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Properties of surface states in Silicon investigated in MSM-structures

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In investigations of deep levels in Silicon two energy levels, one about (E_c - 0.4) eV and one about (E_v + 0.4) eV, show up in several cases (1), (2), (3), (4). These levels have been associated with bulk defects. However, the origin of these levels has not yet been definitely established. In the work reported in this paper in which we have used a new technique (as far as we know) we have studied surface effects in high-purity N-type (10 KΩ cm) and P-type Silicon (10 KΩ cm) samples with evaporated Al and Au contacts respectively (the experimental technique is described briefly below). In our measurements we have found an acceptor-like surface state in the N-type sample at (E_c - 0.41) eV and a donor-like surface state in the P-sample at (E_v + 0.43) eV. (For comparison see ref. (5)). These levels appeared both in the recombination measurements and in photo-conduction measurements. It is our believe that these levels appearing in several photo-conduction measurement in many cases may originate from surface states.

In addition we found that the current decay times (see below) associated with a small disturbance in the number of occupied states at thermal equilibrium where strongly field dependent with the strongest effect in the P-sample. Similar effects are recently reported for p-i-n^+ structures (6). These decay times plotted in a lin-log diagram as function of 1/KT showed for very low applied fields a straight line behaviour over several decades in the time scale. The energy-levels mentioned above where obtained from the slopes of these lines. The result for the N-type sample was an acceptor-like state at (E_c - 0.41) eV. A peak in the DC-current appear when one of the contacts where illuminated by 0.41 eV monochromatic light. The P-type sample showed a somewhat different pattern since in this case the slope measurement gave an energy difference of about 0.65 eV while the light-measurements in this case gave 0.43 eV. Since the sum of these energies gives about the band-gap energy we assume that a donor-like surface state at about (E_v + 0.43) eV (or (E_c - 0.65) eV) appears in the P-sample. At higher fields a characteristic bend of the curves appeared. For the N-type sample this bend or deviation from the straight line towards shorter decay-times could very accurately be described by simply adding emphirically a constant contribution to the temperature. For example for a field of about 500 V/cm at the charged surface this constant corresponded to about 30°. The reason for this contribution to be constant in the N-type sample is probably due to the fact that the contact field varied only slightly with temperature. Since the field dependence of temperature in the P-sample was very strong, the same simple relation does not apply.

The experiments have been carried out in the following way. For example by illumination of the positive contact of the N-type sample by a short pulse of light (9000 A) and measuring the current pulse we get square pulses at room temperature, where the sample showed ohmic behaviour. This indicates that minority carriers traverse the sample without being attenuated and recombine at a high recombination rate at the opposite surface. At low temperatures this recombination rate is considerably reduced giving rise to a long tail of the pulses. Furthermore, the field along the sample is no longer constant but decreases towards the positive contact and increases considerably at the negative contact. In between the metal and the surface the field is again reduced. The field increase is due to an increase in the occupation of the surface states by electrons. This charging of the surface states give rise to a decrease in the DC-current through the sample. A small decrease in the negative charge at the surface caused by the arriving minority carriers give rise to an increase in the DC-current. The decay of the current pulse is then determined by the capture rate of electrons in the surface states and by the recombination rates of the minority carriers. The evidence for the decay of the pulse to be clearly a surface effect is that the flat transit part of the pulse disappears, when the applied field is reversed without any effect on the tail. Furthermore, the amplitude of the transit part is at low temperatures much smaller than the peak amplitude of the tail which indicates that the flat portion of the pulse is a pure transit part. In addition the transit times agree with the expected velocities. The decay of the current pulse has a complicated shape but at the end of the tail at least two clearly exponential decay parts belonging to the same energy level appear. It is surprising to notice that the amplitudes of these two components is nearly the same for both P- and N-type and do not vary mutually with temperature and field. Furthermore, the ratio (about 6) between the decay-constants is approximately constant with respect to temperature and field. Any conclusion regarding this behaviour has not yet been drawn.

Since the DC-current through the particular structures studied seem to be very sensitive to the number of occupied surface states we have carried out calculations with a model in which the charged surface states rather than the contact potential determines the current. The results describes very well the experimental results in a wide temperature range. Also the field distributions, obtained experimentally from the pulse shapes, are also very well described with this model.

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