5th International LISA Symposium

NASA Microthruster Developments

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*Please see IEEE Aerospace Conference Paper #1329, Big Sky, Montana, March 2004

Overview

- NASA LISA Microthruster program has focused on testing and developing US technology in FY04
  - Previous work has included testing Indium based Field Effect Thrusters at NASA GSFC and JPL
- The Busek Colloid Microthruster is the leading US thruster technology likely capable of meeting LISA requirements
  - Competitively selected for ST7-DRS mission mid-2001
  - Major requirements have been demonstrated
  - CDR Successfully completed in May, 2004
- NASA LISA Microthruster Technology development will focus on meeting LISA lifetime requirements
  - Extensively using ST7-DRS design heritage
  - Looking into applying LISA requirements on Colloid Microthruster design
  - Developing lifetime models and identifying failure mechanisms
  - Developing diagnostics and facilities for long duration testing
  - Performing multiple "short" duration (3000 hour class) tests
  - Validating lifetime models with single 8000+ hour test before PDR

Colloid Thruster Basics

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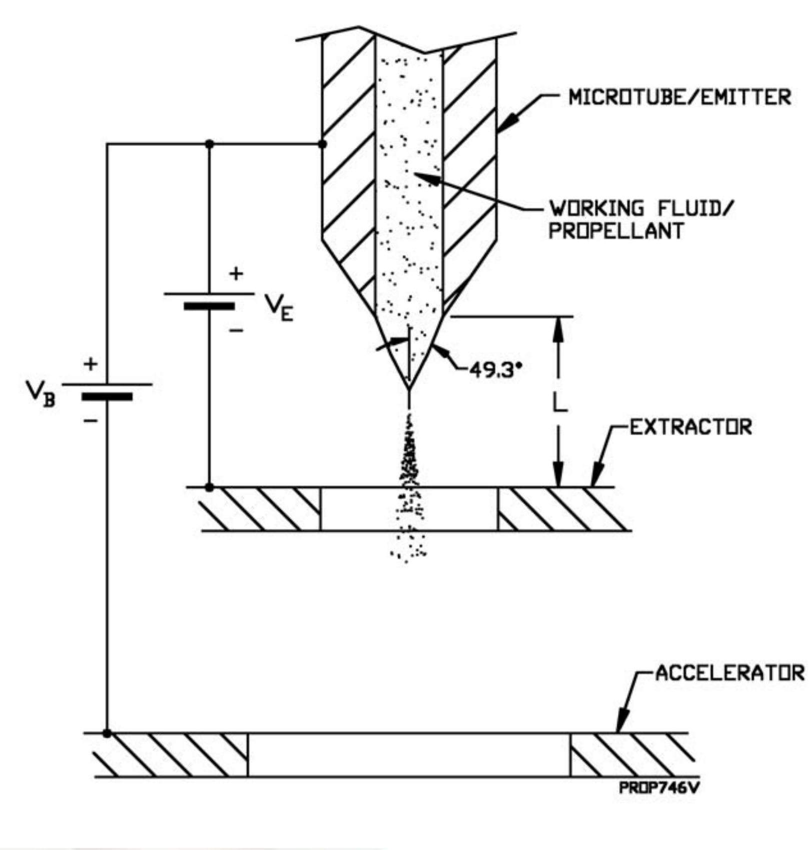
- Colloid Thrusters emit charged droplets that are electrostatically accelerated to produce thrust

$$\text{Thrust} \propto I_B^{\,1.5} \cdot V_B^{\,0.5}$$

- In this design, current and voltage are controlled independently, and the specific impulse is determined by an second accelerator electrode
- Precise control of I_B (~ μA) and V_B (~ kV) facilitates the delivery of micro-Newton level thrust with < 0.1 μN precision
- The beam current, I_B, a stream of positive colloids accelerated to V_B, is neutralized by a cathode/electron source



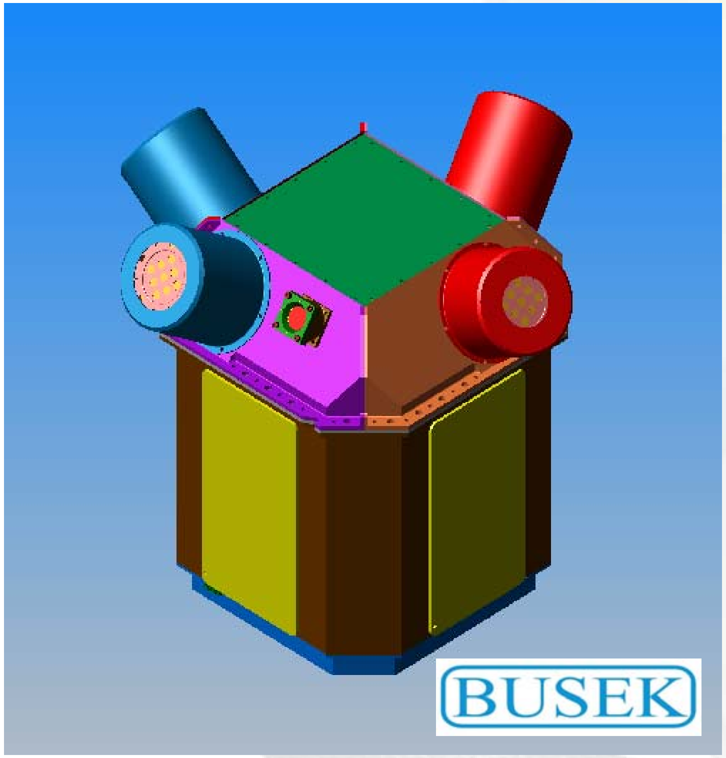
ST7 Microthruster Requirements

Parameter	Requirements
Thrust Range	*T = 5-30 μN* *(T_{max}/T_{min} = 6)*
Thrust Resolution and Adjustability	*$\Delta T \leq 0.1\ \mu N$*
Thrust Noise	*$\Delta T \leq 0.1\ \mu N/\sqrt{Hz}$* *From 1-30 mHz*
Lifetime and Cycles	*2,200 total operating hours* *With 10 Starts/Stops*

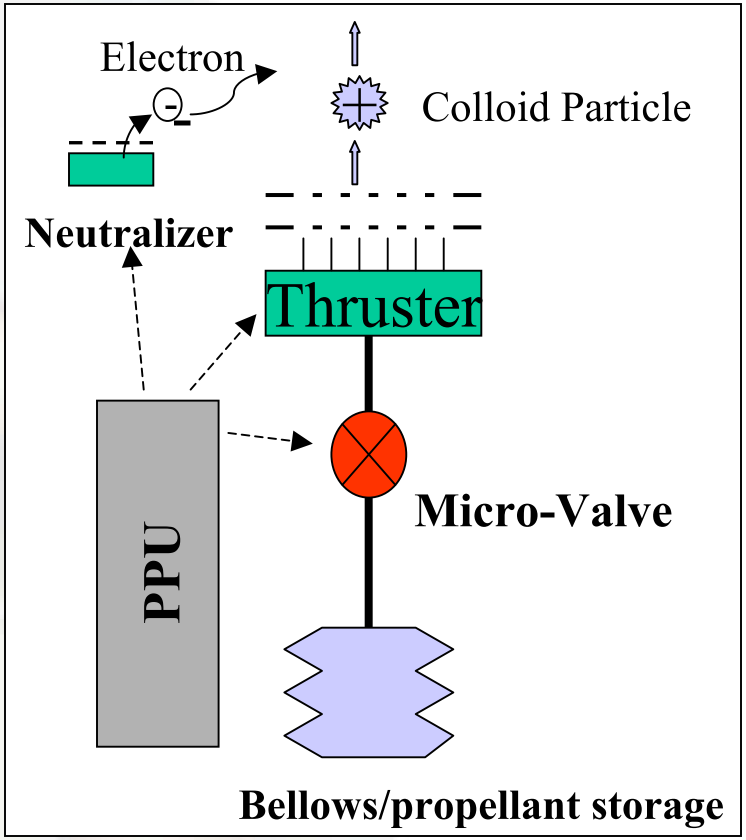
- This leads to the following Colloid Microthruster requirements:
  - < 10 nanoamp beam current accuracy and stability
  - ~ 1 nanoliter/min propellant flow control and stability
  - A unique thrust stand capable of resolving sub-μN forces and thrust noise requirement
- For LISA requirements, mainly a change in lifetime: 44,000 hours in operation 88,000 hour of propellant
  - Requires a larger propellant reservoir than ST7 design or higher I_{sp}
  - Requires unique facilities and development of physics-based models for predicting, testing and verifying lifetime

ST7 Microthruster System Architecture

Cluster with 4 Thruster Systems

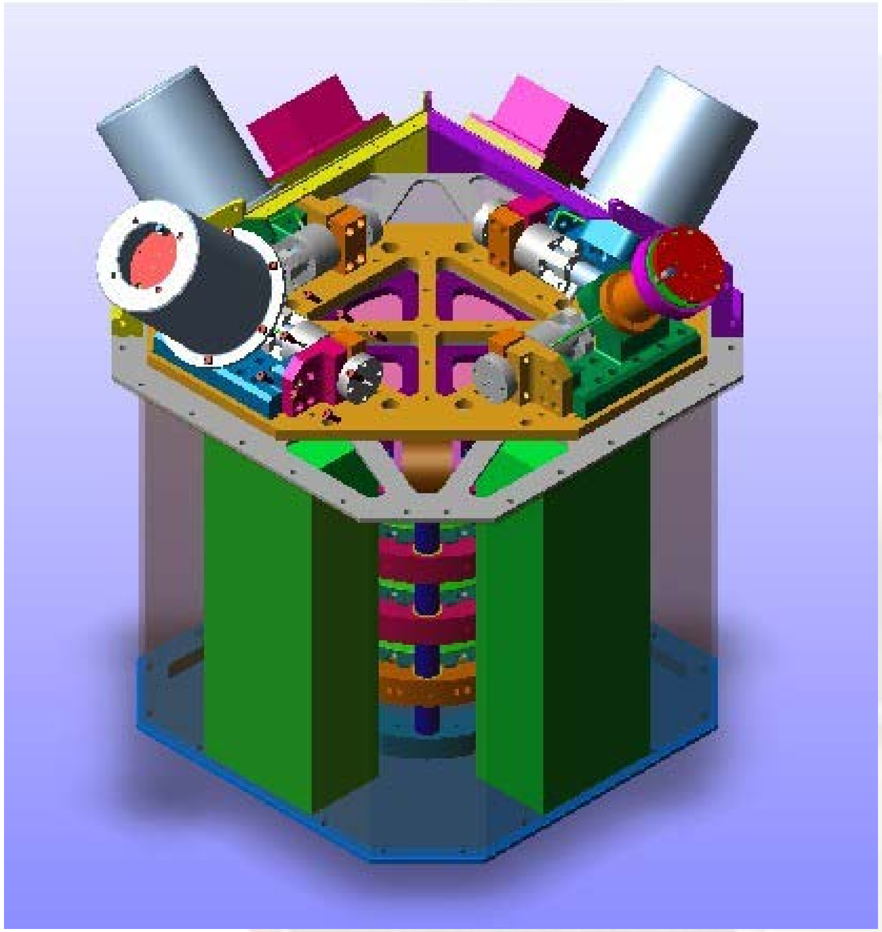


Thruster System

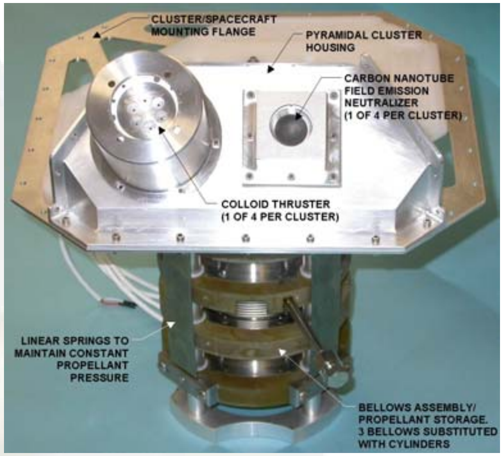


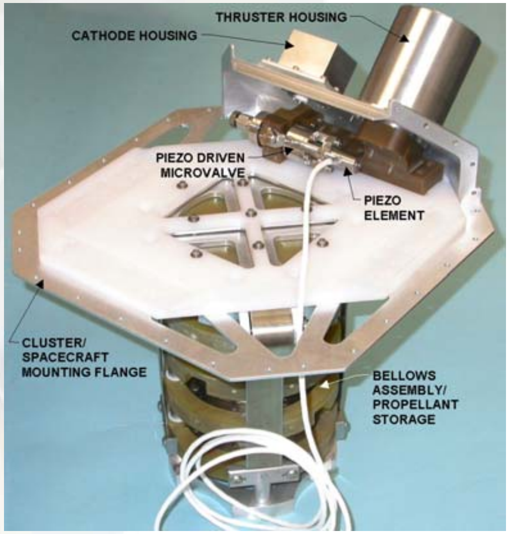
- The DRS has 2 clusters with 4 thruster systems per cluster
- All 8 thruster systems are identical
- There is one neutralizer per Cluster

DRS Breadboard Microthruster

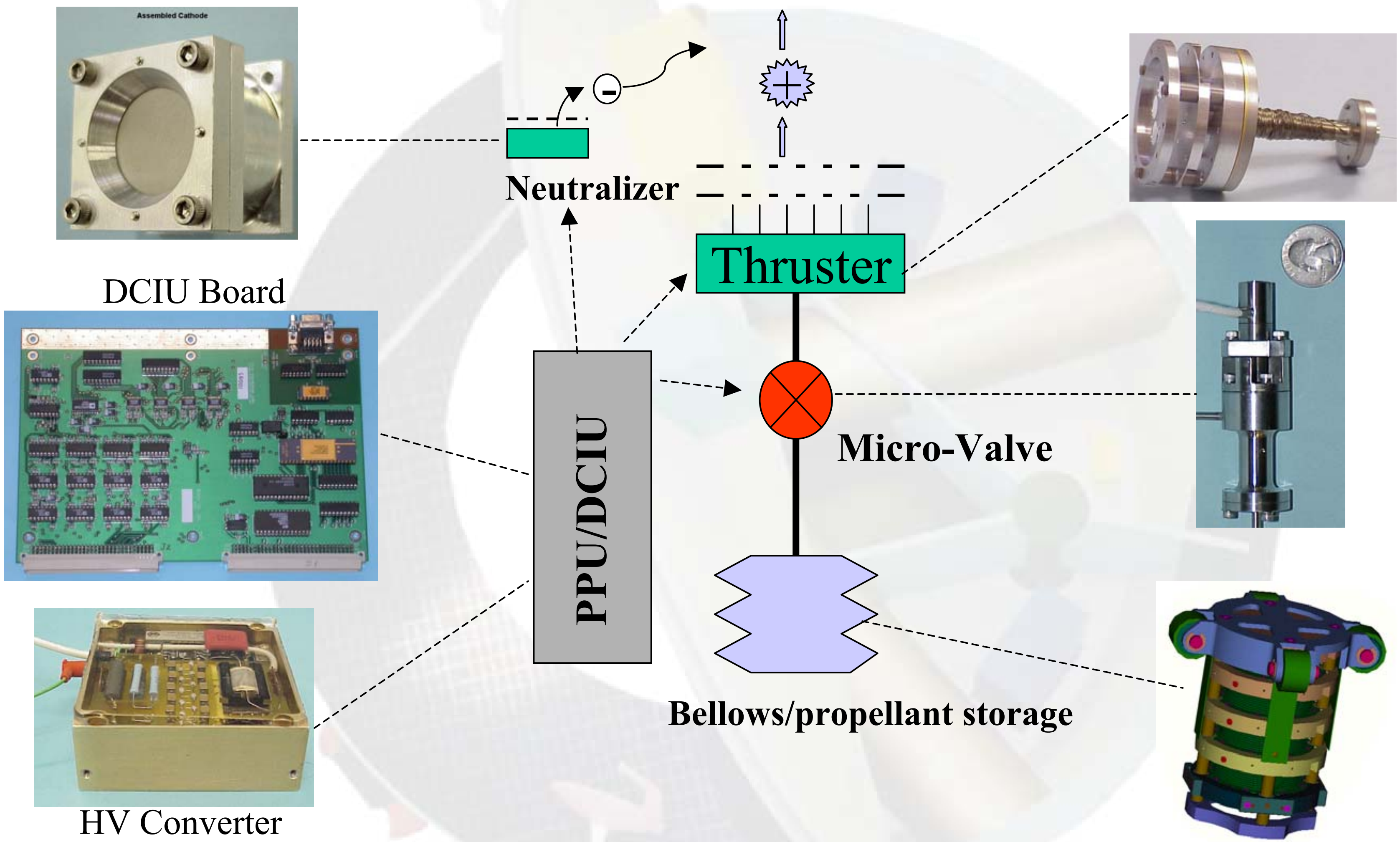


DRS Cluster with 4 Thrusters





Microthruster System and Components



Breadboard Thruster Design

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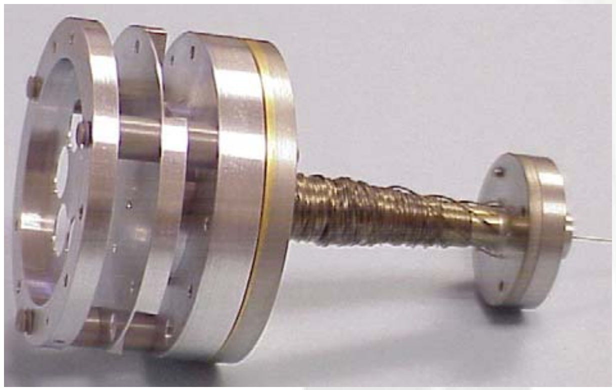

- Main performance goals:
  - Thrust throttle-ability (2 μN < T < 20 μN)
  - Stable performance, able to deliver thrust with noise spectrum lower than specified
- A breadboard 6 emitter electrospray source has been built and tested
  - Includes emitters, extractor and accelerator electrodes
  - Mass: 87 g
  - Typical dimensions: 4x6 cm
- New engineering model will have a 9 emitter thruster head to meet higher thrust requirement, 3-30 μN

Direct Thrust Measurement

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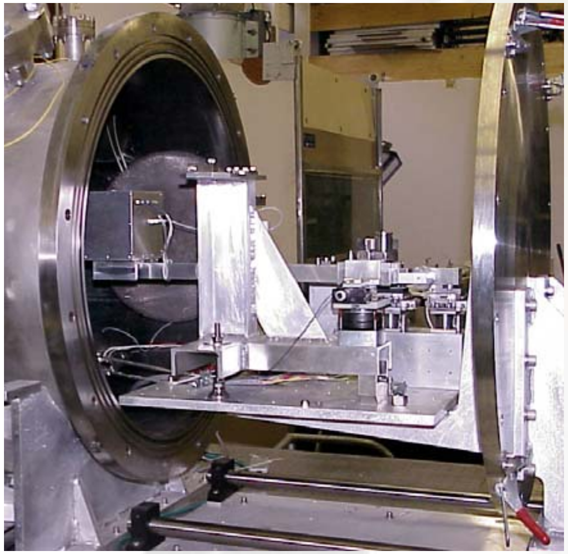
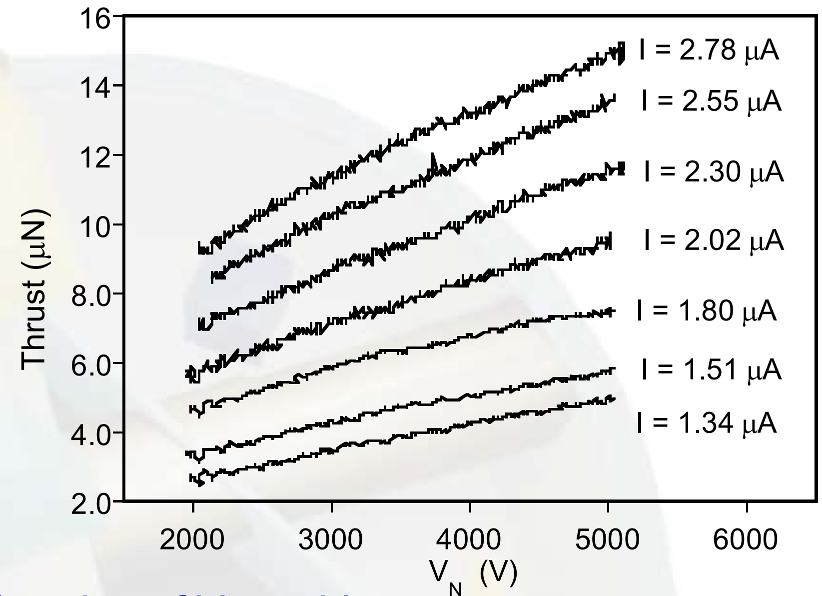


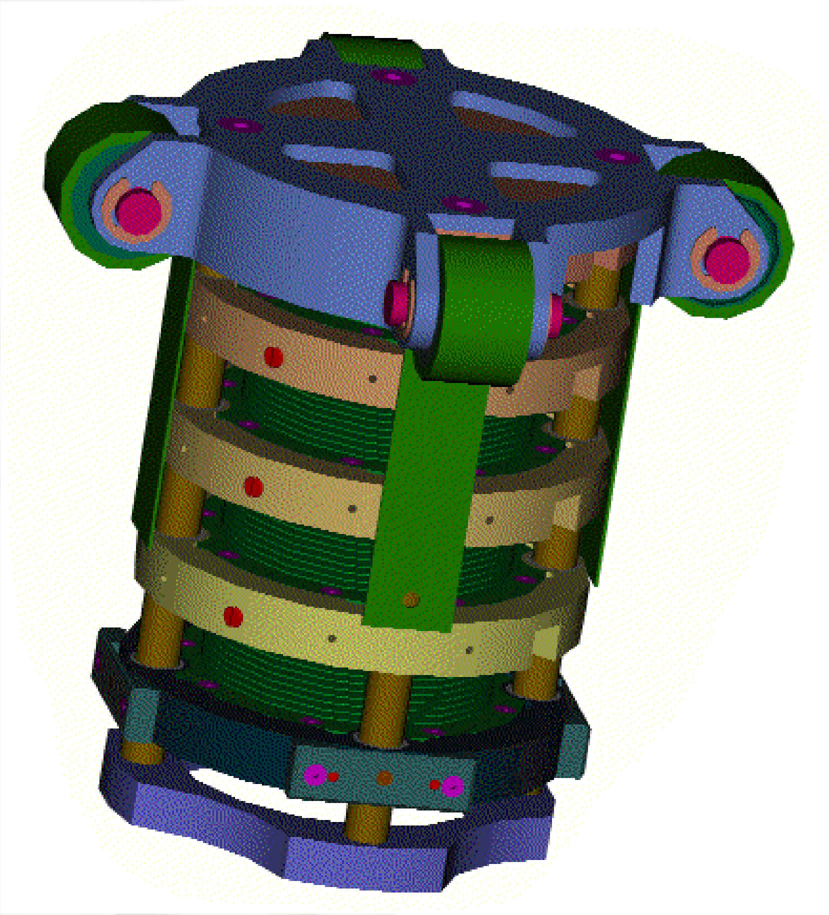


Thrust as a function of V_B and I_B

- V_{max}/V_{min}: 5000/2000 = 2.5
- I_{max}/I_{min}: 2.78/1.34 = 2.07
- T_{max}/T_{min}: 14.9/2.4 = 6.2
- Additional thrust achievable by increasing V_B up to 10 kV. Higher I_B values can also be also employed (slight modification of thruster grids is required)
- More information on thrust measurements can be found in Gamero, et al, Rev. Sci. Inst. 74 (10): 4509-4514, Oct. 2003

Feed System: Propellant Storage & Pressurization

- Feed system consists of 4 electrically isolated bellows, feeding 4 thrusters via 4 microvalves
- All wetted surfaces are stainless steel
- Mechanical pressurization via constant force springs; pressure is 15 psi-10 psi as bellows compress
- 100ml useful volume per bellows
- New design will include larger bellow segments for thrusters that need more propellant



Piezo-Actuated Propellant Flow Control Valve

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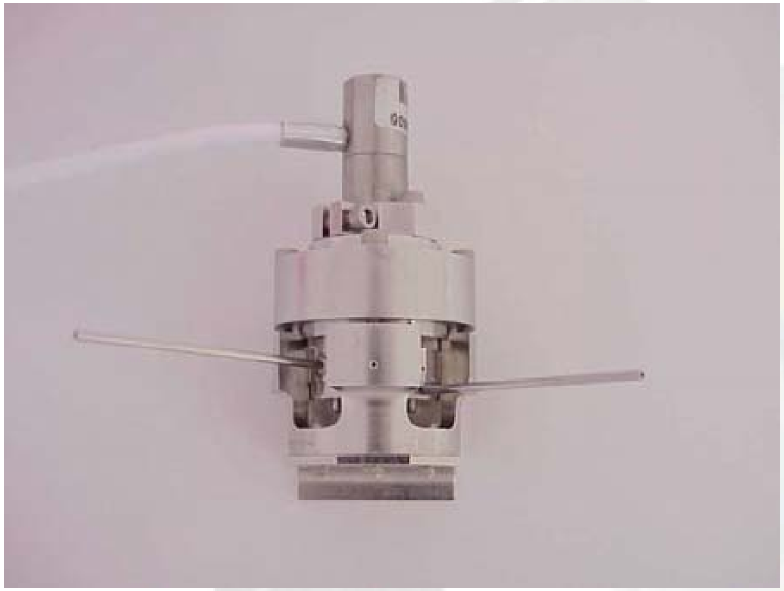
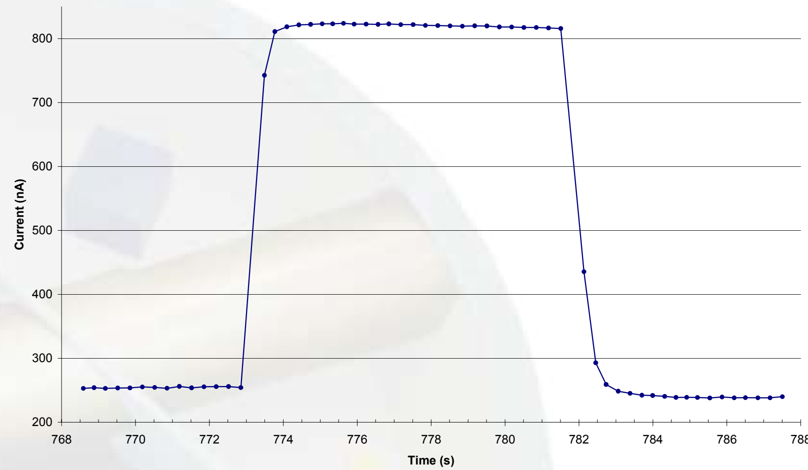


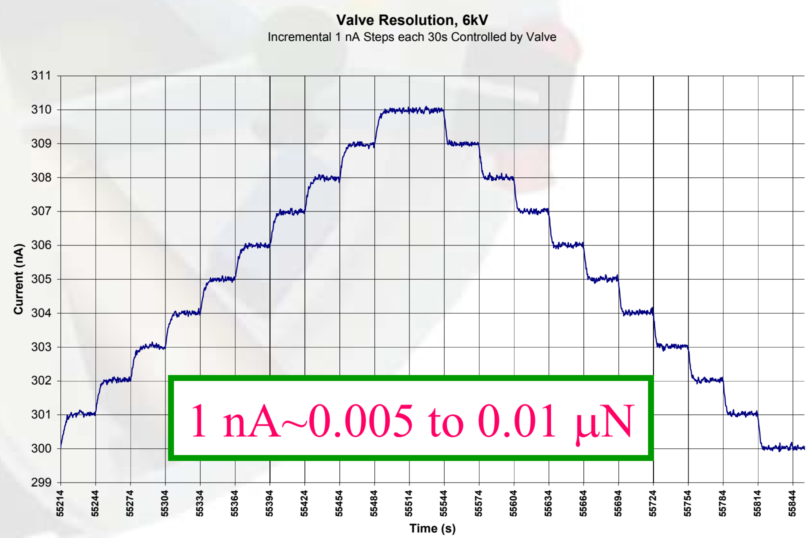
Mass flow $\propto I_B^{\,2}$

Thrust $\propto I_B^{\,1.5}\ \ V_B^{\,0.5}$

Precise flow control is essential.
μValve achieves 1 nA I_B resolution which corresponds to <0.01μN

μValve Response





Busek Field Emission Cathodes

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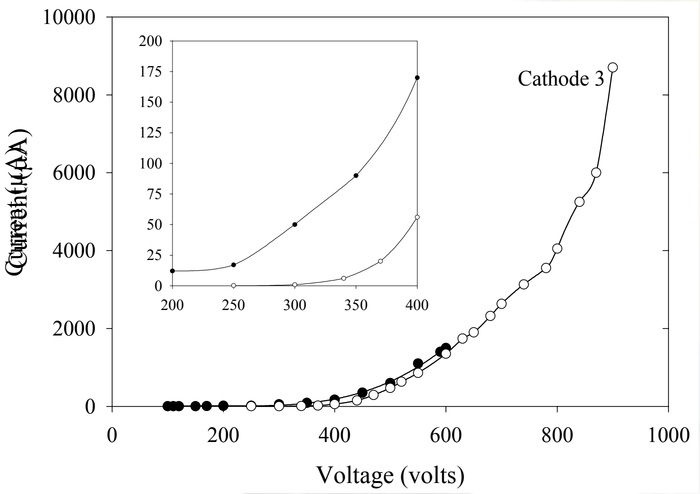
Typical I-V plot:



- Carbon Nano-Tube (CNT) field emission cathode neutralizes positive colloid beam
- Field emission cathodes use Busek-grown multi-wall carbon nano-tubes
- Standard size is shown at left (mass: ~41 grams)
- Standard cathodes provide 10 μA - 1mA of current using gate-to-cathode voltages of 250-770 volts (DRS requires < 50 μA)
- One CNT cathode per cluster
- One cathode completed life test without thruster: over 13,000 hours (at 100 μA)

System Life Test

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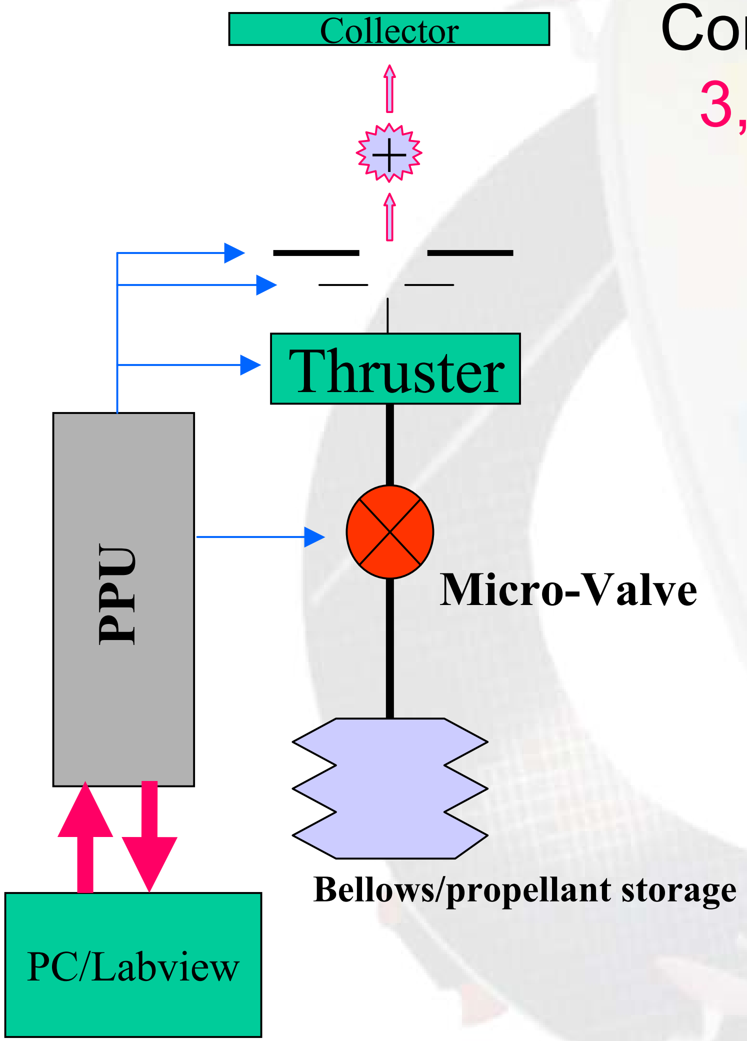
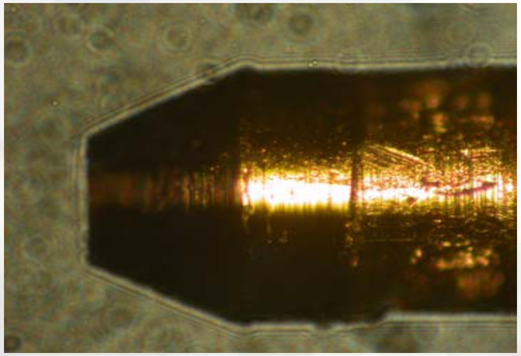


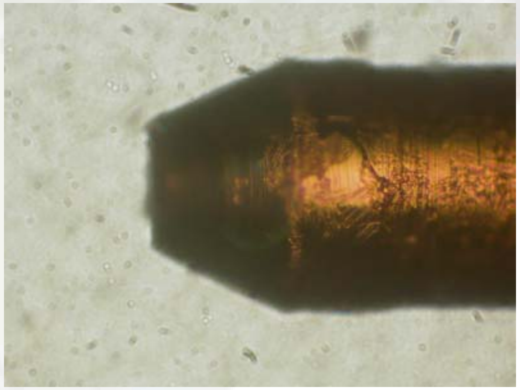
Completed single-emitter system life test

3,300 hours accumulated, no damage

(50% over mission requirement)



Before Test



After 3,300 Hours

Summary of ST7 Busek Colloid Microthruster Developments

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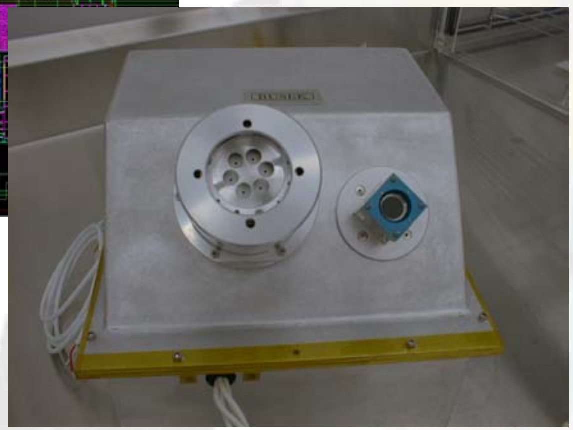
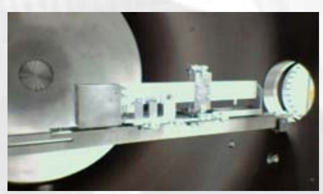
- Key DRS performance requirements were demonstrated
- Key components demonstrated and understood (thruster, neutralizer, μvalve, bellows, HV converters)
- The μvalve, CNT neutralizer, and thruster head are new technology
- System demonstration at breadboard level completed
- System life test of single needle (1.5*mission) completed
- Current effort focused on EM and Flight HW

Summary of NASA's LISA Microthruster Program





- In the next two months we will be testing the Busek breadboard level colloid microthruster in our new facility
  - Effects of radiation exposure
  - Exhaust beam profiling
  - Contamination measurements
- In the next six months we will be procuring a Busek colloid microthruster for LISA
  - Continue setting up facility for long duration testing
  - Developing lifetime models
- In the next year we will begin one of two 3000 hour class tests
  - Tests at both Busek and JPL