Enhanced emission from THz antennas made of low-temperature-grown GaAs with annealed ohmic contacts

N. Vieweg[a,b], M. Mikulics[c], M. Scheller[a,b], K. Ezdi[a,b], R. Wilk[e], H.-W. Hübers[d], and M. Koch[a,b]
[a]Institute of High Frequency Technology, TU Braunschweig, Germany
[b]Joint optical metrology center (JOMC), TU Braunschweig, Germany
[c] Institute of Bio- and Nanosystems and cni - Center of Nanoelectronic Systems for Information Technology, Research Centre Jülich, Germany
[d]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany
[e]Menlo Systems GmbH

Abstract—**We present a systematic study of annealed ohmic contacts and their effect on the performance of THz antennas. Annealing of the ohmic contact causes a strong decrease in the contact resistance and an enhancement of the electric field distribution inside the antenna structure. This doubles the output power of the devices compared to conventional photoconductors with standard Schottky-type metallization fabricated on an identical material.**

I. INTRODUCTION AND BACKGROUND

For several years molecular-beam-epitaxial GaAs grown at a low temperature has been known for its short subpicosecond photocarrier trapping time and its acceptable high carrier mobility. Therefore, this material is frequently used for the fabrication of photonic devices such as photoconductive switches for the generation of ultrafast electrical pulses[1], pulsed terahertz (THz) antennas for THz time-domain spectroscopy[2] and antennas for the generation and detection of continuous wave THz radiation[3]. A lot of effort has been put into achieving a high efficiency for the material and the design of optimal geometries for the device structures[4]. However, further improvement of the performance of LT GaAs-based photonic devices is expected by the optimization of the device contacts. For decades the properties of metal contacts to III-V semiconductors has been intensively studied[5]. From these studies it is well-known that a contact metallization like Ti/Au, which creates Schottky-contacts on conventional n-doped GaAs, shows ohmic behavior on LT-GaAs even without annealing[6]. The annealing of contacts to LT-GaAs is restricted to temperatures below 600°C, since higher temperatures cause subsequent annealing and a drastic change of the properties of the LT-GaAs material itself. At temperatures below 600°C we did not observe a change in the contact properties of the Ti/Au contact, which is in a good agreement to the published data[7].

The ohmic type AuGe-based contact was first used in 1964 by J.B.Gunn[8], and its great success is mainly due to its excellent contact properties on n-doped GaAs. In this letter, we compare the properties of THz antennas made of LT GaAs evaporated with ohmic type contacts (Ni/AuGe/Ni) and conventional Schottky type (Ti/Au) contacts respectively. We show that annealing of the ohmic type contact on LT-GaAs leads to an enhanced emission from the antenna. The performance improvement achieved by the use of Ni/AuGe/Ni contacts is due to the penetration of the ohmic contact region into the bulk of the LT GaAs layer. This behavior is similar to the behavior of such a contact on n-doped GaAs and is in contrast to standard Schottky-like metallization, where the ohmic contact is formed only on the semiconductor surface.

II. EXPERIMENTAL PROCEDURE

We deposited two types of metallic structures on an LT GaAs substrate using a conventional photolithography and lift-off technique. Annealed ohmic contacts were fabricated using a Ni/AuGe/Ni/Au layer stack with 5/90/25/50 nm thickness and subsequent annealing at 420°C for 90 seconds. For comparison, Schottky type metallization is used to fabricate conventional non-annealed ohmic contacts on LT-GaAs. Three antenna designs were produced: i) the MSM structure with an area of 400 µm² and with finger width and spacing of 1 µm and 1.5 µm respectively ii) the typical stripline-fed dipole structure with a photoconductive gap of 5 µm and various dipole length between 20 and 100 µm and iii) a coplanar stripline (CPS) with a gap of 10 µm. The structures are used as emitter antennas and are gated with a femtosecond laser or two-diode lasers for pulsed or photomixing experiments respectively.

III. RESULTS

To confirm our experimental results we simulated the distribution of the electric field in the 5 µm gap between the 100 µm long dipole arms using a FEM (COMSOL) method (Fig. 1). We assumed a region of higher conductivity (ohmic type) under the metal contacts, whereas the Schottky type antenna is modeled without this region. For the ohmic type antenna (doted lines) we obtained a higher density of the lines of force in comparison with the lines achieved for the Schottky type antenna (solid lines).

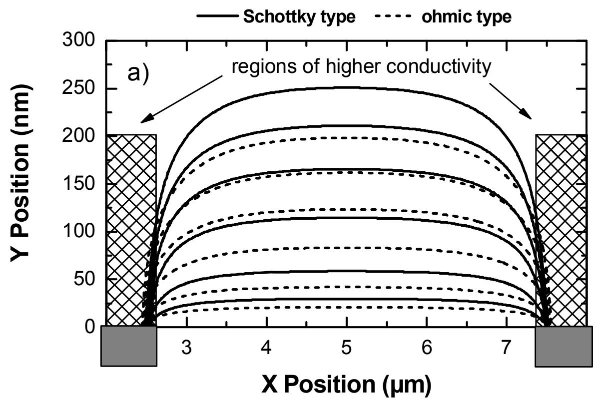

Fig. 1 a) FEM Simulation (COMSOL) of the lines of force between the two electrodes with (ohmic type) and without (Schottky type) a region of higher conductivity, where Y=0 is the metal-LT-GaAs interface

Thus, the electric field strength is at least 1.4 times higher for the ohmic type contacts at a y position of 175 nm. We note that this simulation is based on the model from E.R. Brown[9], where every point in the active volume of the an-

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tenna is electrically neutral. Moreover, the spectral characteristic of the THz emitters is verified with a microwave studio (CST) simulation of the antenna input impedance (Fig. 2b).

As an example we present the experimental results obtained with the 100µm dipole antenna used as a photomixer (Fig. 2). We measured the amplitude of the electric field (Fig 2a) at two different frequencies (125GHz, 290GHz) using a coherent detection scheme, where a second photoconductive antenna is used as a detector. Both antennas are excited by a Toptica DFB laser system (l ≈ 850 nm). For the ohmic type antenna (doted lines) we achieved a peak to peak value which is 1.3 times greater than the value measured with the Schottky antenna (solid lines). To ensure a fair comparison between the two types of antennas, we confirmed our data with measurements, where a Golay cell was used as a detector (Fig 2b). Such a detector is easier to align than the antenna in a coherent setup. The time domain data and the spectrum of the CPS-antenna excited with a 20fs Ti:sapphire laser for both the conventional Schottky type electrodes and AuGe-based annealed ohmic contacts are shown in Figure 3. The use of annealed ohmic contacts leads to at least two times higher THz output power and a significantly improved signal to noise ratio. The Schottky-type antenna exhibits frequency components from 0.1 THz to 4.5 THz, whereas the ohmic type has components up to 6.5 THz (Fig 3b).

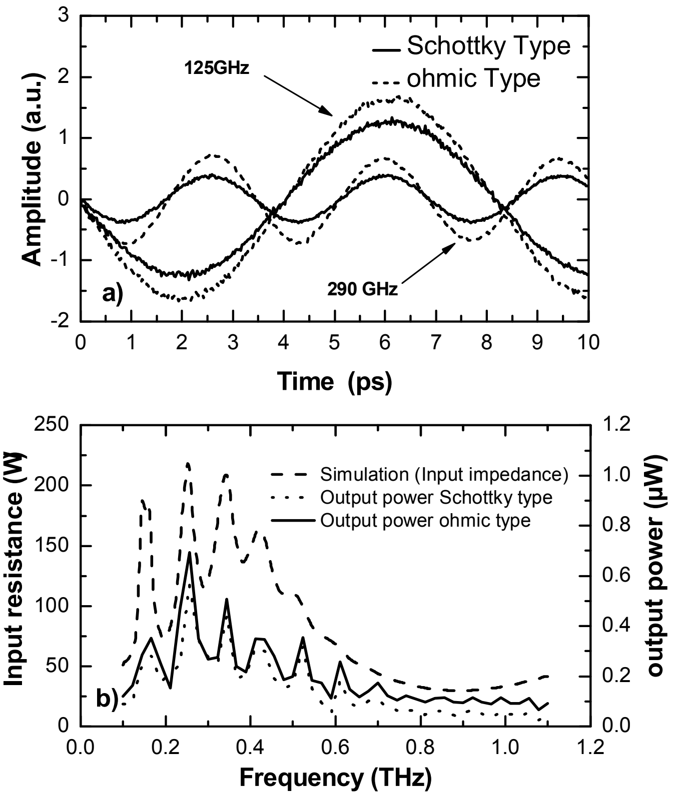

Fig. 2 Data obtained from the 100µm dipole structures used as photomixers. a) electric field obtained via coherent detection b) spectral distribution of the output power measured with the Golay cell and simulation of the antenna input resistance

IV. Conclusion

In conclusion we have compared the performance of THz photomixers and pulsed antennas evaporated with ohmic type (Ni/AuGe/Ni/Au) and Schottky type (Ti/Au) metallization respectively. The antennas with ohmic type contacts offer a higher output signal due to the improved contact properties. Our experimental data were confirmed with an FEM simulation, where we assumed a region of higher conductivity below the contacts. The simulated data support the experimental results

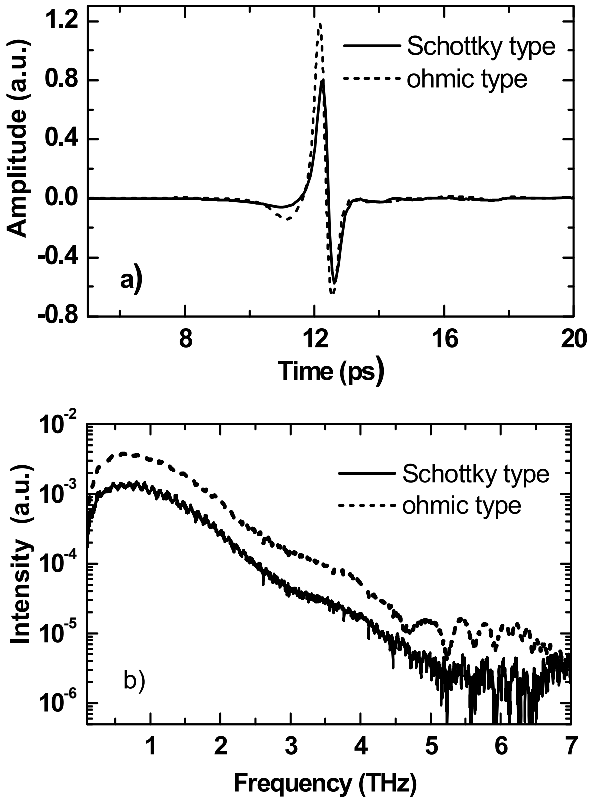

Fig. 3 Data obtained from the coplanar strip lines pulsed with the femtosecond laser a) electric field of the pulses measured via coherent detection b) spectral distribution obtained via Fourier transformation from the set of time domain data.

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