Characterization of a Carbon Nanotube Field Emission Electron Gun for the VAPoR Miniaturized Pyrolysis-Time-of-Flight Mass Spectrometer

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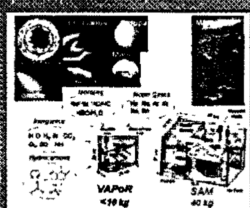
ABSTRACT

We are developing the VAPoR (Volatile Analysis by Pyrolysis of Regolith) instrument towards studying soil composition, volatiles, and trapped noble gases in the polar regions of the Moon. VAPoR will ingest a soil sample and conduct analysis by pyrolysis and time-of-flight mass spectrometry (ToF-MS). Here, we describe miniaturization efforts within this development including a carbon nanotube (CNT) field emission electron gun that is under consideration for use as the electron impact ionization source for the ToF-MS.

INTRODUCTION

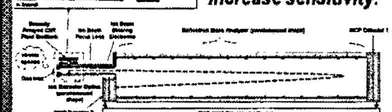
A miniaturized pyrolysis-ToF-MS is under development at NASA GSFC to enable in situ chemical analysis of lunar regolith using a low-power, low-mass, small-footprint package. An aliquot of regolith will be ingested into one of six sample cups. Thermal pyrolysis will release volatile gas that can be analyzed by the electron impact ToF-MS.



APPLICATION

The miniaturized time-of-flight mass spectrometer development will enable analysis of evolved gas from regolith and planetary atmospheres.

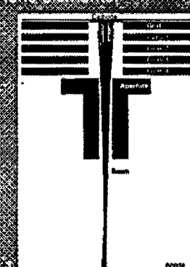
Our plan is to use CNT field emitters for their **high electron concentration**, **robustness**, and **manufacturability** to develop a patterned cathode for the electron impact ionization component of the VAPoR instrument.

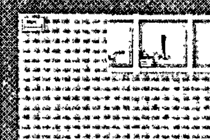


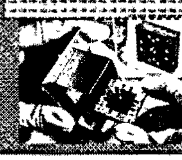
Our design uses a parallel plate geometry to maximize ionization volume and field uniformity. ***Future scale-up of the electron emitters can increase sensitivity.***

METHODOLOGY

We modeled and built a CNT field emission electron gun using patterned catalyst-assisted chemical vapor deposition for the CNT cathode and silicon micromachining for the extraction grid and electrostatic lens elements.





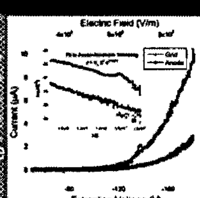


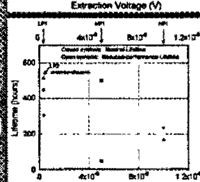
Ultra-clean materials – metals, glass, silicon, and ceramic – and polymer-free integration methods were used to promote long lifetime and stable emission.

RESULTS

In a high vacuum test chamber, we collect current at the grid and at the anode as a function of extraction voltage to evaluate performance of the cathode.

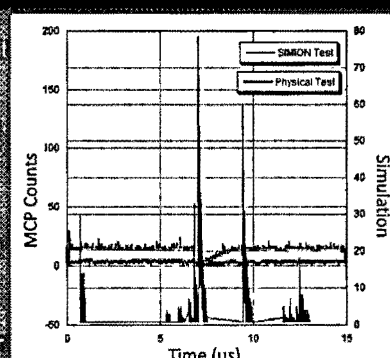
A fit to Fowler-Nordheim tunneling shows a field enhancement factor of 900, consistent with previous reports in the literature. ***The power consumption for this e-gun is only 1 mW***, compared to > 100 mW for thermionic technology.





By measuring the current output as a function of time at constant extraction voltage, we also obtained lifetimes for CNT cathodes under varying vacuum conditions.

Lifetesting results reveal an inverse dependence of cathode lifetime on operating pressure. Here, the partial pressure of N_2 was varied, indicating that mechanical sputtering contributes to CNT degradation.



We integrated the CNT e-gun with the mini ToF-MS core to demonstrate mass spectra in both linear and reflected modes. Mass resolution is currently estimated at > 250 amu at m/z = 18.

Our measurements agree with simulations conducted with a commercial electrodynamics software package (SIMION).

CONCLUSIONS

A CNT field emission electron gun has been designed, fabricated, tested, and integrated with the VAPoR ToF-MS prototype. Several microamps of current are produced using conservative operating parameters, and lifetime up to several hundred hours can be achieved in high vacuum. An unoptimized mass spectrum has been obtained using the integrated ToF-MS prototype.

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