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PHYSICAL ASPECTS OF a-Si:H IMAGE SENSORS

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Large-area optical scanners require sensors with high photoconductivity and fast response. By a-Si:H sandwiched between a metal and an ITO electrode we obtained a low dark current for a high signal-to-noise ratio. The influence of problems like crosstalk and Staebler-Wronski effect is described.

1. INTRODUCTION

Easier document reading for communication and office automation calls for large-area scanners that can read A4 documents without optical reduction. Therefore large area thin film photoconductors that can be fabricated at least 21 cm wide at low cost are required. The most promising way towards such a device is an arrangement of amorphous silicon with Schottky type contacts on both sides. The performance of the sensor has to be:

- high photocurrent
- low dark current
- fast response
- long term stability

These properties can be met by test structures, $2 \times 10 \mathrm{mm}^2$ in size. However problems arise when a sensor with a resolution of 12 points per mm is patterned. A review about image sensors is given by Kempter /1/.

2. PREPARATION

Test samples and the sensor itself were built upon glass substrates. On a titanium electrode, patterned by photolithography, an undoped amorphous silicon film was deposited by glow discharge of pure silane. Indium-tin-oxide (ITO), evaporated by means of an electron gun, serves as a top electrode (also structured by photolithography). Prior to ITO deposition the a-Si:H surface was treated by an oxygen plasma to form a thin silicon oxide layer. Thus, strictly speaking, the upper contact is a MIS-junction. An additional gold strip line is used to reduce the resistance of the ITO electrode and to connect the sensing elements to the readout circuit. Details have been described elsewhere /2/.

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3. PHOTOCONDUCTIVITY

In a sandwich type sample with blocking electrodes the photocurrent is of primary nature, hence limited by unity gain. Losses may occur by absorption or reflection at the transparent top electrode. The ITO had been optimized so that a gain of up to 90 % was obtained.

When illumination is switched on, the photocurrent rises until steady state is reached after about 100 µs. During that time, electrons are trapped in the low field region between the two Schottky contacts, giving rise to a space charge that reduces the band bending. The potential in that region and thus the number of electrons trapped depend on the voltage applied to the sample.

Turning off the light, the trapped electrons will be released from the traps and leave the sample until equilibrium is re-established. The transient current flowing drops to 0.1 % of the steady-state value after 10 µs with a voltage of 3 V applied during the experiment, or after 1 ms without any external voltage (Fig. 1).

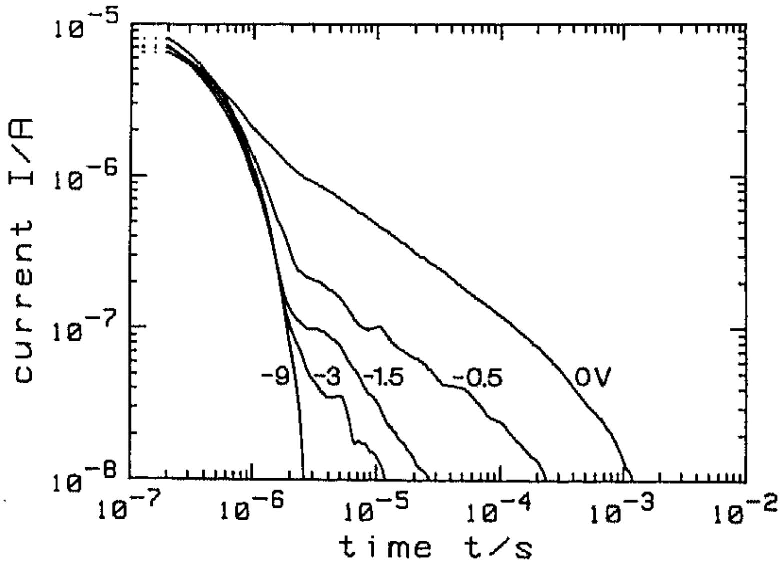

Fig.1:
Photocurrent decay after steady-state illumination for different voltages applied to the sample

4. DARK CONDUCTIVITY

As the photocurrent cannot exceed the value that is determined by the incident photon flux, a low dark current is most important to obtain a high S/N ratio. Since the bulk resistance is not high enough, the dark current must be reduced by a large barrier height of the ITO/a-Si:H junction. The barrier parameters are strongly influenced by the preparation of the interface. We measured the forward current-voltage characteristics of differently prepared samples which for this purpose had been supplied with an ohmic contact /3/.

When the a-Si:H surface is etched by hydrofluoric acid prior to ITO evaporation, a very low barrier of about 0.7 eV is found. We suggest that this is due to a chemical reaction between the amorphous silicon and the oxygen of the ITO, disturbing its stoichiometry /4/. With an intermediate oxide layer the chemical stability is enhanced and the barrier height increases to values ranging from 0.8 to 0.86 eV for thin natural oxide and thick plasma-generated silicon oxide, respectively. Details will be published elsewhere /5/.

5. CROSSTALK

Neighbouring elements of the sensor can influence each other because their spacing is only 10 µm. The drift length of the carriers may exceed this distance if there is a potential difference between them. Long range electric fields collect electrons from regions outside the sensing element itself and therefore lead to a crosstalk between neighbouring elements. As the current flowing is limited by carrier generation in a low field region, the transient decay becomes very slow. Fig. 2 shows the decay without crosstalk (A) and with crosstalk (B); B starts from a higher initial value due to the contribution from the neighbouring elements and shows a slow tail.

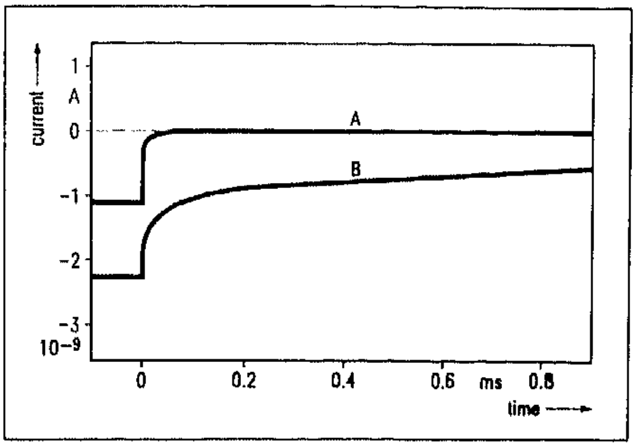

Fig.2:
Photocurrent decay of
an a-Si:H sensor element
A: without crosstalk
B: with crosstalk

6. STAEBLER-WRONSKI EFFECT

The Staebler-Wronski effect /6/ is known to deteriorate the photoelectric properties of a-Si:H. As, in our case, the photocurrent is of primary nature, recombination does not play an important role, so the creation of additional dangling bonds will not influence the photocurrent. Within experimental error of 0.5 %, we found no change in photocurrent after 8h illumination with 100 mW/cm^2 of white light. Only if there is a crosstalk will the photocurrent flowing a long way from neighbouring elements be affected by the Staebler-Wronski effect. Thus a small decrease of a few percent may be observed in the total photocurrent.

Contrary to the case of gap electrodes, where the dark current strongly decreases by the Staebler-Wronski effect, the dark current increases in our sandwich type sensors. For test structures we found increases up to a factor of two. Fine patterned sensors show larger increases which may be more than one order of magnitude. The effect is especially pronounced if the sensor is illuminated with negative bias at the ITO electrode /7/. It depends also upon the preparation of the sensors. We suppose a reduction of the barrier height at the ITO contact due to an increased density of states near the interface, which would explain the larger dark current. The dependence on the geometry of the sample is still not clearly understood and will be the subject of further investigations.

7. CONCLUSIONS

An amorphous silicon based optical sensor is an interesting subject for physical investigations. Its properties are based on its back-to-back diode structure, depending on the contact materials, the bulk a-Si:H, and the preparation of the interfaces. The fine structure patterning influences these properties markedly.

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