Journal of Non-Crystalline Solids 77 & 78 (1985) 1413-1416
North-Holland, Amsterdam

CHARACTERIZATION OF JUNCTIONS BETWEEN TRANSPARENT ELECTRODES AND a-Si:H

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The performance of back-to-back Schottky diode structures suitable for image sensor applications is investigated. Their steady-state and transient behaviour is shown to depend on the preparation of the interface.

1. INTRODUCTION

Large-area image sensors can be built using a thin film of a-Si:H sandwiched between metal electrodes[1]. The requirements for sensor performance are:

- high photo-to-dark current ratio ($>$1000:1)
- fast response (readout time $< 100\ \mu s$)
- fine structure patterning (10 to 100 μm)

Since compliance with these requirements depends on the contacts, the properties of electrodes made from different materials and under various preparation conditions were investigated. We characterized these junctions by their current-voltage characteristics in the dark and under illumination as well as by photocurrent transients.

2. EXPERIMENTAL METHODS

The samples were formed by a 1 μm thick film of undoped a-Si:H covering a stripe of titanium as a ground electrode on a glass substrate. Some of the sensors had an n^+-layer as an ohmic bottom contact. Stripes of transparent palladium or ITO were evaporated as a top electrode, the sandwich being formed at the crossover area of the top and bottom contacts. All the patterning was carried out by photolithography, except for some of the top contacts, where shadow masks were applied. The photocurrent measurements were made with green light and a photon flux of 10^{14} to $10^{16}/cm^2s$. Details of sample preparation and experiments are described elsewhere[2].

3. RESULTS AND DISCUSSION

Fig. 1a shows the dark current as a function of voltage for different samples. Most of the curves saturate in both polarities because of the back-to-back diode sandwich structure. With an ohmic back contact, current densities of 10 mA/cm^2 were achived under forward bias.

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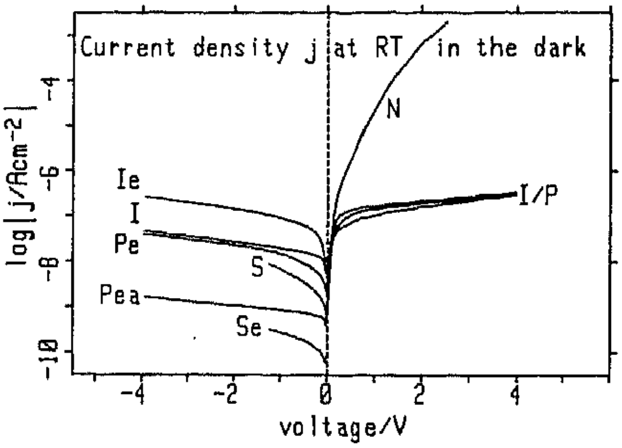


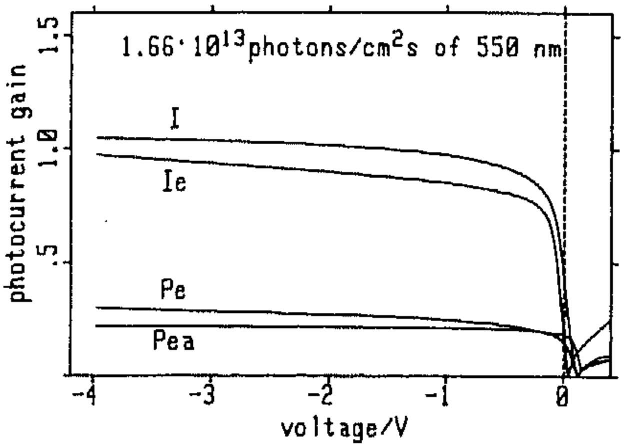


Fig. 1a: J-V characteristics in the dark

Fig. 1b: gain vs. applied voltage

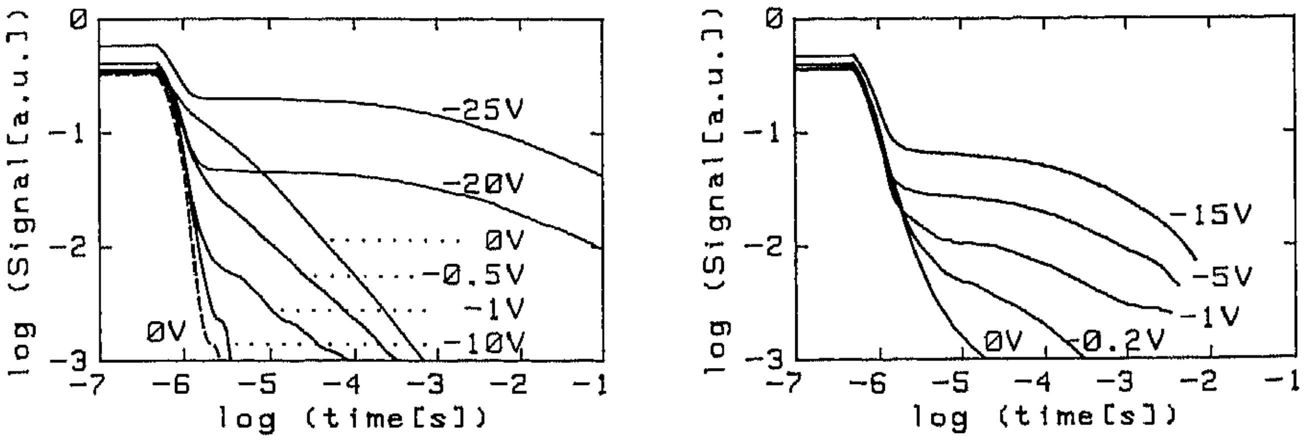
Samples: I = ITO electrode, P = Pd electrode photolithographically patterned,
S = Pd electrode through shadow mask, N = n^+ bottom contact.
Subscripts denote: e = etched a-Si:H surface, a = annealed 30 min at 500 K.

In reverse polarity (ITO negative), great differences in the blocking behaviour, depending on the type of top electrode, can be seen. The ITO electrodes show a poorer blocking behaviour than palladium electrodes. For the latter, etching of the a-Si:H surface with hydrofluoric acid prior to electrode evaporation leads to a pronounced decrease in reverse current.

Etching removes the native oxide layer on top of the silicon film. When ITO is evaporated onto an etched a-Si:H surface, the reverse current is even higher than in the oxidized case. We therefore propose that an oxide layer be reestablished by oxygen from the ITO film, resulting in an oxygen deficit in the ITO at the interface.

Annealing of an evaporated palladium film is known to form Pd_2Si [4,5,6], improving the diode performance. Removal of the residual metal Pd did not increase the sheet resistance, so we conclude that the whole 10 nm thick Pd film was consumed for silicide formation. There are indications that the chemicals of the photolithographic processes degrade the performance of the Schottky diode. As can be seen from Fig. 1a, electrodes evaporated through a shadow mask yield better blocking characteristics. One can assume that sodium ions from the developing solution remain on the amorphous silicon and act as a dopant. Whether this is the case will be the subject of future SIMS investigations.

Fig. 1b shows the gain-voltage characteristics under illumination. At reverse bias, saturation is achieved even at low voltages with a gain of nearly 1 for ITO and 0.2 for Pd electrodes, corresponding to the transmittance of the contacts. From these gain values and from the fact that they are independent of bias over a wide range, we conclude that the photocurrent is of primary nature.



Photocurrent decay vs. time for various negative voltages.
Incident photon flux 10^{16} photons/cm^{2}s, Pd top electrode.
Fig. 2a: —— back-to-back diode
--- ohmic bottom contact
Fig. 2 b: Large-area illumination,
ohmic bottom contact

Fig. 2a displays photocurrent transients, measured under reverse bias after shutting off steady-state illumination. The current decay of back-to-back sandwich structures is voltage-dependent, while samples with an ohmic back contact have a fast response even at low voltages. The fastest transients are limited by the measuring circuit. Increasing negative bias leads to an enhanced photocurrent gain accompanied by a very slow transient. In Fig. 3, $t_{3\%}$, the time at which the signal has dropped to 3% of its steady-state value, is shown for different voltages and samples. Low deposition temperature of the a-Si:H film increases $t_{3\%}$ by several orders of magnitude. The values of $t_{3\%}$ at low voltages or with low-mobility material (low T_d) can be explained by drift limitation of either electrons or holes, including deep trapping. Hole drift currents may be neglected, considering their short path and the strong electric field within the light penetration depth of 100 nm. In contrast to this, photogenerated electrons have to cross a low-electric-field region and, accordingly, show a slow decay. With an ohmic back contact, there is no low-field region in the sample, and the decay times are much shorter. At high reverse bias, an

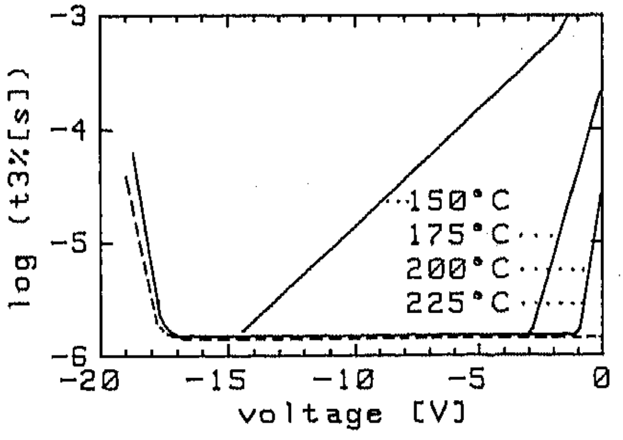


Fig. 3: Decay time $t_{3\%}$ vs. applied voltage for samples of different depositon temperatures and with different bottom electrodes.
—— back-to-back diode
--- ohmic bottom contact

additional current yield was found which increases exponentially with the applied voltage. So the long tail in the current decay must be due to injection of either electrons or holes. Hole injection at the back contact can be ruled out because there are no differences in the slow tails of the transients regardless of whether the back contact is ohmic or not.

Extremely slow transients were also observed when the silicon layer surrounding the sandwich was illuminated. Fig. 2a shows photocurrent transients of a fully illuminated sensor with an ohmic bottom contact. Even at low voltages, the decay curves show a slow response following the initial fast decay. The additional photocurrent yield increases with the square root of the voltage, showing the drift length limitation for carriers generated in the fringe fields of the sandwich. This effect depends on the electrode configuration as well as on contact properties and is thus very important for sensor design.

4. CONCLUSIONS

The requirements for an image sensor consisting of a-Si:H can be met by a back-to-back sandwich arrangement. In such a sensor, the photocurrent is of primary nature and has unity gain. If the applied voltage is not too high, no carrier injection occurs and the transient response is faster than two microseconds. The geometrical structure has to avoid photoconducting fringe regions that show an extremely slow response.

ACKNOWLEDGEMENT

We thank R. Primig, H. Doneyer and W. Müller for preparing the samples, and W. Fuhs and H. Mell from the University of Marburg for valuable discussions.

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