Micromachined Pressure Sensors Based on AlGaN/GaN Circular HEMT Sensing Devices

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MOTIVATION

The III-Nitrides (III-N) groups are very attractive for pressure and strain sensor applications thanks to their excellent piezoelectric properties. Therefore, high electron mobility transistors (HEMTs), and also Schottky diodes and resistors based on AlGaN/GaN heterostructures can be directly used as sensitive detectors especially in harsh environment or at high temperatures (e.g. placed on the wings of an aircraft, inside of combustion engines, etc.).

[*G. Vanko, at al: Sensors and Actuators A, 2011, in press; T. Lalinský, at al: Microel. Eng. 88 (2011) 2426*].

C-HEMT stress sensors fabricated on **bulk substrates** exhibit a good linearity in the piezoelectric response and excellent stress detection sensitivity independent from the measured frequency range. Due to the circular symmetry they are fully compatible with the AlGaN/GaN based circular **membrane structures** preferentially applied for MEMS pressure and stress sensors design. In this work we present - for the first time - a new design concept of a C-HEMT based **micromachined membrane pressure sensor**.

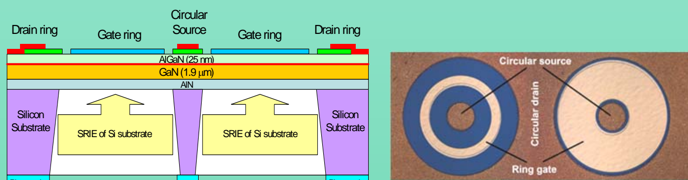

Fig. 1. Cross-section of micromachined pressure sensor: C-HEMT integrated on AlGaN/GaN membrane.

Fig.2. Front-side view of fabricated C-HEMT sensing devices.

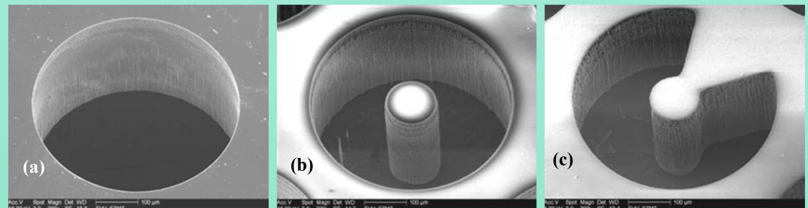

Fig. 3. SEM Micrographs of patterned circular (a), ring (b) and sequential ring (c) AlGaN/GaN membrane of pressure sensor by back-side 330 µm deep DRIE of Si substrate through a 7 µm thick photoresist mask.

Fig. 4. Detail of the patterned 330µm high Si-pillar.

Fig. 5. Back-side view of patterned ring membrane based C-HEMT sensor arrays.

Fig. 6. Detail of C-HEMT sensor from the back-side.

MICROMACHINED PRESSURE SENSOR DESIGN AND TECHNOLOGY

C-HEMT as pressure sensing device is integrated on circular, ring and/or sequential ring AlGaN/GaN membrane defined by a back-side selective deep reactive ion etching (DRIE) of Silicon substrate through 7 µm thick photoresist mask. The circular symmetry of the 2DEG channel of the C-HEMT is fully compatible with the circular AlGaN/GaN membrane structures preferentially used for MEMS pressure sensors design. The front-side processing of C-HEMT device is combined with a bulk Si-micromachining (Fig. 1). Fig. 2 shows the processed C-HEMT devices. Three different membrane configurations (Fig. 3) were designed to be integrated with the C-HEMT. The membranes are obtained by selective time-multiplexed ICP- DRIE of 330 µm thick Silicon wafer through a 7 µm thick photoresist layer. Special substrate holder is used for the non-standard sample geometries with a controllable He-pressure to the back of the sample to provide the necessary cooling but not to destroy the resulting thin membrane. The first AlN interfacial layer (Fig. 1) serves as the etch-stop of the trench-free silicon etching. Low frequency pulsing bias power is used to minimize destructive etching effects at the membrane base.

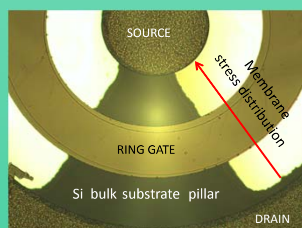

Fig. 7. Stress measurement on C-HEMT AlGaN/GaN membrane.

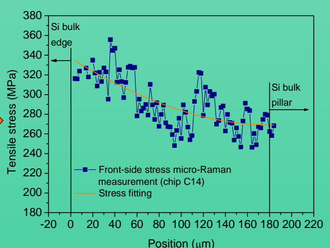

Fig. 8. AlGaN/GaN membrane stress distribution from µ-Raman spectroscopy.

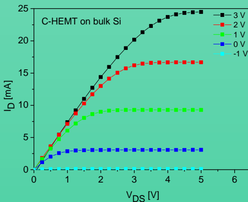

Fig. 9. Output I-V characteristics of C-HEMT on a bulk Si.

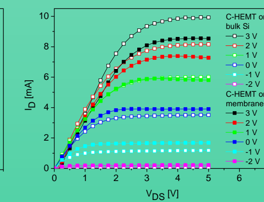

Fig. 10. Impact of membrane on output I-V characteristics.

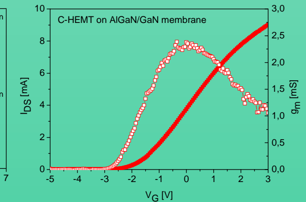

Fig. 11. Transfer characteristic and transconductance of C-HEMT device.

MECHANICAL AND ELECTRICAL CHARACTERIZATION

The initial stress in AlGaN/GaN ring membrane of C-HEMT pressure sensor (Fig. 7) was measured by µ-Raman spectroscopy. Fig. 8 shows the stress distribution across the ring membrane near the Si substrate pillar. It demonstrates the continuous decrease of induced tensile stress in the ring membrane from the Si substrate clamping up to Si pillar in the middle. The average stress value was estimated to be 300 MPa. The impact of membrane on transport properties of the C-HEMT devices was evaluated using dc electrical measurements. The comparison of output I-V characteristics (Fig. 10) reveals a decrease of the saturation current of ~14 % for the membrane based C-HEMT. This decrease can be explained by stress relaxing in AlGaN/GaN after Si substrate etching. However, the membrane has no significant impact on both the threshold voltage and transconductance, respectively (Fig. 11).

SENSOR DEVICE MODELING

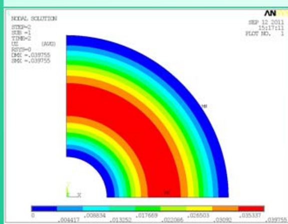

Fig. 12. Deflection of ring membrane [µm] loaded by pressure of 10 kPa.

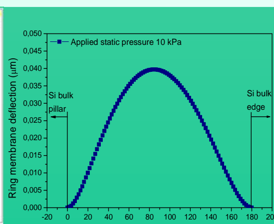

Fig. 13. Dependence of ring membrane deflection on radial position.

ANSYS code is used to determine the deflection of initial stressed membrane loaded by static pressure. SHELL 181 with 6303 elements is used to model the membrane. Initial stress was set to 300MPa (from µ-Raman spectroscopy, Fig. 8) and the applied static pressure to 10 kPa. 1/4 of the 1.9 µm thick and 180 µm wide GaN ring membrane was calculated. The obtained deformation is shown in Figs. 12 and 13 with the calculated max. deflection of 39nm.

CONCLUSIONS

- A new design concept of pressure sensors based on C-HEMT sensing devices integrated on circular, ring and/or sequential ring AlGaN/GaN membrane was introduced for the first time.
- The µ-process steps were experimentally verified.
- The functionality of the membrane-based sensing device proto-types were successfuly verified and tested.
- The initial stress in the ring membrane was estimated to be 300 MPa.
- 39 nm as the max. deflection of the ring membrane loaded by static pressure of 10 kPa was calculated.
- The functionality of C-HEMT integrated on a membrane is available for pressure sensing.

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