flour and seasoning.

We placed four different powdered samples: flour, salt, baking soda and seasoning inside a paper envelope and used the CPTI system to scan the envelope in x and y dimensions. This took approximately 8 minutes because we scanned the envelope in 2 dimensions. Using a 1D chirped probe pulse THz imaging system[3] it is feasible to attain a potential throughput of 12 envelopes/minute. 800 milligrams of each of the sample powders were placed on double sided cellotape and attached to a piece of paper as shown in Fig. 1(a) and placed in an envelope. The envelope was imaged and the transmitted THz waveform was measured at each pixel. The Fourier transform of the THz waveform provides information on the frequency dependent scattering, absorption and refractive index of the sample. In this way the powders can be detected. Figure 1(b) shows a THz image produced by plotting the intensity of the THz pulse at a frequency of 0.3 THz, in Fig. 1(c) we have used simple classification algorithms to differentiate between the different powders. A linear discriminant classifier was trained using the responses for 100 random pixels of each powder then the whole image was classified.

To more accurately assess the applicability of THz imaging to Anthrax detection we considered samples of Bacillus thurengiensis (BT) bacteria. Several bacilli produce spores that are physically and chemically very similar to those produced by B. anthracis, including B. thuringiensis, which is commonly used for insect control in gardens and is non-pathogenic to man and other mammals. Approximately 500 milligrams of B. thuringiensis spore flakes were placed inside an envelope and imaged using the CPTI system. Fig. 2. shows the envelope containing the BT spores and Fig. 3. shows the THz image of the envelope using the amplitude of the responses at 0.3 THz. The spores are clearly visible.

We have shown that THz imaging can detect powders inside envelopes at a concentration of 80 milligrams/cm^2 and that in a carefully controlled experiment classification algorithms can be used to differentiate between different types of powders. We have also presented images of bacteria spores inside envelopes and will demonstrate the performance of classification algorithms in detecting B. thuringiensis.

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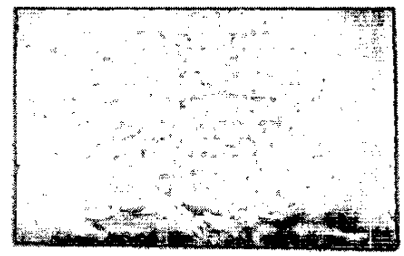
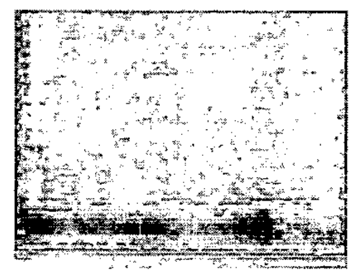


JMC2 **Fig. 2.** Standard optical photograph of the envelope containing the spore flakes. The envelope is backlit to allow the spore flakes to be viewed.



JMC2 **Fig. 3.** THz image of of the envelope containing the spore flakes. The amplitude of the responses at 0.3 THz were mapped to the grayscale intensity.

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JMC3 **4:15 pm**

Three Dimensional Imaging Using T-ray Computed Tomography

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For over a decade it has been known that terahertz time-domain spectroscopy systems can be