TRANSIENT PHOTORESPONSE FROM Co SCHOTTKY BARRIERS ON AlGaN

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ABSTRACT

Co on AlGaN is expected to form a large barrier Schottky contact due to its high work function. We have used this material combination with 18 % of Al in Al_xGaN for the study of transient photoresponse in the photovoltaic mode and in secondary photocurrent measurements after pulsed laser excitation. In reverse bias and in short-circuit mode a fast decay with a characteristic time of a few microseconds is dominant at room temperature. This mode is appropriate for UV detector operation. At elevated temperature, a much slower tail extending to several milliseconds is also observed. In forward bias operation the slow tail is dominating at any temperature. We discuss this asymmetry with respect to fast minority carrier collection within the space charge region for primary photocurrents and the slower majority carrier transport in forward bias.

INTRODUCTION

When GaN and its alloy with Al is used in UV detector applications the so-called persistent photoconductivity effect might limit the detector speed [1]. For example, a slow response with a characteristic time of 8.2 ms was reported for a p-i-n GaN detector [2]. Faster devices were realized with simple Schottky barrier devices having a response time of only 118 ns [3]. An even faster device with a 12 ns decay time was realized with a heterojunction of AlGaN/GaN that showed a responsivity of 0.15 A/W [4].

Usually high work function metals are expected to yield high values for the Schottky barrier height qF_b on n-type AlGaN. In a recent study a value of qF_b = 0.9 eV was obtained from capacitance-voltage (C-V) and current-voltage (I-V) analysis in an AlGaN sample with 11 % Al content grown by MOCVD [5]. As an alternative method, Polyakov *et al.* [6] performed internal photoemission spectroscopy on a Schottky barrier detector formed by a Ni contact on top of a 15 % Al content AlGaN layer with a large barrier height of qF_b = 1.31 eV.

In this work we want to focus on another large work function metal, Co, to study the time dependence of transient photoconductivity (TPC) after pulsed laser excitation. We observe a strong asymmetry in the magnitude and the decay time of the photocurrent transients in forward and reverse bias operation. The dependence on bias voltage, on temperature, and, to a certain extent, on light intensity and wavelength, together with a schematic band diagram of the Schottky barrier device should give a consistent explanation for the measured photocurrent transients.

SAMPLE PREPARATION

The samples were prepared by metal-organic vapor phase epitaxy (MOVPE) on sapphire substrates with Al contents between 2.5 and 18 %. Ohmic contacts, about 10 mm apart, were formed by In annealed at 380 ^{o}C for dark conductivity and secondary photoconductivity measurements. Co contacts with a thickness of 25 nm and a size of 2 x 6 mm^2 were deposited by plasma-induced RF magnetron sputtering (see Fig. 1). The films were characterized by temperature-dependent dark conductivity, photocurrent and photoluminescence spectroscopy, and Hall measurements as described earlier [7]. The carrier densities at room temperature range from 3x10^{16} to 4.6x10^{18} cm^{-3} depending on Al content.

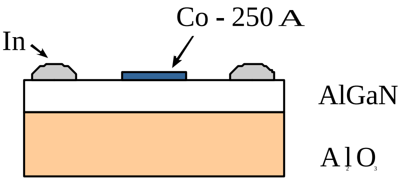

Fig. 1:
Layout of the sample structure with In contacts on the side and a Co Schottky barrier in the middle.

The surface structure of the bare films and the metal coated regions were analyzed by AFM (see Fig. 2). Absorption spectra obtained from photocurrent spectroscopy and compared to transmission data showed a band gap of 3.45 eV. For TPC measurements carriers were generated with green (532 nm, 2.33 eV) and UV (266 nm, 4.66 eV) pulses of 5 ns duration from a Nd:YAG laser system. The pulse energies in the UV ranged from 4 to 400 µJ at 10 Hz repetition rate.

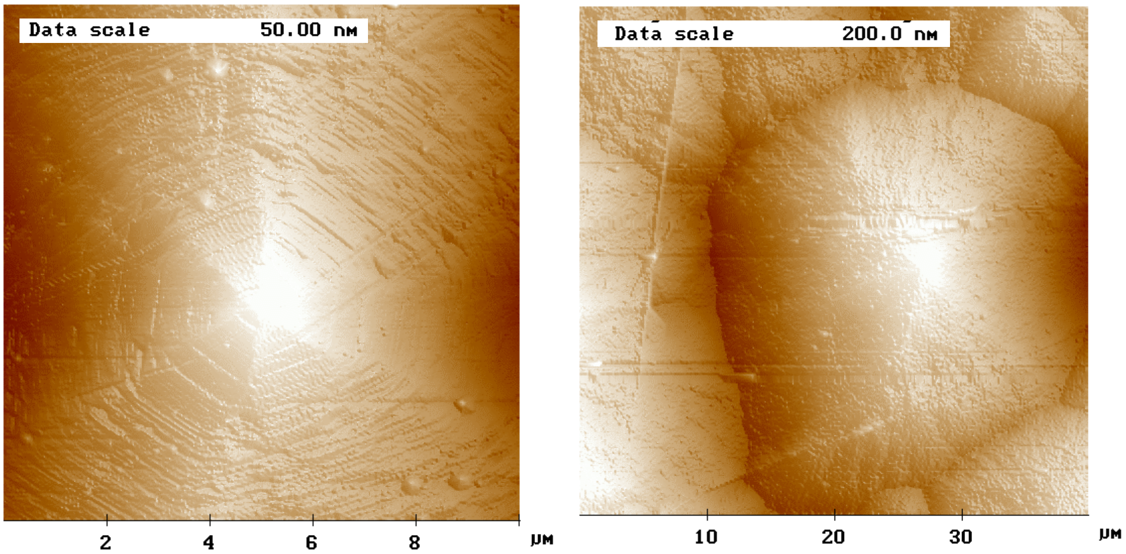

Fig. 2:

(a) AFM picture of GaN surface showing hexagonal shapes.

(b) Surface of GaN coated with 25 nm Co.

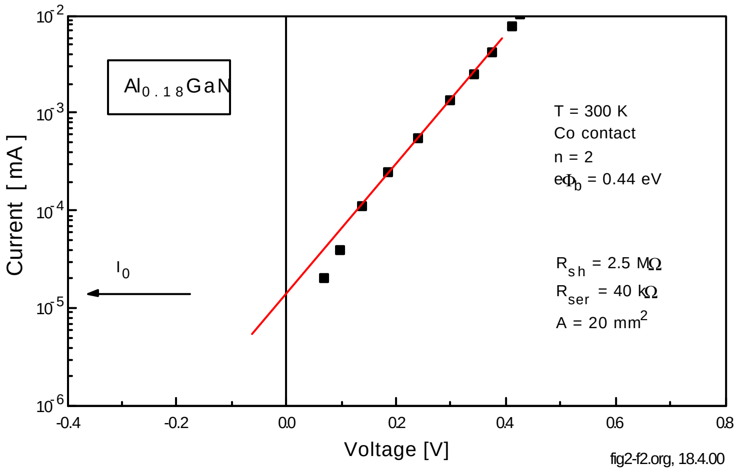

Fig. 3:
Semilogarithmic representation of the I-V characteristic to extract the Schottky barrier height of 0.44 eV. An ideality factor of 2 was assumed.

DARK I-V CHARACTERISTICS

From the dark current versus voltage characteristic measured at room temperature we extracted the Schottky barrier height of Co on AlGaN based on the following equation:

$$J = A^{*}T^{2}e^{-q\Phi_b/kT}\,(e^{qV/nkT} - 1) \qquad (1)$$

where A* and n are the effective Richardson constant and the diode ideality factor, respectively. From the magnitude of the reverse bias current densit we could calculate a Schottky barrier height of 0.44 eV. This value is lower than expected from the large work function of Co, which might indicate the presence of a large interface defect density.

PHOTOCURRENT TRANSIENTS

We measured the photocurrent transients as a function of applied voltage bias V_b to the Co-In contacts between -20 and +20 V, taking special attention of the short-circuit case at V_b = 0 V. Figure 4 was taken at T = 300 K. In reverse bias, i.e. for V_b < 0 V, a fast initial decay is seen with a decay time of 0.8 µs, followed by a small long shoulder. At

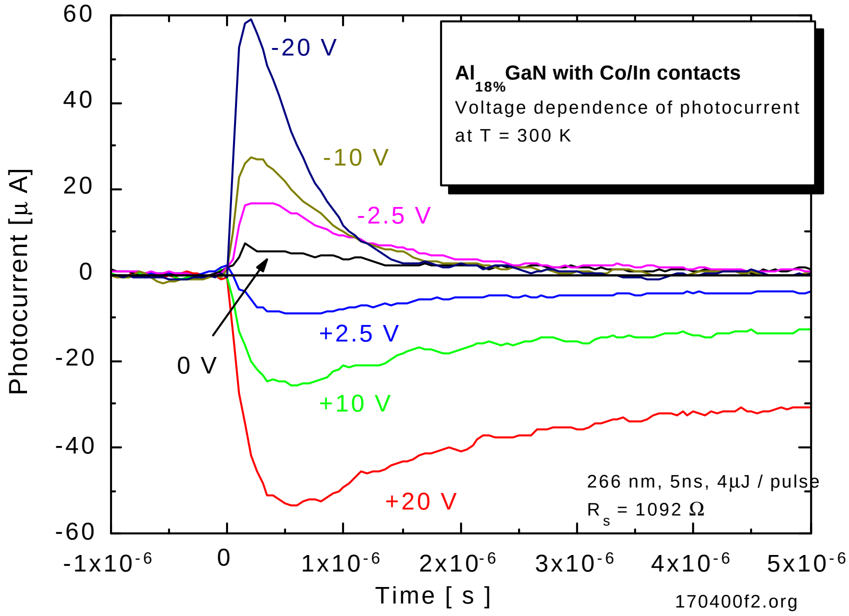

***Fig. 4**: TPC of Co-In on AlGaN as a function of bias voltage with the 266 nm line of a Nd:YAG laser The sample temperature is 300 K.*

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zero bias a small long shoulder is left over. This long-time decay represents the main signal for all forward voltages.

Figure 5 shows the same measurements but now at T = 500 K. Here also the reverse bias signal contains an appreciable long-term portion. We have reported the magnitude of the photocurrent transient at $t = 5$ µs in Fig. 6 for both temperatures. The forward bias region shows ohmic behavior of the photocurrent, whereas in reverse bias the signal is suppressed at room temperature.

***Fig. 5**: TPC of a Schottky barrier of Co on AlGaN as shown in Fig. 4, however, at elevated temperature of T = 500 K.*

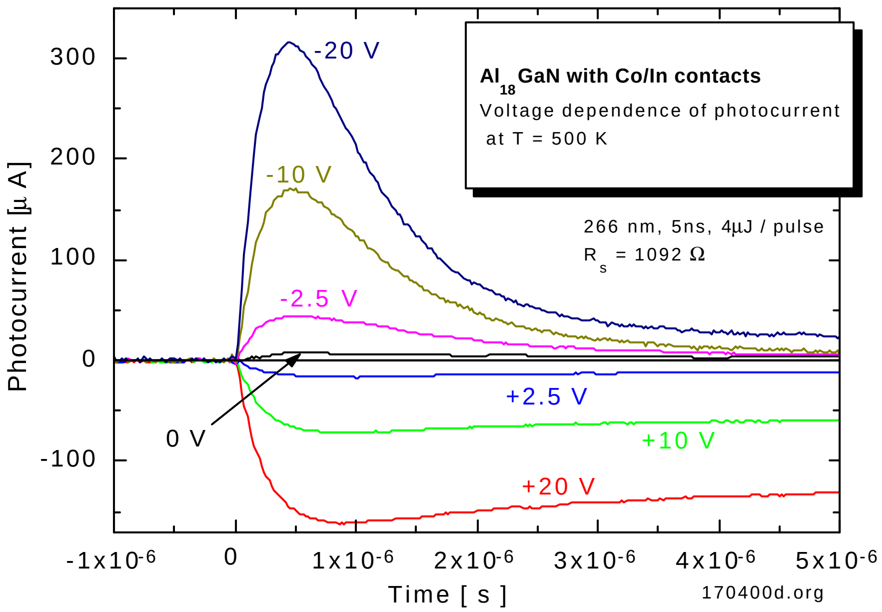
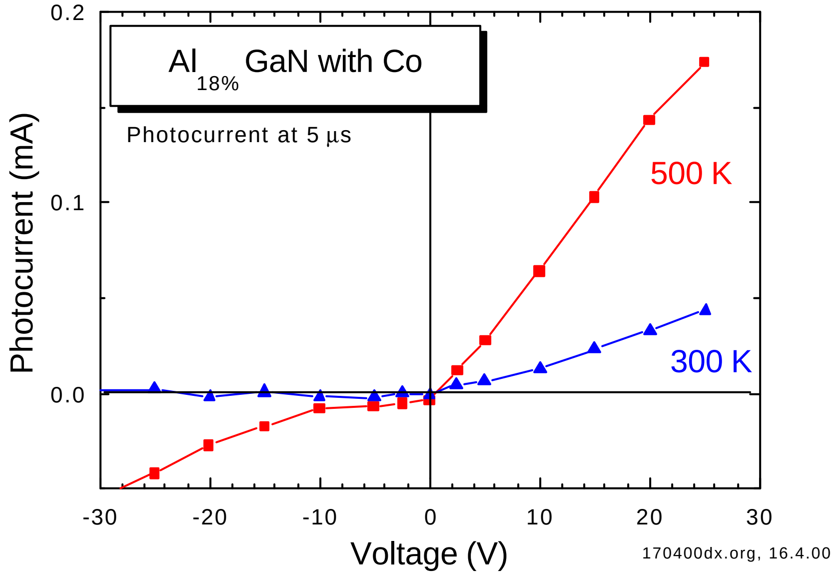


Fig. 6:
Photocurrent signal at 5 ms as a function of bias voltage taken from figures 4 and 5 for T = 300 K and T = 500 K, respectively.



The photocurrent transients did not show the fast initial decay when the green laser line at 532 nm was used. This applied to both forward and reverse bias operation. This finding is consistent with the fact that green light is homogeneously absorbed throughout the AlGaN film and the high field surface region, which would sweep out the carriers fast, has a relatively small influence.

For comparison, we also looked at the photovoltaic response of an Al and an In contact on pure GaN by shining green light through the substrate onto the back side of the contacts. Surprisingly enough, both contact showed a small photovoltage, but, in relation to Co, with opposite sign.

Without having studied the following effect in detail yet, we observed a relatively slow increase of the magnitude of transient photoconductivity with increasing the laser pulse energy. Monomolecular and bimolecular recombination cannot describe the data. The increase follows a power law with an exponent of about 0.25, which indicates that recombination time decreases strongly at large intensities. The reason for this could be that the high carrier concentration created by the high-power laser pulse is reducing carrier lifetime. Further work is needed to understand this trend in detail.

DISCUSSION

Co has a work function qF_m of 5.0 eV, so a high Schottky barrier qF_b is expected as in the case of Au ($qF_m = 4.9$ eV). From the electron affinity rule, and taking the electron affinity of 4.2 eV of GaN into account [6], one would infer $qF_b = 1$ eV. The modest value of 0.44 eV obtained above from I-V analysis suggests that interface states are present that pin the Fermi level. An improvement is expected after cleaning and annealing steps are performed prior to the sputtering process.

To analyze the asymmetry found with respect to the characteristic times of the photocurrent decay in forward and reverse bias operation we will consider the band diagrams given in Fig. 8. We note that the UV light is absorbed within 50 nm from the surface of the AlGaN film, due to the high absorption coefficient of about $2x10^5$ cm^{-1}. Next, from the carrier density we can calculate a space charge width of 170 nm. Therefore the fast decay in short-circuit current mode and in reverse bias can be explained by the fast hole collection in the strong surface field. Photogenerated minority carriers (electrons) will be important in the case of forward bias, where holes can no longer reach the front contact. In this case the photocurrent is a secondary photocurrent, it shows the characteristics of the persistent photoconductivity effect in bulk GaN and AlGaN with a slow tail extending into the ms time region [7].

As can be seen in Fig. 6, for elevated temperatures, also in the reverse bias mode a significant photocurrent signal is observed, since the barrier is reduced. In addition, Fig. 5 shows that now the long-time decay component is present at negative bias voltage.

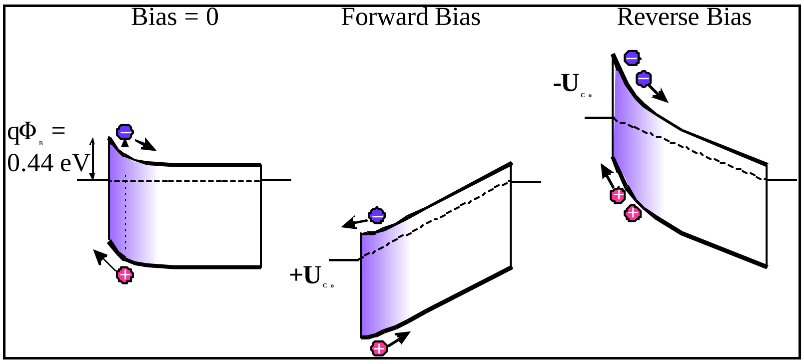


***Fig. 8**: Schematic band diagrams for three operating regimes.*

A detailed analysis of the forward region near zero bias in Fig. 6 reveals that the photocurrent signal vanishes for V_b = 0.92 V. This is about twice the value of the Schottky barrier height and indicates that the electric field in the junction region is compensated by the external voltage.

Finally, we noted that some degradation of the photoconductivity, of the order of 20 % after 10 min, was setting in under UV illumination with 0.4 mJ laser pulses. So this energy is an upper limit for reliable experiments. We want to note also that already at this pulse energy the estimated photocarrier generation rate is about $1.2x10^{30}$ cm^{-3} electron-hole pairs per cm^3 and s.

CONCLUSION

A Schottky barrier device using a high work function metal, Co, on n-type AlGaN was studied with respect to response times when used as a UV photodetector. From dark I-V curve analysis we obtained a barrier height of 0.44 eV. In short-circuit current mode the detector has a response of about 2 µs. When used in secondary photocurrent mode under forward bias a long photocurrent tail appears up to the ms range indicating persistent photoconductivity. In reverse bias both contributions are present. These observations can be explained by the dominant contribution of fast hole transport through the junction field in short-circuit current mode and by slow diffusion-related majority carrier transport in forward bias mode.

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