Numerical Simulation of Thermal Runaway in a THz GaAs Photoconductor

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Introduction

- Terahertz (THz) radiation (light frequencies of 0.1 THz – 10 THz) has a variety of military, commercial, and academic applications.
- Photoconductive switches and photomixers can be used to generate THz radiation.
- Low-temperature-grown (LTG) GaAs and ErAs:GaAs have shown promise as photomixing materials due to their short carrier lifetimes (< 1 ps).
- Photoconductors are limited in output power by device failure at large bias voltages and intensities.
- Thermal breakdown of PC devices has not yet been well-studied due to high numerical and analytic complexity.
- COMSOL Multiphysics software was used to simulate a GaAs photoconductor under breakdown conditions to determine if thermal runaway is causing device breakdown.

Computational Methods

- Per the hypothesis, deep-level traps in GaAs photomixers may be causing an exponential temperature dependence on device carrier concentration.
- To test this, we included a temperature dependent electron concentration for above room temperature conditions:

$$\sigma = \sigma_0 e^{-\frac{\Delta E}{kT}}$$

- Optical absorption caused carrier generation in the photoconductor (based on Beer's Law):

$$G(y) = \frac{\alpha I}{h\nu} e^{-\alpha y}$$

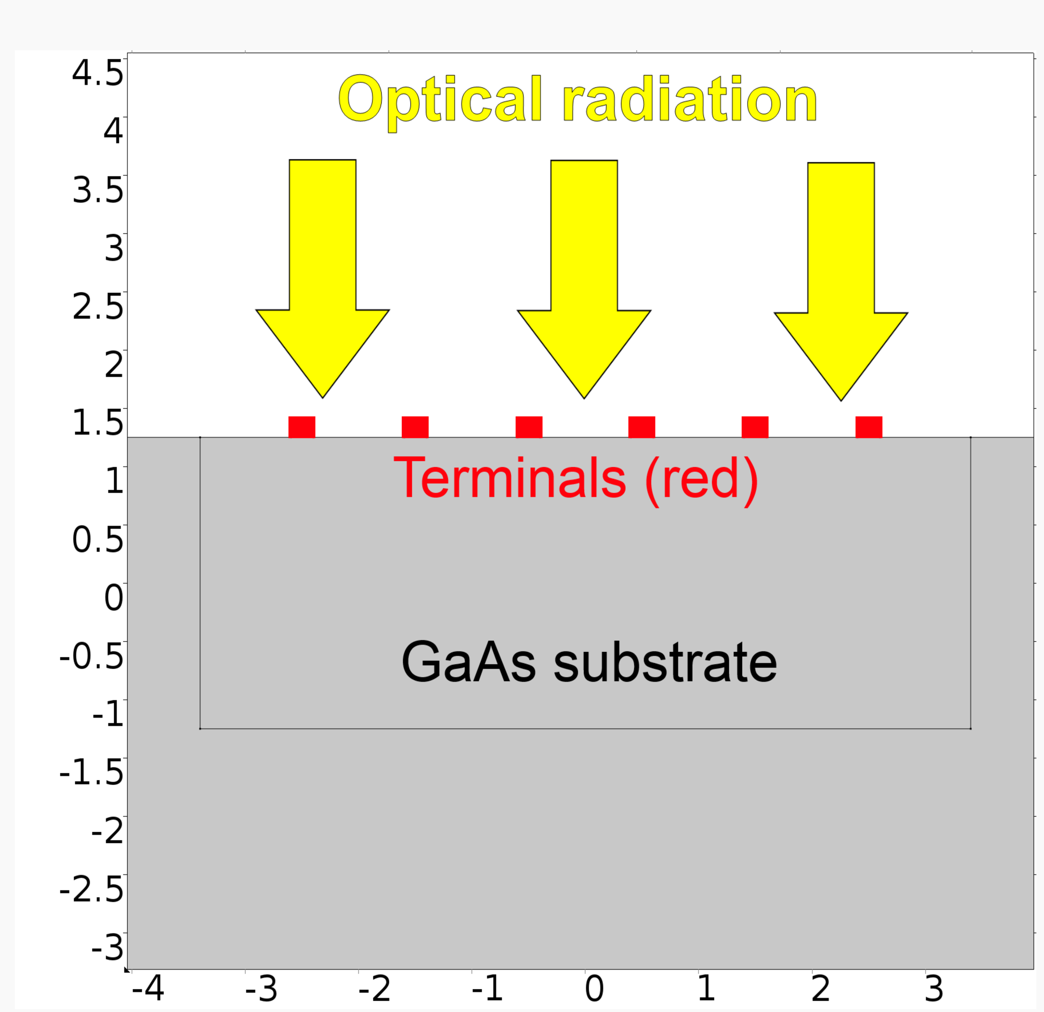
- Heat transfer equations, both Joule heating from dark current and photocurrent and optical heating from laser power:

$$0 = k\nabla^2 T + \mathbf{J}\cdot\mathbf{E} + \alpha I e^{-\alpha y}$$

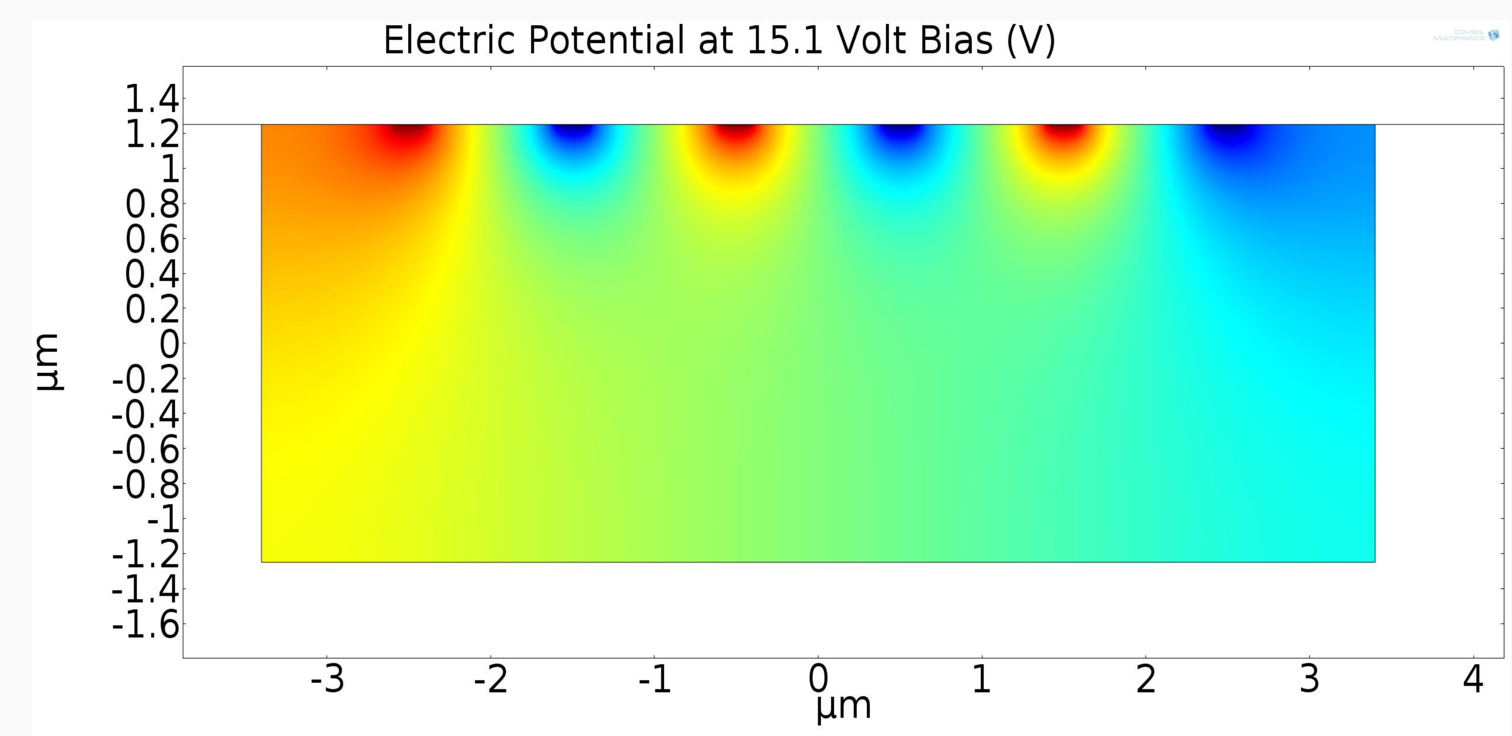
- Semiconductor transport equations were solved, with a Shockley-Read-Hall recombination term.

Device and Model

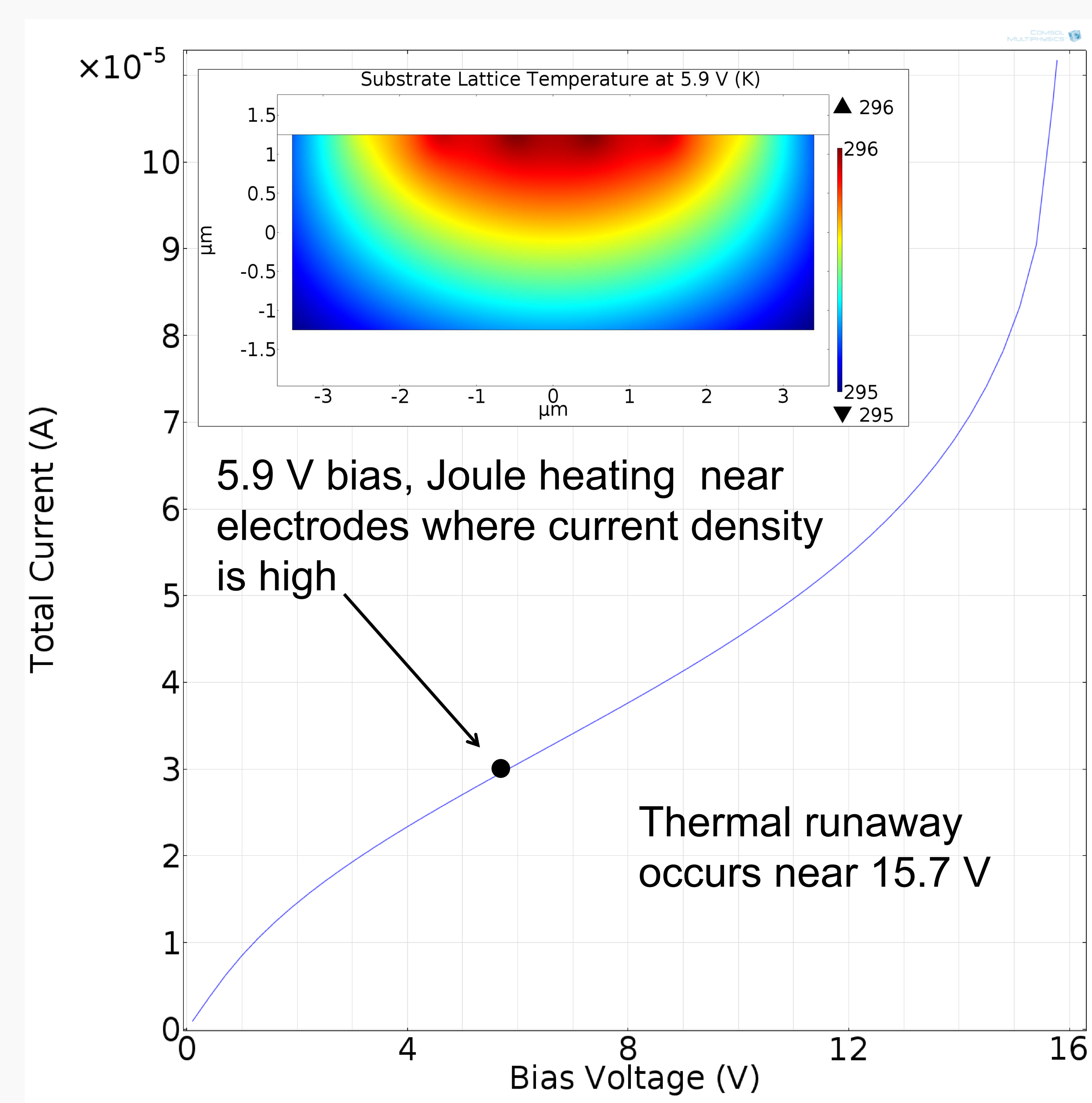
Photograph of a 9x9 μm physical photomixer: "finger" electrodes visible in center of image.



Results



The electric potential plot reveals the strong field between the interdigitated electrodes of alternating potential.



The IV curve for the device exhibits quasi-linear behavior for intermediate voltages, but increases rapidly as voltage approaches 15.7 V – characteristic of thermal runaway.

Conclusion

- These results support the hypothesis that device breakdown results from thermal runaway associated with exponential increase in carrier concentration.
- Numerical simulation reveals a strong qualitative agreement between COMSOL data and breakdown behavior observed in real devices.
- Future work: search for quantitative agreement between COMSOL Multiphysics simulations and experimental data.

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