N211-086 TITLE: N-Polar Gallium Nitride High Electron Mobility Transistor in Low-Cost Process Technology for mm-wave Transceiver Applications

RT&L FOCUS AREA(S): 5G; Microelectronics

TECHNOLOGY AREA(S): Electronics; Materials / Processes; Sensors

OBJECTIVE: Demonstrate robust N-polar Gallium Nitride (GaN) E-band low noise amplifiers (LNAs) with <3.5 dB noise figure at 83 GHz, and device NFmin < 1 dB at 30 GHz. The device and LNAs must use a native growth N-polar epitaxy process on a low-cost substrate that can be scaled to diameters of 150 mm and above.

DESCRIPTION: N-polar GaN has demonstrated breakthrough high-power density performance in the W-band, and matched or exceeded power performance of traditional Ga-polar GaN at lower frequencies including X and Ka-band. GaN transistors and monolithic microwave integrated circuits (MMICs) today are expensive, with a significant portion of the cost coming from the Silicon Carbide (SiC) substrates and their smaller diameters (200 mm substrates will lower MMIC cost by 6X for low cost substrates). Alternate substrates will be lower thermal conductivity and/or increased microwave loss, the impact of which should be considered. A single epitaxial structure will lead to a 50% reduction in integration cost of an LNA, Power Amplifier (PA) and transmit / receive (TR) switch. Tradeoffs in performance of individual circuits is anticipated in order to meet the topic objectives in a single device epilayer structure. Examples for the current state of the art for Ga-polar GaN HEMT on SiC follow; HRL's T4A process provides excellent NFmin below 1 dB at 30 GHz and approximately 0.5 W/mm power density. Ga-polar GaN-on-SiC HEMT's data at 94 GHz at 2 W/mm and 22% power-added-efficiency (PAE) has been reported. Nitrogen polar (N-polar) GaN HEMTs, at 94 GHz, have demonstrated ~9 W/mm at 28% PAE on SiC and 4 W/mm, 30% PAE on Sapphire. N-polar GaN LNA's have not been reported. Availability of N-polar GaN device materials in substrate diameters from 100-200 mm is being established through DoD investment in technology transition and manufacturing.

PHASE I: Design and fabricate a low noise N-polar GaN HEMT device with noise figure (NF) min <3 dB at 83 GHz and <1 dB at 30 GHz, with epitaxy grown on a low-cost substrate and with an epitaxial design capable of supporting both power amplifier devices with >4 W/mm and >25% PAE and transmit/receive (T/R) switches. Characterize noise and S-parameters and extract noise and linear models. Develop a Phase II plan.

PHASE II: Refine the design of and fabricate a prototype E-band 81-86 GHz LNA demonstrating <3.5 dB NFmin and >15 dB gain. Characterize the noise and small-signal performance. On the same wafer, fabricate split path, double throw (SPDT) T/R switches and characterize their performance at small and large signal level under continuous wave (CW) conditions. Based on the measured performance, survey and identify E-band transceiver applications for the Phase II results.

PHASE III DUAL USE APPLICATIONS: There are many emerging transceiver applications for both DoD and commercial systems for E-band. The U.S. Federal Communications Commission has established that portions of E-band are available in the U.S. for high density, high data rate wireless services that will enable point-to-point communications, SATCOM, and 5G services. The International Telecommunication Union permits several bands for radio and satellite operations. For example, SpaceX has applied to use portions of E-band in their Starlink Gen2 satellite constellation. E-band will enable new high-resolution imaging and surveillance sensors for DoD systems and commercial applications such autonomous vehicles. In Phase III, transition and demonstrate the N-polar device fabrication to a full wafer fabrication at wafer diameters > 150 mm. Refine the designs developed in the Phase II. Based on the phase II application survey for an E-band transceiver application, develop the TR module specifications to satisfy this application. Design and fabricate a prototype integrated TR module and package into a waveguide housing with all bias and control signals integrated. Characterize under relevant operating conditions. Based on the results, further refine the designs.

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KEYWORDS: GaN; Gallium Nitride; low noise amplifier; transceiver; High Electron Mobility Transistor; HEMT; Nitrogen Polar; Noise figure