Imaging Fourier transform spectroscopy using an uncooled microbolometer array

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Abstract—**We report on the characteristics of an uncooled microbolometer detector array relevant for its performance in an imaging Fourier transform spectrometer. The saturation limit of the microbolometer detectors was measured and the non-linear response below saturation determined to be less than 4%.**

I. INTRODUCTION

THE advantages of Fourier transform spectroscopy (FTS) are well known: High throughput, simultaneous measurement of all wavelengths, broad spectral coverage, intrinsic wavelength calibration, simplified intensity calibration and the best instrumental line shape of any spectrometer. These attributes are particularly desirable for conducting spectroscopic investigations in the energy starved THz region. Moreover, since an FTS provides a stigmatic image of the object plane, FTS provides hyperspectral imaging capability when combined with detector arrays. The recent development of relatively inexpensive, uncooled, compact microbolometer arrays has enabled investigations into the utility of thermal iFTS applications, which have hitherto been limited by the need for expensive, cryogenically-cooled detector arrays. Two detector characteristics are particularly important for FTS applications: linearity and frequency response.

Since the Fourier transform is a linear transform, accurate spectral retrieval is critically dependent on the linearity of the detector response to radiant energy. While the detector response time and read-out rate define the minimum observation time, it is the linearity which ultimately defines the photometric precision that can be achieved with the iFTS.

The time it takes a bolometer to change its temperature in response to incident radiation is commonly represented as the thermal relaxation time constant, τ. Bolometers are made of materials with a large temperature coefficient mounted onto a dielectric substrate to establish a thermal connection to a heat sink. More sensitive measurements require a larger absorber with higher heat capacity, leading to a slower relaxation of the bolometer. The relaxation time can be reduced by increasing the thermal conductance between the bolometer and the heat sink. The electro-thermal interaction between the heating of the bolometer from the absorbed radiation and the resulting change in dissipated electrical power increases the apparent thermal conductivity [2]. The effective relaxation time of a bolometer is therefore given by the ratio of the heat capacity to the effective thermal conductance.

The interferometer of an FTS introduces illumination changes at timescales driven by the rate of change in optical path difference (OPD), i.e. it is related to the speed at which the linear translation stage moves. The time constant of the detectors in an FTS must be smaller than the time scales at which the illumination changes, and should not change over the required range of optical loading.

The thermal conductance of a bolometer may change in a non-linear fashion when it is subject to large variation in optical load, as is the case in an interferometer where the illumination can be up to a factor of 2 higher at the point of symmetry in the interferogram than the average illumination. The high dynamic range of the illumination may cause the bolometers to exhibit a change in the relaxation time. If the relaxation time of the bolometer changes during a scan, the recorded interferogram will exhibit asymmetrical features about zero path difference. The spectral phase, defined as φ = arctan(Imaginary(Spectrum) / Real(Spectrum)), is used to characterize such asymmetries. A linear phase indicates a displacement of the recorded interferogram with respect to the assumed point of symmetry, while a non-linear phase indicates other common asymmetries encountered in FTS due to chromatic elements such as the beamsplitter and filters, and also detector and electronics time constants.

In this paper we present results from a study of the linearity of a microbolometer array under varying radiant loading. The uncooled bolometer array used in this study contains 160×120 pixels on a 50 μm pitch and is optimized for the spectral region of 8 to 12 μm[1]. The analysis is extended to characterize the performance of the microbolometer array when integrated into an iFTS.

II. EXPERIMENT

This study consists of two parts: Measuring the linearity of the bolometer responsivity as a function of optical loading, and confirming the temperature sensitivity of the bolometer frequency response does not introduce non-linear phase effects in the iFTS spectra.

In order to characterize the linearity of the microbolometer responsivity under varying optical loading, measurements were obtained of a temperature controlled blackbody source operating at discrete temperatures between 230 and 700 °C. An adjustable iris placed between the blackbody and microbolometer allowed for precise control of the radiant loading.

In order to evaluate the microbolometer performance when coupled with an FTS, a simple Michelson interferometer was assembled with two flat mirrors and a 6.5 μm thick polypropylene beamsplitter which provides good modulation efficiency over most of the microbolometer bandpass. With one of the mirrors fixed in position, the other mirror is displaced by a linear piezo translation stage with an overall travel of 800 μm and accuracy of ~20 nm. A commercial mid-infrared F/1.0 lens was coupled to the detector array. Double-

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sided interferograms were recorded at 0.5 μm steps of the linear translation stage to provide a maximum OPD of just below 800 μm, resulting in a Nyquist frequency of 5000 cm^{-1} and a resolution of 6.25 cm^{-1}. The spectral resolving power for the nominal bandpass of the microbolometer array reaches approximately 180.

While the microbolometer manufacturer specifies a relaxation time below 25 ms, which is suitably less than the 90 ms interferometer modulation period in our study, we have measured the non-linear phase of the imaging FTS to determine whether the relaxation time varies enough with optical load (T = 200, 300, 400 and 500 °C) to have a negative impact on the measured spectra.

III. RESULTS

As expected, the microbolometer saturated at high optical loads (T > 400 °C) corresponding to a resistance of 95 kΩ or an optical load of ~1 μW. Stray radiation from outside the iris aperture is accounted for by subtracting a reference measurement of the closed aperture from all detector readings. A linear least-squares fit was performed on the first ten data points for each set of measurements at a given temperature. The difference between the measured data and the fit, divided by the fit, i.e. the relative non-linearity, is shown as a function of radiant load in the lower part of Fig. 1. This analysis shows that, below the saturation limit, the non-linear response of the

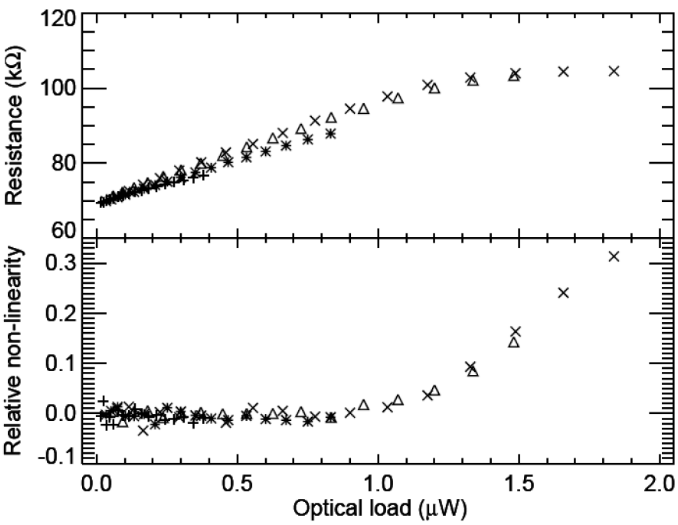

Fig. 1. Resistance and relative non-linearity of a microbolometer detector at different source temperatures;
T = 230 °C(+), 400 °C(∗), 600 °C(Δ), 700 °C(×)

detectors is less than 4%.

The reproducibility of the non-linear phase (shown in Fig. 2) indicates that there is no significant contribution from a variation in detector time constant or other non-linearity when measuring temperatures of up to 500 °C with the imaging FTS. These results confirm that variations less than 0.033 μW in the optical load, on time-scales of >90 ms, do not negatively affect the spectral results.

Calculating the true bolometer spectral response is complicated by the simple design of the FTS used for these

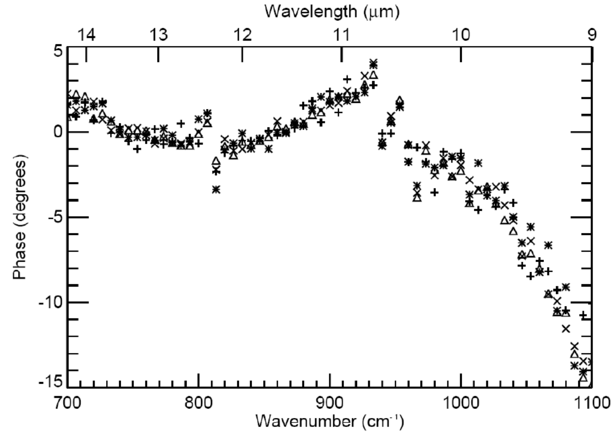

Fig. 2. Non-linear phase of a continuum measurement at different source temperatures; T = 230 °C(+), 400 °C(∗), 600 °C(Δ), 700 °C(×)

tests. The beamsplitter material introduces absorption features and its thickness is responsible for the cyclical variations in the spectra (channel fringes). While the thickness of the beamsplitter was tuned to provide maximum modulation efficiency at the frequencies of interest, calculating the true bolometer response requires calibration against a standard source and detector and is left for future study. Fig. 3 shows the normalized intensity of the observed spectrum, the normalized theoretical source spectrum and the transmission of the 6.5 μm thick polypropylene beamsplitter. The observed spectrum includes the characteristics of microbolometer, germanium lens/window, beamsplitter, atmosphere and black body. The germanium window and lens do not transmit above 16 μm, and the FTS modulation efficiency has minima at ~600, 1200, and 1800 cm^{-1}. A spectral leak at ~ 4.5 μm can be seen, but will require more sophisticated measurement to characterize properly.

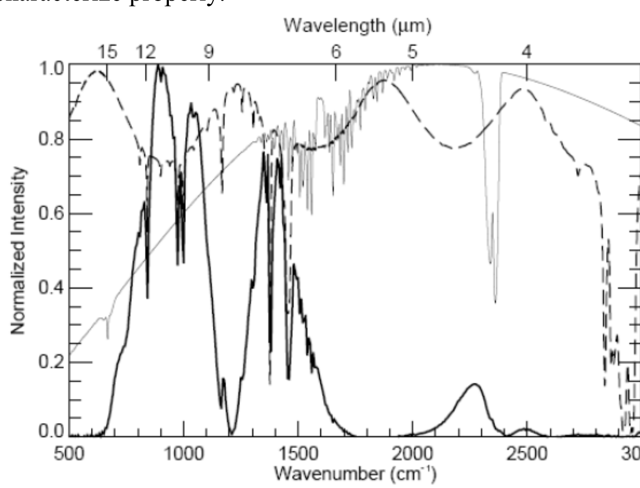

Fig. 3. Observed spectrum on one of the pixels (thick), black body spectrum (thin) and the transmission of beam splitter (dashed)

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