Summary of Research

Optimizing Performance of Far-Infrared Photoconductors: New Approach for Interpretation and Calibration of Transient Response

Final Report

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Overview

The goals of the proposed work were to determine if final steady state current values for Ge:Ga photoconductors could be predicted from the initial fast component of the transient response and to develop algorithms to operationalize this approach. This required transient measurements as a function of photon background and signal sizes, for both single shot and modulated signals. In addition, we proposed to address the nature of the hook response and the effects of non-equilibrium background fluctuations.

Primary results can be summarized as follows:

1) For single step increases in photon flux, we find that the fast fraction of the response (the fraction, from 0 to 1, of the total signal change that occurs rapidly, following the transient time for the light change) is a constant, independent of background and signal size. This allows a determination of the final value from the initial response. However, this result is only obtained when two limiting conditions are met – a) the detector is initially at steady state and b) the turn on time for the signal is short compared to the slow transient response times in the device.

2) The fast fraction is not constant for non-equilibrium starting conditions – i.e., for signals imposed on a constantly changing background and/or for a series of modulated inputs where the time between modulations is not sufficient to restore the steady state.

3) The hook response arises from an initial decrease in the slow component of the response. This means that the presence of the hook does not change the initial fast fraction. However, the onset time for the hook response decreases with increasing signal size. This has the practical effect of making it difficult to capture the full fast fraction for larger signals.

4) Use of transparent contact geometry can significantly reduce (though not fully eliminate) the hook response and decrease the associated transient times in the detector, compared to the common transverse geometry for Ge:Ga detectors.

Experimental results

Detector transient measurements were made for a) variable signal size on fixed photon background and 2) fixed signal size on variable photon background. A standard transversely illuminated Ge:Ge detector was used and the hook effect was clearly observed. Results showed that the fast fraction was constant for a fixed signal imposed on a variable starting background. In contrast, variable signals on a fixed background showed a clear trend of decreasing fast fraction with increasing signal size.

In comparing the experimental results to the modeling results (described below), it became clear that the variation in apparent fast fraction was due to the interaction between the turn on time for the signal and the onset of the hook response, which causes a transient decrease in signal. This is a key result in helping detector users understand the importance of the relative times (signal onset and detector transient response) in interpreting their detector output.

Simulations suggest that reduced illumination in the near-contact region can produce the hook behavior. A comparison was performed of the transient response of the same Ge:Ga material and ultimately device using both standard transverse and transparent (through contact) geometry (Figure 1). Results showed that the hook effect was significantly reduced with the transparent contact illumination and that the transient response time was also decreased.

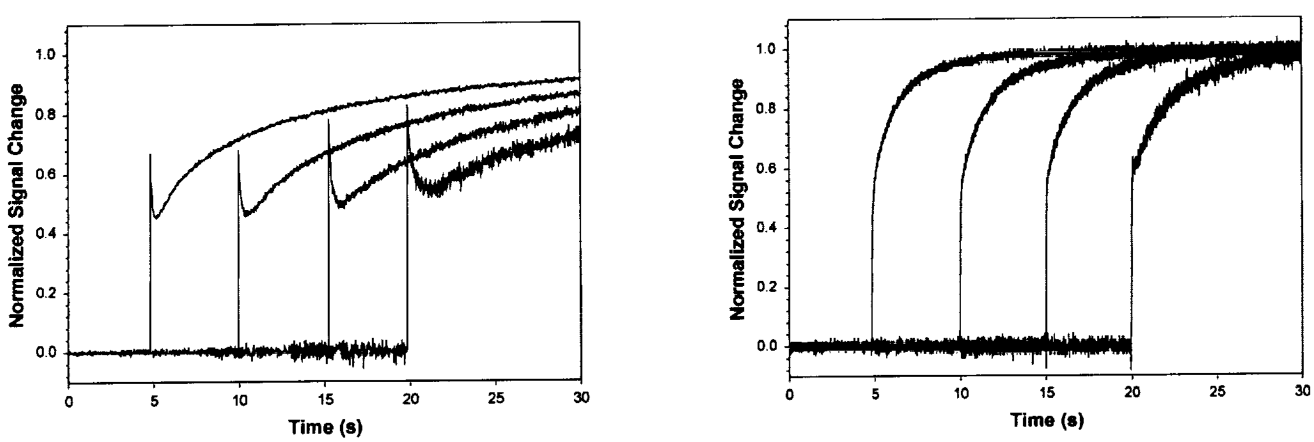

Figure 1: Measured transient response for a Ge:Ga photoconductor with standard transverse contact geometry (left) and transparent contact geometry (right). T = 3.0 K and applied field of 1 V/cm. Results are normalized for comparison but represent a range of signal sizes with absolute signal size increasing from right to left.

Finally, the ratio of the fast to slow fraction of the full transient response can be used as a direct measure of the photoconductive gain, $\mu\tau E/L$. This means that such measurements as a function of applied field E also provide a measure of the $\mu\tau$ product, an important material parameter. Three sets of measurements of the fast/slow fraction as a function of field, for different materials, have been completed.

Simulation results

The combination of numerical simulation of the transient response with the ability to make direct transient measurements of individual devices was a key to much of the progress made during the grant period. One key simulation result (Figure 2) was the behavior of the hook response as a function of increasing signal size. While experimental results had long demonstrated that the hook response increased in magnitude with increasing signal size, the actual short term behavior was often inaccessible experimentally. Simulation results showed that the onset of the hook decreased in time with increasing signal size and illustrated how this result, in combination with the finite turn on times for the added signals, would result in the apparent decrease in fast fraction with increasing signal size.

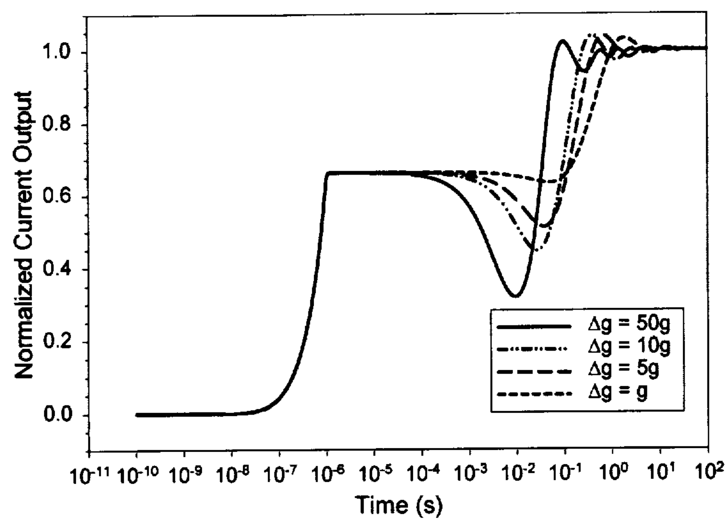

Figure 2: Simulated transient response, with non-uniform illumination, as a function of signal size on fixed background. All simulations are for Ge:Ga with T = 3.0 K and an applied field of 1.0 V/cm. A logarithmic time scale is used to illustrate the full transient response.

Simulations were also performed to compare the effects of uniform versus non-uniform illumination and to study the behavior of modulated signals. The behavior of fixed signals on varying background is a complex area requiring further study, but one that is being heavily investigated in preparation for the launch of the SIRTF satellite. The simulation shown in Figure 3 gives an example of a recent simulation for a series of calibration signals before, during and after a background change. A variety of simulations like this have been performed and compared to experiments on the Ge:Ga detector arrays for MIPS.

Development of a specific algorithm to extract final signal values from the fast component was replaced by studies of the transient response to calibrator/signal patterns. The goal was to obtain a much wider range of data on the transient response following and during background changes. The periodic calibrator approach will be utilized by the MIPS instrument on SIRTF. It provides a direct means of addressing the fast fraction variations. Additional work is needed to determine the feasibility of an algorithm that combines the fast fraction information and the rate of change of the underlying current response.

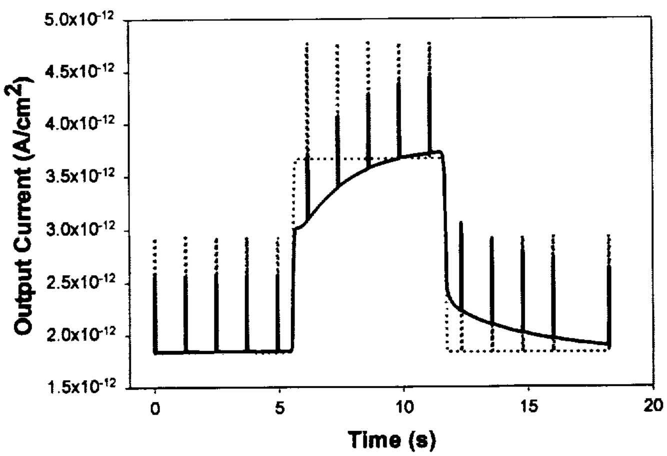

Figure 3: Comparison of flux generation rate (red) to output current (black) for Ge:Ga detector with hook response. T = 3.0 K with applied bias of 50 mV for a 0.5 mm intercontact distance (1 V/cm). Pulse signals and background change both have magnitude $\Delta g = g$ with $g = 2.2 \times 10^9$ $cm^{-3}s^{-1}$. Simulations at higher/lower flux levels would move the transient to shorter/longer times.

NASA Community interactions

During the grant period, collaboration was maintained with co-investigators Prof. George Rieke of the University of Arizona and Dr. A. Michael White of Malvern, England. Presentations of the work were given at a MIPS (Multiband Imaging Photometer for SIRTF) team meeting in Pasadena, CA in June 2001 and at the NASA/DLR Far-IR, Sub MM & MM Detector Technology Workshop in Monterey, CA in April 2002. Simulations and results from the experimental work have been shared with groups in the US, Europe and Japan.

The work has demonstrated the limits of using the fast fraction of the transient response to determine final signal values and shown the importance of the relative times of the signal modulations and the transient responses involved.

Ongoing Work

At the end of the grant period, a new dewar was completed to allow for transient measurements of individual devices at lower backgrounds than could be achieved in our older experimental system. This system will be used to continue studies of the transient response. This will be especially useful in completing the work on measuring the fast/slow component ratio as a function of applied field. This work will provide the detector community with direct measurements of the key $\mu\tau$ material parameter in their devices.

Additional work is also required on the modulated responses. While much experimental and simulation data have been collected, a comprehensive description has not yet emerged. The variation in measured fast fraction is a complex function of the background, ratio of signal to background, and both onset times and relative durations of the signals. Work in this area will continue.

Finally, the ultimate goal of increasing understanding of the transient response and the growing knowledge from the performance of ISO as well as SIRTF photoconductors should be attempts to develop new devices that eliminate the transient response problems. We have begun both an experimental and modeling program in that direction. Four alternative contact detectors were fabricated during the grant period, with various combinations of ohmic and blocking contacts. These devices are being evaluated for their transient response. In addition, simulations have shown that modification of the near contact region, perhaps with variable depth implants, may be used to create detector responses with large fast fractions (approximately equal to one) and delayed transient behavior. A combined simulation/detector fabrication effort should be made to evaluate these alternate contact possibilities for both transient response and effect on device responsivity.

Publications and presentations

A list of publications and presentations associated with the grant to date is given below. We anticipate an additional two publications – one dealing with the modulated response following background variations and one dealing with the measurement of the $\mu\tau$ product directly from the transient behavior.

N. M. Haegel, *D. R. Palmieri* and A. M. White, "Current transients in extrinsic photoconductors: comprehensive analytical description of initial response," Applied Physics A **73**, 433-439 (2001).

N. M. Haegel, *W. R. Schwartz, J. Zinter*, J. W. Beeman and A. M. White, "Origin of the Hook Effect in Extrinsic Photoconductors," Applied Optics **40**, 5748-5754, 2001.

N. M. Haegel, *C. Pullen, W. R. Schwartz, M. P. Smylie* and *J. Zinter*, "Transient Response of Extrinsic Photoconductors under Non-uniform Illumination," 26th IRMMW, Toulouse, France, Sept. 2001.

N. M. Haegel, "Numerical Modeling of Transient Behavior in Far-Infrared Photoconductors," NASA Far-IR, Sub-mm and MM Workshop, Monterey, CA, April 2002. (invited)

W. R. Schwartz, M. P. Smylie and N. M. Haegel, "Transient Modeling and Measurements for Ge:Ga Photoconductors," NASA Far-IR, Sub-mm and MM Workshop, Monterey, CA, April 2002.

Italics indicate student (undergraduate) co-authors.