Executive Summary

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1. Title of the Project: **"Development of Gallium Nitride (GaN) Based Technology Platform for THz Applications."**

2. Date of Start of the Project: 01/10/2021

3. Aims and Objectives:

- To pursue disruptive and translational approaches for addressing fundamental roadblocks in developing Gallium Nitride (GaN) based technology platform for THz applications.
- Demonstration of GaN based THz Devices.

4. Significant achievements (not more than 500 words to include List of patents, publications, prototype, deployment etc)

I. A rigorous device-circuit co-design investigation of AlN/GaN HEMT was performed to explore its feasibility for power amplifier operation at frequencies ~1 THz. Both class A and class AB operations were invested. A novel device-circuit co-design methodology was adopted, which involves (i) device design optimization using a well-calibrated TCAD setup, (ii) careful extraction of large-signal model cards with I-V, C-V & S-parameter matching, and finally (iii) source-load pull-based power amplifier design exploration, for every device design investigated. For PA operation, class A and class AB operations were invested while exploring PA gain, output power, efficiency at 1dB compression point, and linearity through dual-tone (IMD3) investigations. Besides, a complete range of device design parameters was investigated to explore the ultimate scalability limit and narrow down the device design window that can enable THz operation. It was found that while the intrinsic unity gain frequency (f_T) had weak dependence on some of the device design parameters like Lgd (gate-to-drain spacing), Lgs (gate-to-source spacing) and Tr (gate recess depth), the PA performance was a strong function of a combination of these parameters in conjunction with Lg (gate length) and Lfp (field plate length). Moreover, while f_T was found to drop monotonously with increasing Lfp, the maximum frequency of PA operation vs. Lfp was a strong function of the class of operation and Lg. Besides, it was found to be a weak function of Lfp for Lfp <10nm. Similarly, while f_T improved with increasing Tr, the maximum frequency of PA operation dropped with increasing Tr. Furthermore, PA linearity was also a strong function of these device design parameters and class of operation. Keeping in mind the finding of this work, it can be concluded that AlN/GaN HEMT with Tr= 0-1nm, Lfp= 0-10nm, Lsd= 50-70nm, Lgs <50nm and Lg= 20nm, when operated in class A condition, has a feasibility to offer ∼1 THz operation. The same requires a narrower design window (Tr= 0nm, Lfp= 0nm, Lsd= 50nm, Lgs < 50nm and Lg= 20nm) to enable THz operation when operated in class AB condition. Finally, it is worth highlighting, for the purpose of benchmarking, that earlier works on InP HEMTs also demonstrated>1 THz operation with device's ft around 600GHz, as seen in this work.

II. GaN-on-Si RF HEMT devices were fabricated, which included the tedious task of optimising various parameters like the etching chemistry, deposition gas pressure, sccm flow, optical and electron beam resists etc. The fabrication flow for the whole process has been optimized and devices of 1µm and 800nm have been fabricated using this process flow. A maximum ON current of 720mA/mm and fT of 14 GHz has been achieved with these devices.

"**Exploring the Feasibility of AlN/GaN HEMTs for THz Applications Using a Novel Device-Circuit Co-Design Approach**", *Harsha B Variar, Ajay Singh, Ankit Soni and Mayank Shrivastava*, 6th International Conference on Emerging Electronics, 2022.

5. Concluding remarks

In future, these characteristics will be enhanced further by using smaller gate length, optimized passivation like high κ oxide such as $Al_xTi_{1-x}O$, efficient field plate design or T-Gate structure, optimized gate and ohmic metal stack etc. In the end the device robustness will be checked by subjugating it to standard and novel DC and RF stress conditions that the device faces in the real world applications. This will help develop a robust GaN-on-Si RF HEMT technology with optimum performance-reliability trade-offs.