Highly Sensitive Lock-in Thermography Investigation of Local Heat Sources Implying 2-Dimensional Spatial Deconvolution

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The spatial resolution of the thermographic investigation of local heat sources is influenced by the lateral heat spreading in the sample, usually leading to a "halo" around local heat sources. For the lock-in thermography, the extension of this halo is governed by the frequency-dependent thermal diffusion length, which in silicon is about 1 mm for $f_{\text{lock-in}}$ = 30 Hz and which decreases with $1/\text{Ö}f_{\text{lock-in}}$. In order to minimize this thermal halo, a highest possible lock-in frequency should be applied. On the other hand, a high lock-in frequency leads to a reduced amplitude of the surface temperature modulation because of the heat capacity of the sample. Thus, microscopic lock-in thermography investigations should be based on a highly sensitive detection system with lock-in frequencies as high as possible. If a local heat source is at a certain depth below the surface of a solid, its lock-in thermogram generally appears blurred due to its depth, and high lock-in frequencies cannot be used owing to their short thermal diffusion lengths.

Based on a mid-wave high speed FPA thermocamera and on-line floating point data processing, a novel lock-in thermography system has been developed, which allows periodic surface temperature modulations down to 10 µK (rms) to be detected after an integration time of 30 min [1]. The frame rate of the camera is 217 Hz, leading to a maximum possible lock-in frequency of 54 Hz. Using a microscope IR-objective, a pixel resolution below 10 µm can be attained. This system enables the investigation of weak periodic heat sources, which have been unaccessible by thermal methods before. The system has been applied successfully to the investigation of surface-near shunts in solar cells [1] and of gate leakage currents in MOS devices. It can also be used for other types of non-destructive testing.

Since a lock-in thermogram can always be interpreted as a convolution of a local power distribution with a complex point spread function, it is possible to reconstruct the local power distribution from measured thermograms numerically. Each spatial deconvolution procedure, however, is strongly influenced by the noise and artifacts of the image. Moreover, the results often show spurious local oscillations. We have developed a 2-dimensional deconvolution program for lock-in thermograms ("VecDec" = Vectorial Deconvolution [2]), which uses an iterative algorithm working with both phase components in real space to reconstruct the local power distribution from only one measured phase-independent amplitude image. The appearance of spurious oscillations is suppressed by exploiting a positivity constraint condition, setting all negative heat sources appearing to zero. By selecting the number of iterations, a compromise can be chosen between the degree of deconvolution and the noise degradation factor. Both heat sources located at the surface and in the depth of a specimen can be reconstructed.

Fig. 1 shows a lock-in thermogram (amplitude image), together with the deconvoluted power distribution and the amplitude image simulated from this power distribution, of a group of weak shunts located at the surface of a multicrystalline Si solar cell. The thermogram was measured at a frequency of 54 Hz. We see that the thermogram originates from several distinctly separated local heat sources, and that this power distribution reconstructs the measured image very well. Fig. 2 shows the amplitude image, the deconvoluted lateral power distribution, and the simulated amplitude image of a special ultrasonic (US) test device. In this device a horizontal 2 mm diameter hole, located 2 mm below the surface of an Al block, was filled with metal particles and exposed to US of 20 kHz, which was amplitude modulated at 0.85 Hz. Some part of the US energy is converted into heat by the metal particles. The diameter of the buried heat source is correctly reconstructed by the deconvolution procedure. Here, the known average depth of the source was used for the calculation. The region without any noise beside the heat source is probably due to the fact that the depth position of the heat source is not constant here.

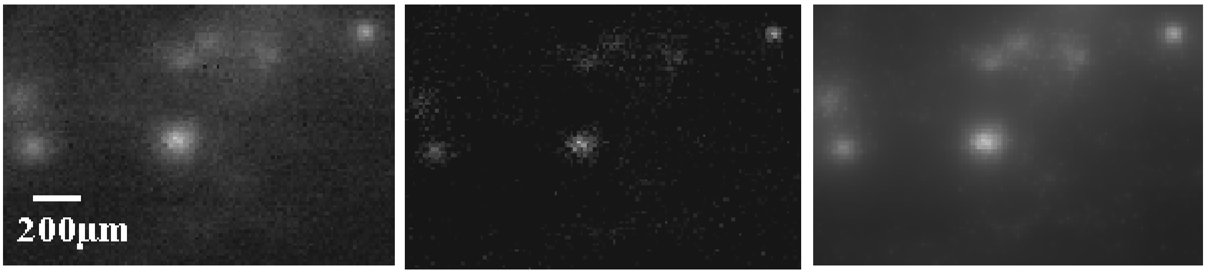

Fig. 1: Measured T-amplitude image (a), deconvoluted power distribution (b), and T-amplitude image simulated from this power distribution (c) of a group of shunts in a Si solar cell. The maximum measured T-amplitude is about 1 mK (effective value), measure time 10 min.

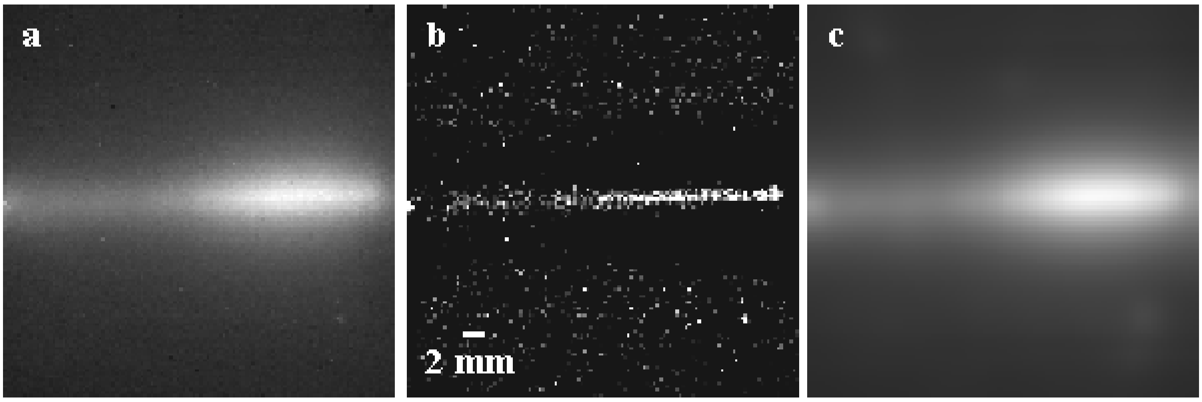

Fig. 2: Measured T-amplitude image (a), deconvoluted power distribution (b), and T-amplitude image simulated from this power distribution (c) of a cylindrical US-excited heat source located 2 mm below the surface of an Al block. The diameter of 2 mm of the buried heat source is correctly reconstructed.

[1] O. Breitenstein, M. Langenkamp, O. Lang, and A. Schirrmacher: "Shunts due to Laser-scribing of Solar Cells Evaluated by Highly Sensitive Lock-in Thermography", 11th International Photovoltaic Science and Engineering Conference (PVSEC-11), Sapporo 09/1999, Technical Digest pp. 285-286

[2] I. Konovalov and O. Breitenstein: "Evaluation of Thermographic Investigations of Solar Cells by Spatial Deconvolution", 2nd World Conference on Photovoltaic Energy Conversion, Wien 07/1998, Proceedings pp. 148-151