Lateral Field Emission Transistors For Extreme Temperature Operation

W. Max Jones and Axel Scherer
Electrical Engineering, California Institute of Technology, 1200 East California Blvd, Pasadena

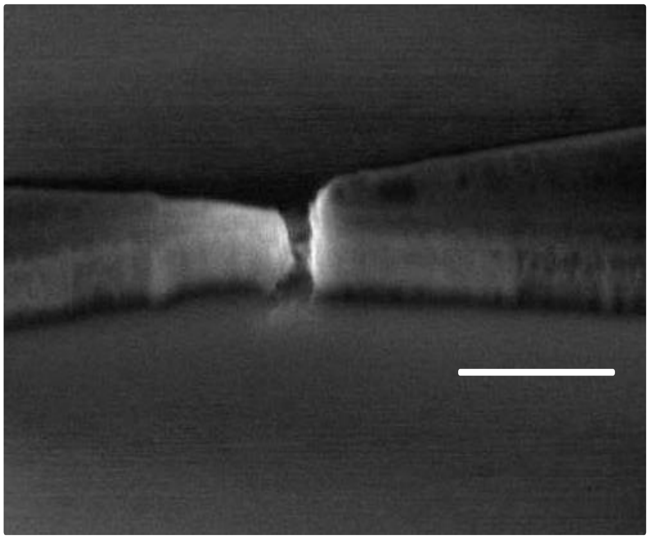
High temperature environments have always presented a challenge to solid-state transistors with silicon MOSFETs unable to operate at temperatures above 300C[1] and silicon carbide devices unable to operate at temperatures above 600C[2]. Unfortunately, there are many applications that require operation electronics in precisely these environments. For example, NASA missions to the surface of Venus would require electronics that can operate in excess of 450C. These niche applications present an opportunity for alternative electronics paradigms.

Miroscale and nanoscale field emission devices operating on the principle of Fowler-Nordheim tunneling have long been a source of academic interest[3]. When emitter and collector gaps are smaller than 200nm, atmospheric operation is possible[4], and a combination of low transit times and very small device capacitances makes THz operation a possibility[5]. In principle, field emission never becomes linear with increasing temperature, so field emission transistors should be able to operate at temperatures higher than the maximum operating temperatures of solid-state transistors. Stable field emission has been demonstrated up to 500C[6].

Our group has produced lateral field emission diodes and transistors through a CMOS compatible process consisting of multiple, vertically stacked emitting, collecting, and gating layers. Our devices are capable of operation at atmospheric pressures in an inert gas, producing microamperes of current at sub-10 volt turn-ons, and long operating lifetimes. Building on our previous work, we will demonstrate a modified version of our multilayer lateral field transistors operating at extreme temperatures in an inert atmosphere. This opens the possibility for circuits and systems built out of field emission devices and designed for extreme temperature operation.

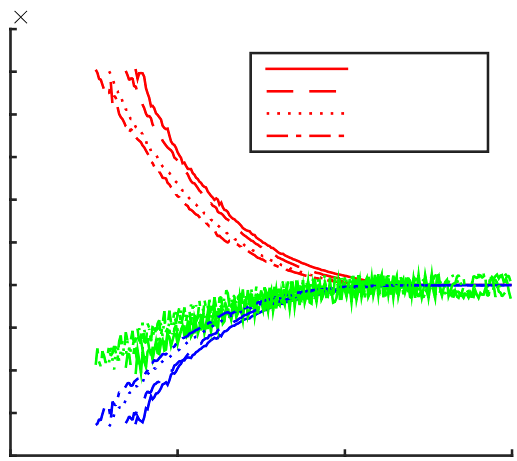
[1] Neudeck, P. G., Okojie, R. S., & Chen, L. Y. (2002). High-temperature electronics-a role for wide bandgap semiconductors?. *Proceedings of the IEEE, 90*(6), 1065-1076.
[2] Phillip Neudeck, Michael Krasowski, and Normon Prokop, “Assessment of Durable SiC JFET Technology for +600C to -125C Integrated Circuit Operation,” ECS Transactions, vol. 41, pp. 163–176, 2011.
[3] G.N. Fursey, Field Emission in Vacuum Microelectronics, 1 ed. Springer US: New York, 2007
[4] Laura Pescini, Armin Tilke, Robert H. Blick, Heribert Lorenz, Jörg P. Kotthaus, Werner Eberhardt, and Dieter Kern. "Nanoscale lateral field-emission triode operating at atmospheric pressure." Advanced Materials 13, no. 23 (2001): 1780-1783.
[5] Jin-Woo Han, Jae Sub Oh, and M. Meyyappan, “Vacuum nanoelectronics: Back to the future? Gate insulated nanoscale vacuum channel transistor,” Applied Phyiscs Letters, vol. 100, 2012.
[6] L. Wang, G. Wei, F. Gao, C. Li, and W. Yang, “High-temperature stable field emission of b-doped sic nanoneedle arrays,” Nanoscale 7, 7585–7592 (2015).

Figure 1:



Vertically layered, gated field emission device at 45 degree tilt. The emitter collector gap is 68nm. Scale bar represents 500nm.

Figure 2



The current-voltage characteristic for the three terminal Fowler-Nordheim device. The red portion is the emitter current, the blue portion is the collector current, and the green portion is the gate leakage current.