Combined electrical and optical heating in thermal wave microscopy of semiconductor devices

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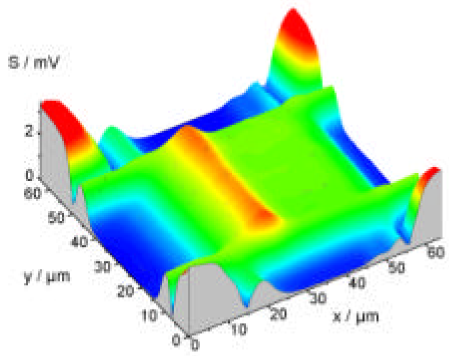
Over the last twenty years thermo-reflectance microscopy (TRM) of thermal waves have become a very versatile and powerful tool for the analysis of semiconductor materials and devices. TRM offers a relatively good spatial resolution in a completely non-contact way. Using either optical excitation or elctrical heating one can obtain information about thermal and electronical properties or temperature distributions (e. g. hot spots). Here we will show how the combination of these two methods can reveal further information, that cannot be achieved by only using a single form of modulated heating.

In this work insulating lines and channels implanted by focused ion beams on SIMOX wafers have been investigated by thermal reflectance microscopy using optical and electrical excitation. Hot lines and hot spots can be visualized by modulated electrical heating. Insulating lines forming channels can only be imaged only with simultaneous optical and electrical excitation. Best contrast for the observation of the insulating lines adjacent to a channel are achieved by recording the reflectance signal at 4 f where f is the modulation frequency of the optical and electrical pump. The contrast enhancement of the double excited thermo-reflectance signal is found to be mainly of a thermal origin.



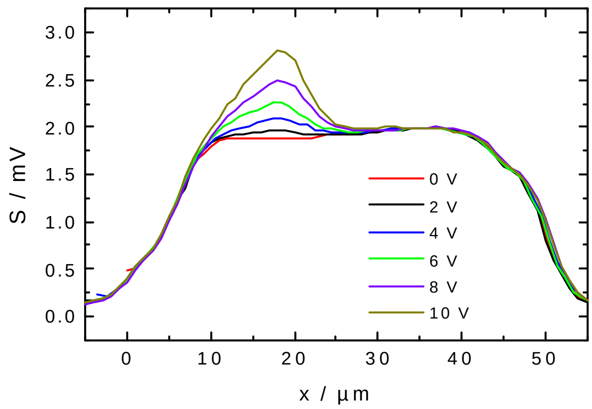


Fig.1: *Image of a buried non-conducting line implanted in a IPG-device recorded with a thermo-reflectance microscope with voltage of 10 V applied between source and drain (left). Cross section of the image at different voltages.*

Spatially resolved thermo-reflectance measurements with optical excitation showed only very little or no contrast between the substrate and the implanted lines. This may be due to the layered structure of the substrate. From frequency dependent thermo-reflectance measurements it can be seen that the signal is dominated by the thermal wave, which is only negligibly af-

fected by the implantation. But it could be shown that the contrast between the substrate and the implanted lines can be
enhanced by applying an additional electrical heating across the implanted lines. Using a DC voltage for electrical heating the signal amplitude can be increased at the isolating line giving a fairly good contrast. Instead of a DC voltage an AC voltage can also be used. In this case one has to detect at higher harmonics of the excitation frequencies and signal only from the isolating lines is obtained.

When dealing with continuous insolating lines it is also possible to work with pure electrical heating at high voltages, but this method fails when applied on isolating lines with small channels. Then only a hot spot at the channel can be observed. By using combined optical and electrical heating it is now possible to examine the implanted structures in presence of conducting channels. Here it could be shown that the best spatial resolution of the implanted structures can be obtained by applying an AC voltage and detection at the fourth harmonic.

The physical reasons of the effects of combined heating is identified to be due to the additional Joule heating by photo-generated carriers and the modified charge density. Therefore, an increase of the recombination time will increase the contrast of the thermal image contrarily to the conventional thermo-reflectance with optical excitation only. From the studies as a function of the polarity of the electrical excitation the heat sources are identified to be located at the border of the insulating line in the depletion zone of the reversed biased site. The combined excitation of the thermo-reflectance signal also offers sensitivity to the implantation dose which is attributed to the modification of the reversed bias resistance on the doping. In the case where the modulation frequencies of the sinusoidal shaped electrical and the rectangular shaped optical excitation are the same the best contrast is achieved for the detection of the thermo-reflectance signal at 4f. The contrast can in addition be influenced by a phase shift between optical and electrical excitation.

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