Monolithic Integration of HEMT-Based Common Gate Oscillator with Active Integrated Antenna in the GaN Material System

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Abstract and Introduction:

This project focused on the preparation of high electron mobility transistors (HEMTs) and the design of a HEMT-based, single-lithography-layer oscillator with active integrated antenna circuit with target oscillation frequencies up to 100 GHz. HEMT devices are well known for their suitability in high frequency microwave circuits, possibly for two reasons. Firstly, HEMTs offer high electron densities, high breakdown voltages and superior drain currents as well as transconductance, making the devices suitable for high power, high frequency application. Secondly, because of reduction in columbic scattering and collisions, HEMT devices are known to display low-noise characteristics. These two factors combine make HEMTs amenable to nano-scale microwave oscillator design. Focus on reduction in device size is a growing demand and the prevalence of cellular phones, WiFi and other radio devices is increasing. Thus, the design of a low-cost, nano-scale microwave oscillating circuit is desirable. In this project, AlGaN/GaN HEMTs were fabricated with recessed gates in order to enhance aspect ratio, transconductance, cutoff frequency and maximum frequency of oscillation [1].

Methods:

This project can be divided into two main categories: HEMT fabrication and single-lithography-layer oscillator circuit design. In the former, AlGaN/GaN HEMTS, consisting of undoped GaN buffer layer, AlN spacer layer and AlGaN barrier layer, were grown on sapphire substrate. The device then underwent mesa isolation via argon sputtering techniques. Source/drain ohmic contacts were then patterned through a multilayered evaporation process in a Ti/Al/Ni/Au sequence [2]. After rapid thermal annealing, Schottky barrier Ni/Au gate contacts were placed using electron-beam lithography. Several series of HEMTs were fabricated with different gate lengths (100 nm, 300 nm, 500 nm) and source to drain spacings (3 μm, 3.5 μm, 4 μm, 4.5 μm, 5 μm). Argon dry etching was then used to create the recessed gate under the gate contact with recess depth of approximately 10 nm. For the oscillator design, the HEMT was the central device of interest. Thus, focus was given to HEMT fabrication and optimization regarding high frequency performance.

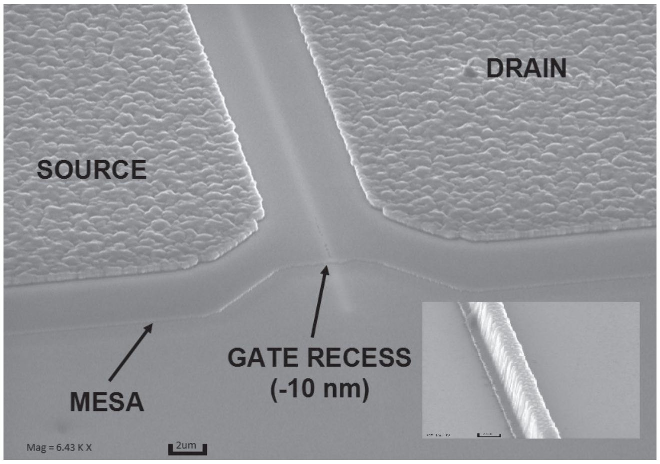

Figure 1: SEM micrograph of HEMT structure with gate recess. Insert shows SEM micrograph of gate recess.

Figure 1 shows a scanning electron microscope (SEM) image depicting an example of the HEMT structure without gate metallization: the mesa, patterned source/drain ohmic contacts, and the recessed gate structure. The inserted image shows an up-close SEM micrograph of the gate recess with gate metallization.

The second part of the project focused on the design of an oscillator and active integrated antenna with an oscillation frequency up to 100 GHz. A single-lithography-layer design is attractive because it can reduce manufacturing costs. To that end, a common gate oscillator circuit was selected for its simplicity and use of a voltage controlled transistor.

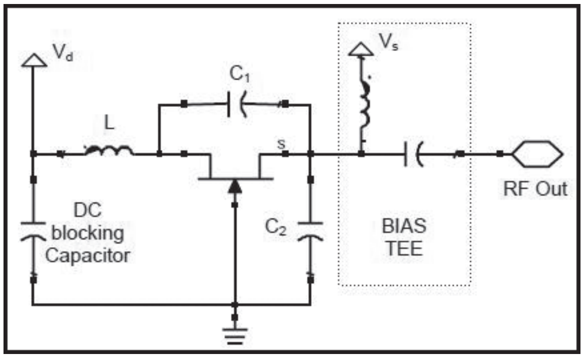

Figure 2: Common-gate oscillator circuit schematic.

Figure 2 shows the oscillator circuit schematic [3]. A circuit following this schematic was fabricated and tested successfully by Xu, et al., with gate-source bias of -5.3 V and drain bias of 20 V [3]. The remaining discrete circuit elements in the oscillator schematic include inductors and capacitors that comprise the LC tank subcircuit, DC blocking and a bias tee. Meanderline and interdigital geometries were selected to achieve single-lithography-layer realization of inductors and capacitors respectively. First, the capacitors were designed based on previously obtained empirical results. C1 and C2 in Figure 2 were designed as interdigital capacitors with eight structural fingers, finger spacing of 1 μm, finger width of 200 nm and overlap length of 8 μm. This design yielded a capacitance of roughly 2.7 fF.

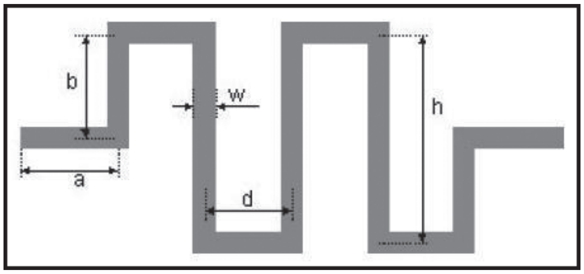

Figure 3: Meanderline inductor with characteristic dimensions.

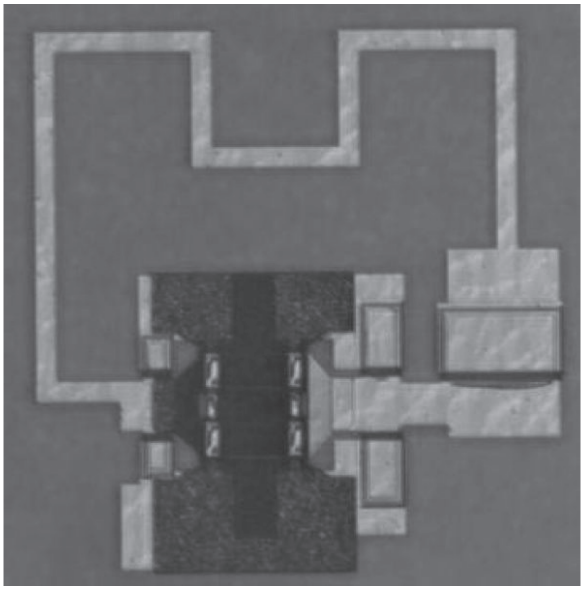

Figure 4: Example oscillator layout.

Figure 3 shows a meanderline inductor with characteristic dimensions [4]. A five-turn meanderline inductor with a = 140 μm, b = 160 μm, d = 80 μm, and h = 320 μm and thickness of 8 μm would yield an inductance of approximately 1.5 nH [5]. With these inductor and capacitor values, the tank circuit was calculated to oscillate at around 111 GHz.

The DC blocking capacitor was designed to achieve a capacitance approximately ten times that of C1, C2. To that end, the number of finger structures was increased to 24, and the overlap length was approximately 24 μm, while maintaining the same finger spacing and finger width as C1 and C2, or 1 μm and 200 nm respectively. The source bias tee structure was realized using a planar radial stub. More specifically, an oscillation frequency of 111GHz of an electromagnetic wave yielded a wavelength, λ, of approximately 2.68 mm. A transmission stripline, orthogonal to the RF signal stripline, of length λ/4 led to the radial stub. The stub angle was 90° with radius of λ/4.

Finally, for its wide-band characteristics, a simple bowtie antenna will be used as the integrated antenna element.

Future Work:

Future work includes arranging the described circuit elements for single-lithography-layer fabrication.

Furthermore, integration of coplanar waveguides for signal transmission is needed to improve signal quality and provide a better means to probe and inject signals. Figure 4 shows an example oscillator layout [3].

Acknowledgements:

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