Development of GaN-based Gunn-Effect Millimeter-Wave Sources

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Theoretical and experimental studies conducted for the purpose of development and optimization of GaN-based Gunn diodes for THz are reported. GaN Gunn-diode oscillators with $0.3\mu m$-thick GaN diodes are expected to have fundamental frequency of *750GHz* and power density of $3\times10^{5}W/cm^{2}$. GaN In an effort to verify the experimental characteristics of GaN Gunn diodes, device layers were grown by MOCVD and special device patterns have been developed. On-wafer characterization of the fabricated GaN negative differential resistance (NDR) diodes revealed increased power capability compared with GaAs Gunn devices The processing necessary for realization of such diodes with increased power handling is also addressed.

Theoretical and experimental studies of electron transport in GaN-based semiconductors indicate that electron *v-F* characteristics in these materials exhibit inter-valley electron transfer at high electric fields [1, 2]. The threshold field in GaN is much higher than that of GaAs (*~150KV/cm* vs. *3.5KV/cm*) promising increased power and frequency capabilities for GaN-based Gunn-effect devices. Based on the above considerations it is attractive to explore the use of III-V Nitrides in Gunn devices for THz signal generation.

A first analysis of microwave potential of GaN-based Gunn diodes was recently reported by the authors and demonstrated significant power and frequency improvements over conventional III-Vs due to increased electrical strength, reduced relaxation times, and increased electron velocity in GaN [3]. This work further extends these studies of GaN Gunn diodes to include studies of the possibility of THz generation using GaN. Recent progress in the development of GaN-based Gunn devices using GaN layers grown by MOCVD at the University of Michigan is also presented in this work.

The frequency and power capability of GaN-based millimeter-wave sources was evaluated using large-signal harmonic analysis based on energy-balance device simulations. GaN material parameters used for this purpose were based on previously reported characteristics of GaN-based devices [3, 4].

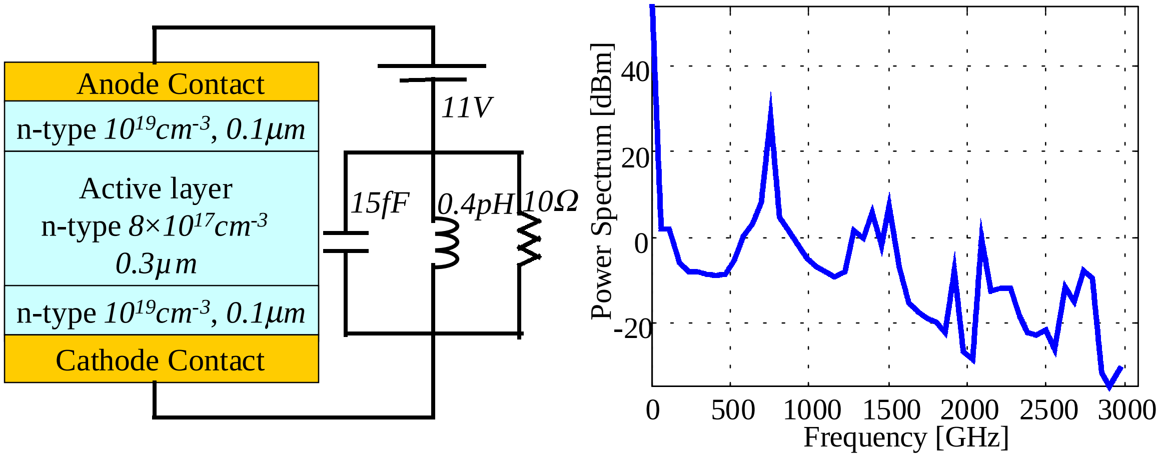
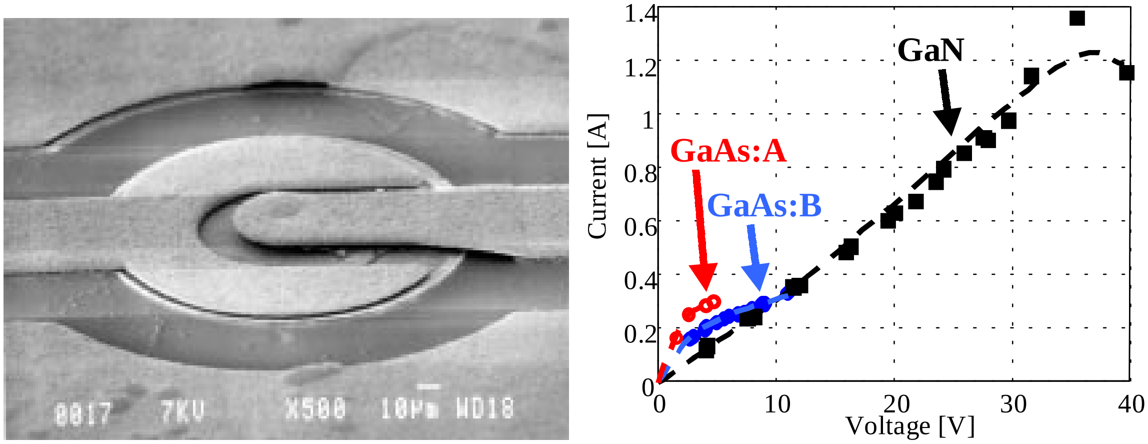


Figure 1. Schematics of GaN Gunn source and its power spectrum showing fundamental operation at *750GHz*

A schematic of a proposed THz source based on GaN Gunn diode is shown in Figure 1. The design features a thin and highly doped active layer ($0.3\mu m$, $8\times10^{17}cm^{-3}$) and, thus, it is expected to operate at a much higher frequency than currently available using GaAs devices. A power spectrum of the THz GaN Gunn oscillator was obtained by harmonic analysis showed fundamental frequency of *~750GHz* and a conversion efficiency of *~1%*. This high frequency capability of GaN is due to short relaxation times, high electron velocity, and large threshold field in this material.

A GaN diode with $3\mu m$-thick active layer and doped at $1\times10^{17} cm^{-3}$ designed to operate a W-band frequency range was selected for the purpose of experimental verification. GaN Gunn layers were grown on sapphire substrates in the in-house MOVPE system at an ambient temperature of $1120^{o}C$ and a growth rate of $1.4\mu m/hour$. Integrated devices for on-wafer testing were fabricated on isolated circular mesas using dry etching techniques and Au plating for airbridge interconnects and heat sinks as shown in Figure 2a. The fabricated GaN devices were characterized using pulsed I-V measurement system to eliminate influence of self-heating due to presence of sapphire substrates. Characteristics of GaAs Gunn diodes were also measured and shown in Figure 2b for comparison purposes. Obtained results indicated that current and voltage capabilities of GaN Gunn diodes significantly exceed that of GaAs devices, but a more efficient heat-removal techniques, such as substrate removal or flip-chip bonding on AlN substrates are necessary for complete RF testing.



(a) (b)

Figure 2. (a) SEM photograph of a fabricated GaN Gunn diode and (b) pulsed IV characteristics of GaN Gunn diodes demonstrating increased voltage and current capabilities compared with GaAs devices.

Overall, large-signal numerical simulations were performed to investigate a possibility of THz signal generation using GaN-based Gunn diodes. Based on the results of the large-signal simulations, GaN NDR layer structures were designed and grown by MOCVD at the University of Michigan. On-wafer characterization of the fabricated GaN NDR diodes revealed increased power capability compared with GaAs data. More efficient heat removal techniques necessary for reliable RF operation are currently under development.

Acknowledgments

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