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SCTS: scanning capacitance transient spectroscopy

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Abstract

A new working mode of scanning capacitance microscopy (SCM) is presented, extending the possibilities of the measurement from lock-in amplitude mapping to recording of capacitance transients arising as response of abrupt bias changes. Effect of Au doping in Si on SCM and scanning capacitance transient spectroscopy (SCTS) was observed. The decay time of capacitance transient, measured locally on slightly doped region shows good agreement with the conventional DLTS results.

Keywords: Capacitance transient spectroscopy; Scanning capacitance microscopy; DLTS

1. Introduction

The different scanning microscopies, utilizing beams of electrons, ions, photons, or mechanical probes, in most cases can be considered as repetitive localised realizations of well-known, ''traditional'' macro-scaled experiments. In beam-induced cases, localization of the measurement is achieved by local excitation of the focused beam followed by integral detection. In complex probe associated methods the excitation or detection or both can be local.

In this aspect it is worthy to examine the additional information, that can be obtained by sophisticated signal detection, manipulation and processing, together with those local properties of the materials and structures, that can be determined by analysing them.

The aim of our work is to explore what are the optimal excitation parameters of the Scanning capacitance microscopy (SCM) for detection of gold-doped regions in Si, and to demonstrate the possibility of a local transient measurement similar to the macroscopic deep-level transient spectroscopy (DLTS) by detecting the waveform of the capacitance response of SCM.

2. Experimental

2.1. SCM modification

The SCM for example can be interpreted as differential C/V measurement with highly localized detection. In conjunction with an AFM, used to visualize the surface morphology, it maps the AC amplitude of the capacitance change, excited by sinusoidal bias of the semiconducting specimen, using lock-in technique [1,2].

Applying square wave excitation of the isolated sample, and monitoring the output of the UHF Capacitance Sensor Unit of the SCM, capacitance transients can be measured using a digital oscilloscope with signal averaging capability. Better tuning of SCM becomes possible this way, and additional properties of the semiconductor sample can be investigated, localizing the area on the AFM image. The types of apparatus shown in Fig. 1 are Digital Instruments D3100S-1 AFM with SCM1 Scanning Capacitance Box, HP 33120A Function Generator and Tektronix 211A Digital Storage Oscilloscope.

2.2. Sample preparation

Oxide mask with windows was formed on $\langle 1\,0\,0\rangle$ n-Si ($5\,\Omega$cm), followed by evaporation of 3 nm Au layer at $T_{evap} = 900^{\circ}$C in the case of Sample T1, and at room

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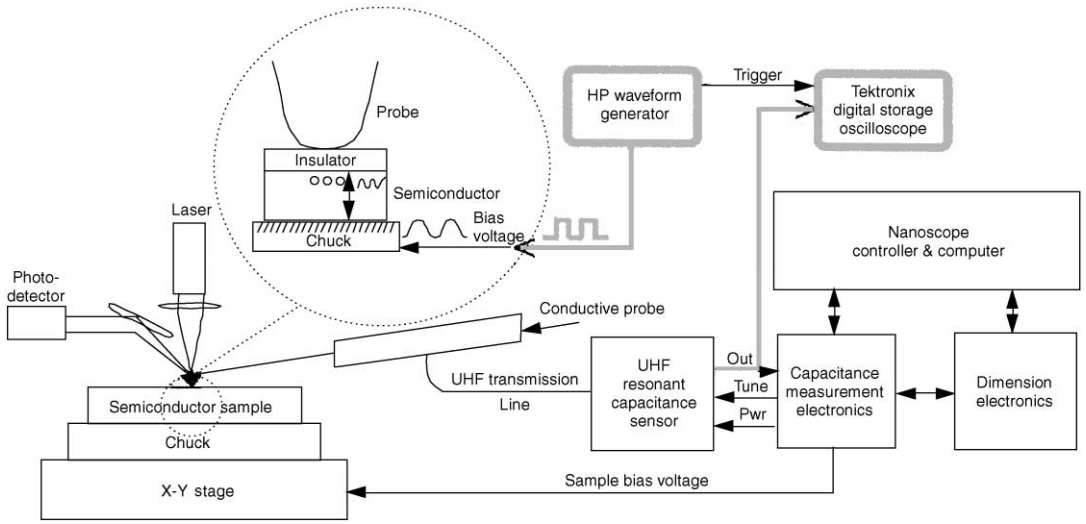

Fig. 1. Modification of SCM electronics [1] for transient recording.

temperature in the case of T2. Finally, the Au and oxide layers were removed by etching.

3. Results

3.1. DLTS measurements

For traditional DLTS characterization gold Schottky barriers have been deposited onto the T1 and T2 samples. The sample T2 has been measured at 274–313 K, while sample T1 at 297 K, using a Semilab-type lock-in DLTS analyser. The frequency of the Au-related peak on sample T1 is $\upsilon_{peak} = 0.79$ kHz. The corresponding transient time constant is $\tau_{max} = 0.424/\upsilon_{peak} = 0.54$ ms [3].

3.2. SCM measurement optimisation

Transient measurements had been used to optimise the parameters of SCM imaging in order to obtain maximal contrast between the undoped (Fig. 2a) and Au evaporated (Fig. 2b) areas. The relatively short transient, excited by a [−10 V/0 V] square wave bias showed differences in amplitude strong and in time constant weak. The SCM image, obtained with sinusoidal excitation of [−5 V ± 5 V] amplitude and 10 kHz frequency and lock-in detection is shown in Fig. 2c.

3.3. Capacitance transient measurements

Transient with different amplitudes and shapes were measured on the hot-evaporated T1 sample, and is shown in Fig. 3.

Far in the substrate the transient with [± 2.5 V] bias is similar to the T2 (cold) results as shown in Fig. 3a and Fig. 2a. The heavy Au doping seems to block the rise of transient (Fig. 3c). In the substrate area near to the edge of the Au-doped region, where slight doping can occur due to diffusion during the evaporation at 900°C, a low-intensity slow transient with $\tau = 0.52$ ms can be observed, at the $+2.5 \rightarrow -2.5$ V transition.

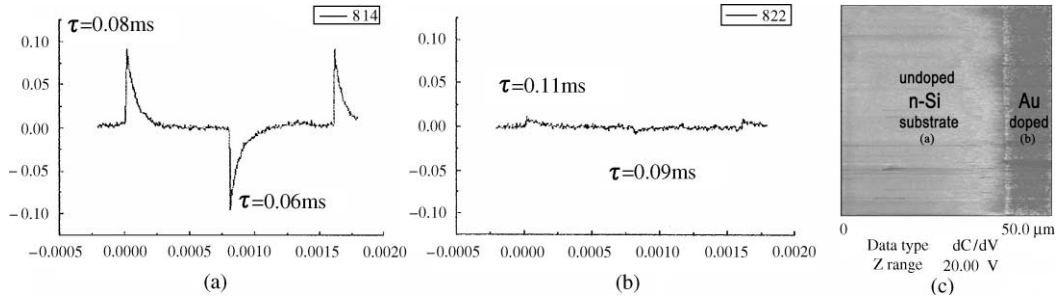

Fig. 2. Capacitance transients of the substrate (a) and Au evaporated (b) area of sample T2, together with optimised SCM image (c).

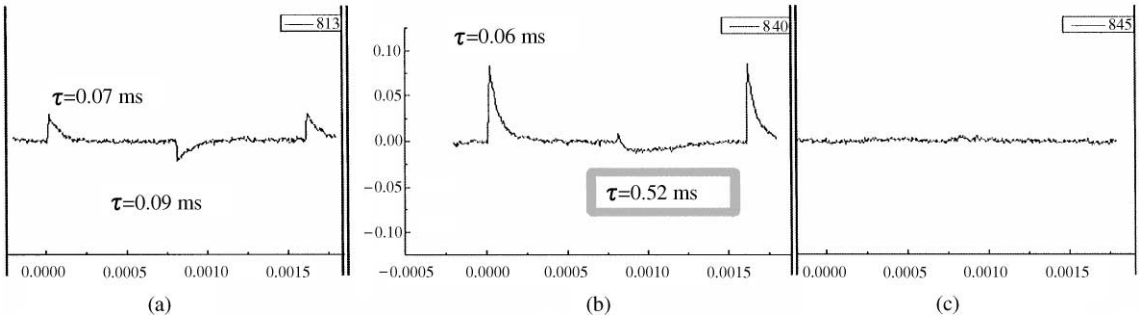

Fig. 3. Capacitance transients measured on Au-free remote (a), Au diffused (b) substrate areas and on Au evaporated area (c) of sample T1.

4. Conclusion

The Au-doped regions of n-Si can be seen by conventional SCM only as low-intensity areas (almost no signal). The conventional SCM measurement at different bias frequencies can produce different contrast, due to transients in capacitance response with different time constants from different device areas. This effect, if not checked, can cause unexpected systematic errors in quantitative lock-in SCM measurements.

The areas slightly doped by gold show definite changes in the transient shape. The time constants are near to those, which can be calculated from DLTS peak frequency determined by macro-scale measurements at room temperature, therefore can be interpreted as the effect of localized Au centres. Further research to clear the local behaviour of Au centres. together with instrumental improvement in excitation and detection are planned, which can open the way to the measurement of activation energy, as well as mapping of deep levels of the selected energy (Scanning Probe-DLTS).

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