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Thermal/Temporal Response of the NSOM Probe/Sample System

H.D. Hallen, B.I. Yakobson, A. LaRosa, and M.A. Paesler

Physics Department
North Carolina State University
Raleigh, NC 27695-8202, USA

ABSTRACT

In measurements of sample temporal response with a near-field scanning optical microscope, or NSOM, one must account for the temporal response of the probe. The coupling of thermal and temporal effects in an NSOM fitted with a coated tapered fiber probe is considered. Study of the perturbation of cw infrared light by a pulse of visible light simultaneously sent through an illumination mode NSOM allows one to separate the relatively slow thermal response of the probe from the appreciably faster response of a silicon sample imaged with the probe. Temporal and thermal contrast in NSOM imaging are discussed in terms of the results.

1. EXPERIMENT

Illumination mode NSOM is a frequently exploited technique for sub-wavelength optical imaging [1]. We have performed illumination mode NSOM studies exploiting temporal contrast by simultaneously using pulsed visible light and cw infrared light of wavelengths 0.633 and 1.55 μm respectively. The frequency of the pulsed light is varied, and the induced change in the ir signal at the frequency of the pulsed light is synchronously measured [2].

The experiment was designed to measure the temporal response of free carriers in semiconducting samples. Results of such experiments [3] show that the technique allows for the imaging of defects in silicon with subwavelength resolution. We have found that a slight modification of the experiment allows us to measure the probe's temporal response. In particular, we remove the Si sample from the near-field of the probe, and place it instead in front of the detector where it simply filters out the pulsed visible light from the detected signal.

2. RESULTS

The frequency dependence of the infrared signal through a probe/sample system is shown in figure 1. The probe was an aluminum coated tapered glass fiber and the sample was a silicon wafer. The response of the system is relatively constant as the frequency is increased from dc up to about 10 Hz. The response falls with further increasing frequency until another plateau is reached. A second knee then appears at a frequency of approximately 10 kHz.

The low frequency response of the probe/sample system is dominated by the thermal response of the probe [4]. For the probe used, three thermal effects of relatively equal significance can affect the throughput. In brief, the partially absorbed pulsed visible light that impinges on the walls of the aluminum probe results in probe heating. This heating in turn can effect the probe optical throughput through a number of channels. For the probe used in this experiment three channels of relatively equal absolute magnitude come into play:

- The radius of aperture at the end of the probe increases with rising temperature resulting in enhanced throughput.
- The probe lengthens at higher temperature thus increasing the distance between cut-off and the aperture and resulting in a diminished throughput.
- The reflectivity of the metal coating falls with temperature causing a decreased throughput.

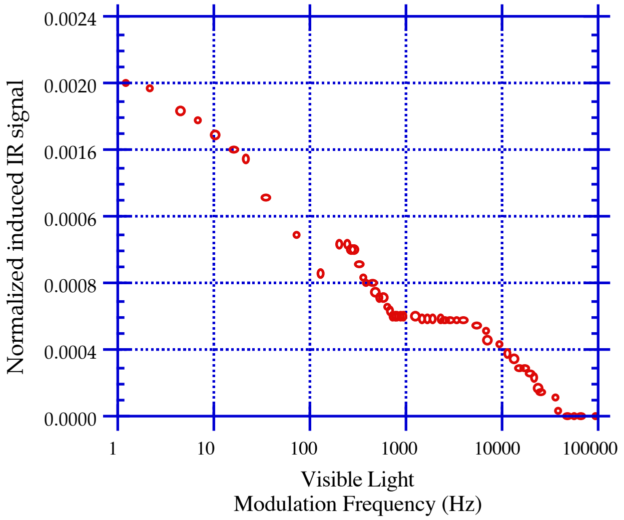
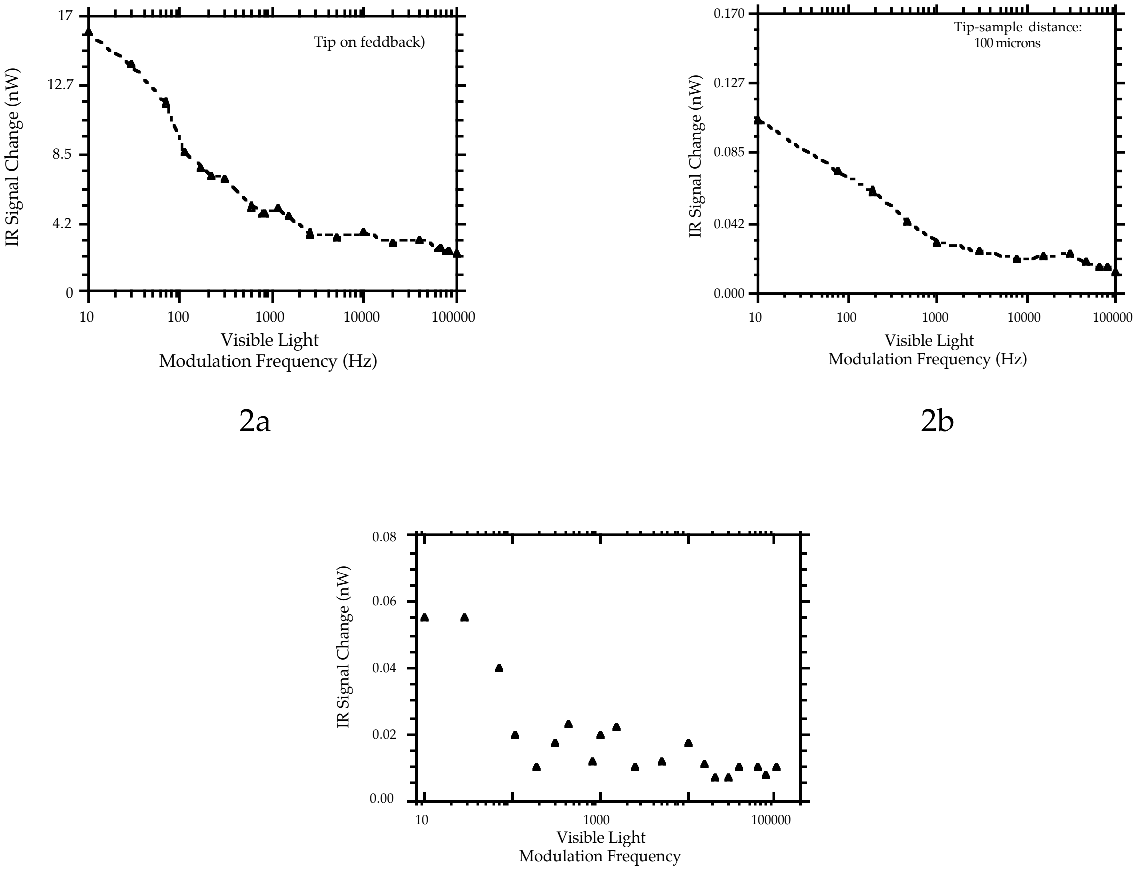


Fig. 1. The normalized magnitude of the modulated infrared signal in an illumination mode NSOM used to image a silicon wafer. The infrared light incident into the NSOM is continuous. The knee at ≈ 10 Hz represents a roll-off due to the thermal response of the probe. The knee at ≈ 10 kHz reflects the dependence of the ir transmission of the sample on the silicon free-carrier population. These photo-excited free-carriers are generated by visible lighted in the NSOM chopped at the frequency plotted on the abscissa.

The separation of the sample and probe thermal behavior is demonstrated in figure 2 where the temporal responses of these two components of the NSOM optical system are considerably more difficult to isolate.

Figure 2a is similar to figure 1 in that it represents the frequency response of an illumination mode NSOM while a semiconducting sample is being imaged. As with figure 1, two knees are observed. Now, however, the responses are considerable closer in frequency and require considerable care in interpreting. One can recognize knees at ≈20 Hz and at ≈100 Hz corresponding to response times of 10 and 2 ms respectively.



2a

2b

2c

Figure 2. The frequency dependence of the transmission of ir radiation through an illumination mode NSOM. In figure 2a, the transmission of the probe/sample system is plotted. Data in figure 2b were obtained on the same system but with the sample sufficiently far from the probe to obviate the contribution of the sample to the temporal dependence of the ir transmission. Figure 2c is the total system response minus the probe response. That is, c = a - b. The difference plotted in figure 2c represents the temporal response of the sample alone.

In figure 2b, the tip has been retracted so that the sample response has become negligible and the temporal response of the ir signal has been measured. Only the ≈10 Hz knee persists. Thus, we interpret the lower frequency roll-off to be indicative of the thermal response of the *probe*. Figure 2c is a plot of the difference between the sample/probe system and the probe alone. That is, figure 2c is the difference between figures 2a and 2b. With the response of the probe subtracted, only the response of the *sample* is plotted. Evident in figure 2c is the higher frequency knee at 100 Hz. The subtraction process confirms the separation of the sources of the low and high frequency response as being the probe and the sample, respectively. Far-field measurements [5] confirm that the average carrier lifetime for this sample agrees with the local value (≈100 Hz) obtained here.

3. DISCUSSION

The arsenal of contrast mechanisms employed in NSOM imaging includes temporal imaging. In such imaging, however, one must be careful to separate the role of the sample from that of the probe. As we have shown, by studying the NSOM imaging system with and without a sample in place one can isolate the contrast rising from interactions in the sample. In such a manner, the response of the sample can be studied and temporal contrast can be used in NSOM imaging.

Of note in the present study, however, is an additional consideration. In particular, it is conceivable, that the thermal dependence of the probe throughput may be used in imaging of the thermal properties of the sample. For example, if the thermal properties of a sample varies from position to position, then the temperature of the probe might be expected to be a function of the position of the probe above the sample. The probe's optical throughput in turn might vary with this position, and one might have added thermal contrast to the ever-increasing tools at the near-field microscopist's disposal.

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