**Thermal Characterization of GaN Vertical Devices Using Optical Methods**

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**Motivation**

Wide-Bandgap Electronics
- In the near future wide-bandgap (WBG) electronics will replace the legacy Si-technology in military and clean energy applications
- Recent advancement of GaN has allowed development of power conversion systems that operate at higher power, frequencies, and temperatures with a smaller footprint

Self-Heating and Reliability Issues
- Excessive device self-heating leads to degraded performance, shorter life time, and triggers failure mechanisms
- Thermal characterization has yet to be performed on GaN vertical devices
- Optical thermometry: Non-invasive and non-contact measurement, high spatial resolution

GaN p-i-n Diodes
- GaN p-i-n diodes are attractive due to their high-voltage, low leakage current, and high power applications
- The devices studied feature a mesa consisting of a p-GaN, i-GaN, and n-GaN
- The p-contact was deposited on top of the mesa structure

**Infrared (IR) Thermal Microscopy**

Infrared (IR) Thermography
- Most widely employed technique in industry
- Rapidly generates qualitative 2-D temperature maps
- Relates a material’s thermal emission to surface temperature rise
- Spatial resolution 4µm: 2.7 µm

Challenges
- Depth averaging due to semi-transparency of GaN to IR wavelength
- Low emissivity of metals leads to inaccurate results

Technique Advancement
- Explored accuracy of emissivity correction based upon two reference temperatures as compared to those obtained from the conventional 1-temp method

Future Work
- Utilization of carbon based high-emissivity nanoparticles for local temperature measurement
- Resolve accuracy of the calibration process associated with the z-Temp method

**Raman Thermometry**

Raman Thermometry
- Allows assessment of temperature rise based upon phonon peak shift and/or line broadening
- Ideal for measuring temperatures of semiconductor materials
- Sub-micron spatial resolution (< 0.5 µm)
- Optimal for studying lateral devices (e.g., AlGaN/GaN HEMT, MEMS, etc.)

Challenges
- Overlapping signals from doped layers stacked into a mesa are collected
- This renders the use of existing methods to be difficult
- Metallic materials lack distinct Raman peaks due to fluorescence
- Conventional Raman thermometry methods are unfeasible for vertical devices

Technique Advancement
- Nanopowder-Assisted Surface Raman Thermometry
- TiO₂ nanoparticles were deposited on metal electrode and GaN surfaces
- Allows for surface temperature assessment based upon the temperature dependent Raman response of the E₂ phonon mode of TiO₂

Future Work
- Apply WBG nanopowders with higher purity and study their effectiveness for being used as nano-thermal probes

**Thermoreflectance Thermal Imaging (TTI)**

Thermoreflectance Thermal Imaging
- Utilizes change in reflectance of a material with temperature rise
- Optimal technique for metallization structures
- High spatial resolution (< 0.5 µm)
- Ideal for studying vertical devices (capable of probing their metallic contacts)

Challenges
- Assumes linear change in temperature with reflectance
- Material and surface finish dependent
- Intrinsic calibration errors in conventional methods due to thermocouple inaccuracy

Technique Advancement
- Improved accuracy associated with temperature calibration via thermocouple correction based upon Raman thermometry

**Conclusions**

- Pioneering thermal characterization was performed on GaN p-i-n diodes
- Made improvement over conventional optical thermometry methods
- Each measurement technique was optimized for application on vertical WBG devices

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