Silicon Carbide, Vacuum Tube Nanoelectronics: Application for Exploration Missions Requiring Category III/IV Planetary Protection

J. O. Arnold[1] and Meyya Meyyappan[2]

[1]AMA at NASA Ames Research, Moffett Field CA, 94035

[2]NASA Ames Research Center, Moffett Field CA, 94035

Acknowledgment: Jin-Woo Han

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Outline

- **Category III/IV Planetary Protection Policy - Purpose and applicable missions. [1] Space Research Today, COSPAR Bulletin # 200 Dec. 2017.**
- **Penetrating sterilization techniques and incompatibilities (Pugel, et. al., March 2017 IEEE Aerospace Conference) [2].**
- **Why and what are SiC vacuum tube nanoscale electronic systems that are being funded for development by NASA SMD? [3]. What attributes make them amenable to penetrating sterilization by simultaneous application of dry heat and irradiation?**
- **Take home message**
- **Forward work**

Category III/IV Planetary Protection [1]

- **Committee on Space Research (COSPAR) maintains international standards and procedures to guide compliance with a UN Space Treaty to avoid biological contamination of bodies resulting from Space Exploration.**
- **Category III (mostly flyby and orbital) and IV(mostly probes and landers) apply to forward contamination of Enceladus, Europa, Mars "Special Regions" and others "TBD".**
- **For Enceladus and Europa, the probability of inadvertent contamination of their oceans by terrestrial organisms is to be less than $1X10^{-4}$ per mission.**
- **Mars requirements are subdivided into four categories: One for orbiters and three for landers at "special regions" depending upon mission objectives relating to the search for extant Martian Life. See [1] for detail.**

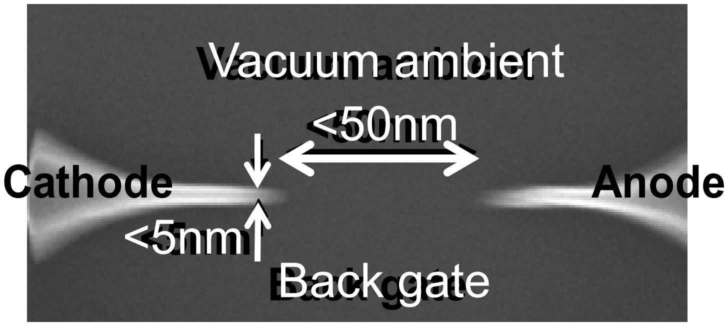
Policy compliance requires spacecraft sterilization and any recontamination. Ideally, dead spores are removed.

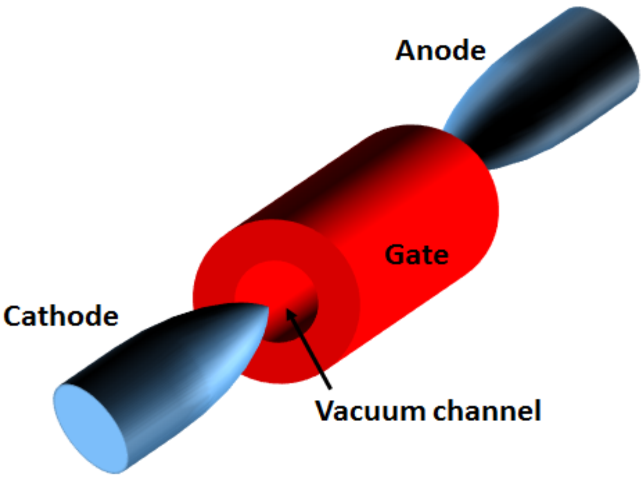
From "Brushing your spacecraft's teeth "A review of Penetrating Bio Reduction Processes" March 2017 [2]

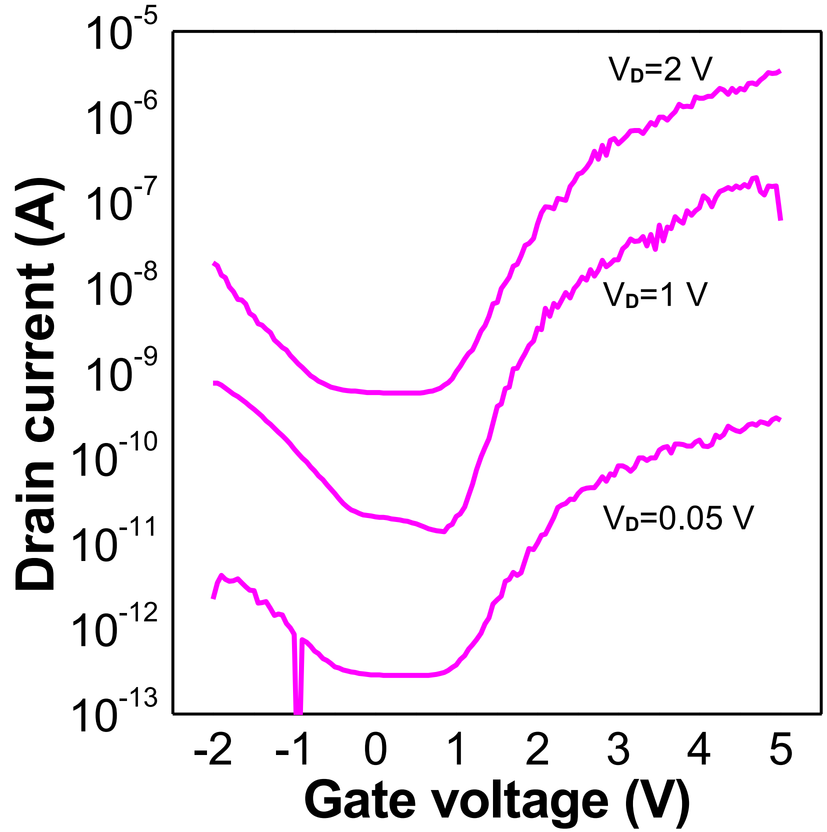
Technique	Examples of Potential Incompatibilities
Dry Heat Microbial Reduction (DHMR)	Thin films, Joints or interfaces with disparate coefficients of thermal expansion.
Gamma Rays (Cobalt 60)	Radiation sensitive electronics. Polymer degradation.
Gamma Rays Plus Heat	Electronics rated for less than 100-150 krad and 95-100 ^{O}C.

- "Dry Heat Microbial Reduction (DHMR): NASA and ESA have approved DHMR processes. "NASA has invested in qualification of DHMR hardware."
- "Gamma Scalability is already a reality. DoD and the Dept. of Homeland Defense use Gamma Radiation for Sterilization."
- "Dead microbes are not removed by the gamma process, so additional methods would be required if organic contamination is a requirement for planetary protection."
- "Gamma + Heat (Thermoradiation): Promising for parts, subsystems, or integrated systems that may be able to tolerate test parameters for temperature and radiation."

SiC Vac Tube Nanoscale Electronics [3]
Presently tested at 200 ^{O}C &1 Mrad







- **Manufactured with standard Integrated Circuit plasma etching techniques.**
- **SiC -> Temps from 500 to 600 ^{O}C; Vac. Tube Technology -> Rad. Resistance**

  > 1 Mrad -> High likelihood for Penetrating Sterilization via Thermoradiation.
- **Temps to 500 – 600 ^{O}C -> Dead spore removal via dry heat ashing [4]?**

Sterilization Approach

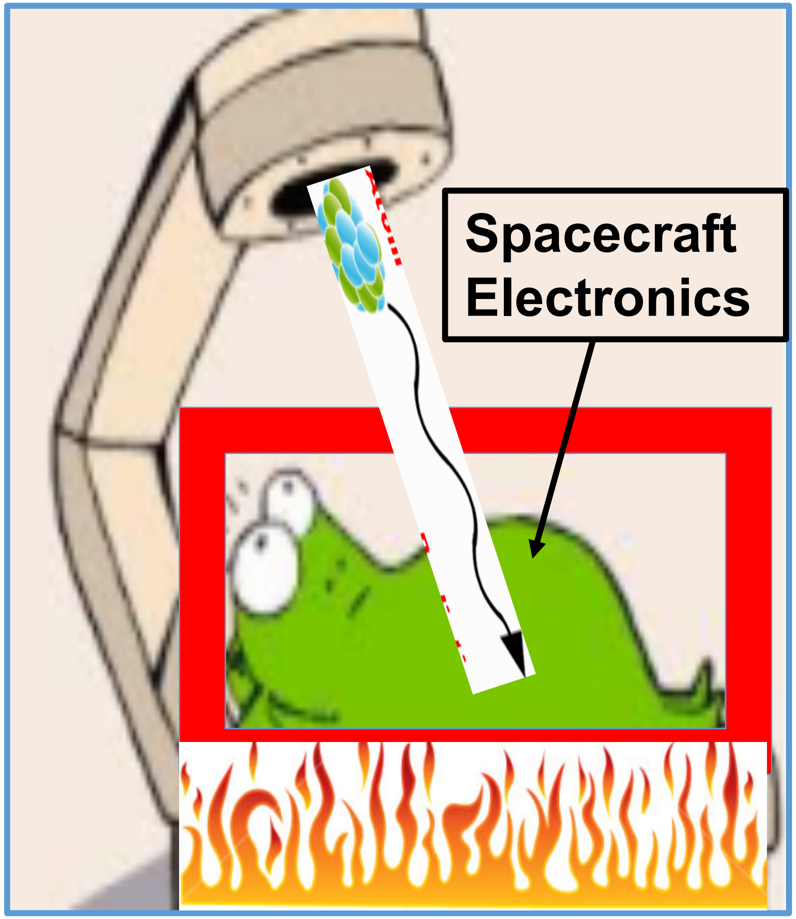
Cobalt 60 Gamma Rays + Heat = THERMORADIATION

Synergy of Thermoradiation [2]

$$N(t) = N_o e^{-(kT + kR + kTR)t} \quad [5]$$

- **2.5 Mrad alone to kill "standard" spores.**
- **95 – 110 ^{O}C + 150 Krad gives 4 – 7 logs spore reduction in 15 hours.**

How would sterilization affect SiC nanoelectronics performance?



Take Home Message

- **SiC Vacuum tube nanoscale electronics is an emerging technology funded by SMD for future missions to Europa because of its resistance to high levels of radiation.**

- **Attributes of the emerging technology strongly suggest it is amenable to: (1) sterilization by thermoradiation and (2) removal of dead spores and organic residue by ashing to 600 ^{O}C.**

If this proves to be the case, the potential incompatibility in use of thermoradiation for electronics sterilization for category III/IV missions to Enceladus, Europa and Mars "Special Regions" could be overcome.

Forward Work

- **Fabricate and demonstrate SiC Vacuum tube nanoscale electronic circuits that can operate at 500 ^{O}C under 1 Mrad radiation within 2 years (Funded by SMD).**

Additionally, the value of the technology could be greatly enhanced by:

- **Demonstrating Microbial reduction via Thermoradiation as described in NASA SP-5105 [5] and the rate equation shown above.**

- **Evaluate removal of dead spores and organic residue by ashing to temperatures approaching 600 ^{O}C.**

- **Demonstrate performance of nanoscale electronics pre/post sterilization and ashing.**

If this research was conducted and positive outcomes realized, it is possible that sterilizable, spore free, SiC nanoscale electronics could be available for future missions to Enceladus, Europa and "Special Regions" on Mars.

References

[1] "Space Research Today, COSPAR's Information Bulletin", No. 200, pp 11-25, December 2017.

[2] Pugel, D. E., Rummel, J. D., and C. Conley, "Brushing Your Spacecraft's Teeth: A Review of Biological Reduction Processes for Planetary Protection Missions", IEEE Aerospace Conference March 2017.

[3] Han, J.W., Moon, D.I., and Meyyappan, M. " Nanoscale Vacuum Channel Transistor, Nano Letters, 17, 2146-2151 (2017).

[4] Barnes, R. M., et.al., "Introduction for Preparation for Trace Element Determination". In Microwave Assisted Sample Preparation for Trace Element Analysis, 2014, https://www.sciencedirect.com/science/book/9780444594204

[5] NASA SP-5105, "Advances in Sterilization and Decontamination, A Survey" 1978.

Questions?

James.O.Arnold@NASA.gov

M.Meyyappan@NASA.gov

Backup

1970's Viking PP Approach

Photo Shows the entire 1976 Viking Lander being prepared for final sterilization: Heated to 120 ^{O}C for 30 hours. It's still the "Gold Standard" of Planetary Protection