MEMS Technology for Jet Fuel Atomization

James Nabity, Sean Rooney
TDA Research, Inc

Turbine Engine Technology Symposium 2004
Fuel-Injector Technology Workshop
2 September 2004
**MEMS Technology for Jet Fuel Atomization**

The original document contains color images.
Acknowledgements

- ONR – Dr. Chris Brophy
- AFOSR - Dr. Mitat Birkan
- AF - Dr. Balu Sekar
- University of Colorado
  - Dr. John Daily, Professor
  - Mr. Gopi Krishnan, PhD candidate
Outline

• Objective
• Atomizer technologies
• MEMS atomizer
• Approach to design, build and test
• Conclusions
Objective

• Develop a MEMS atomizer to produce small (<50µm) droplets
  – improve gas turbine flameholding
  – reduce emissions
Baseline Technologies

- **Air blast / air assist** (Many types; internal mixed type shown here)

- **Others**: Simple Orifice, Poppet Orifice, Ultrasonic, Electrostatic Charge, **Inkjet**

![Diagram showing the process of inkjet printing](image)

- **Initial state**: Remove voltage to release diaphragm and eject droplet.
Droplet Size Measurements

The Basic Design

- Electrostatically actuated diaphragm pump with passive valves:
  - Electrostatic for high displacement/low power.
  - Passive valves for simplicity.
What is Important?

• Need high pump efficiency: \[ \eta = \frac{Q_{\text{net}}}{Q_{\text{ideal}}} \]
• Valves are critical

• Dielectric – cleanliness is everything
Approach

• Analytical & numerical performance modeling
  – Fuel ejection & droplet formation
  – Micropump operation (especially, the valving)
  – Stiction

• Fabrication
  – Materials, processes and assembly

• Engine integration

• Testing
Fluidic Valve Performance Evaluation

Flow rectification

Steady  2.2
Periodic  1.4

forward

reverse
Performance Modeling

• TDA’s Quasi 1-D Micropump Model

\[ L = \omega \]

\[ \frac{md^2v}{dt^2} + F_e + F_k \]

fill cycle

expulsion cycle

\[ CV \]

\[ G_0 \]

\[ \tau \]

1

2

\[ e \]

\[ \infty \]

Diaphragm

Plenum

Outlet

Inlet

\[ L_{\text{diaph}} = 1000 \ \mu m \]

\[ t_{\text{diaph}} = 10 \ \mu m \]

\[ t_{\text{plenum}} = 100 \ \mu m \]

\[ t_{\text{passages}} = 100 \ \mu m \]

\[ L_{\text{passages}} = 330 \ \mu m \]

\[ W_{\text{in passages}} = 66.7 \ \mu m \]

\[ \alpha_{\text{valve}} = 5 \ \text{degrees} \]
ANSYS Results
(30μm sinusoidal deflection at 700 Hz)
Model Performance Predictions

![Graph showing model performance predictions.](image)

- **volumetric flow rate, cc/min**
- **actuation frequency, Hz**

**Lines and Markers**:
- **ANSYS** (solid blue line)
- **1-d model** (dashed green line with triangle markers)

**Legend**:
- **uniform**
- **pyramidal**
- **total**
- **net**
Stiction

• Nemesis to MEMS

diaphragm is free-standing where stand-offs prevent stiction, but collapses elsewhere

• Therefore, use Mastrangelo elastocapillary & peel numbers
Materials

• Silicon – most commonly used material
  – 3-inch SSP wafer costs about $10
  – <1800°F
• Silicon carbide – 20X the cost, but good to 2900°F
• Silicon carbide nitride – also expensive, but highest temperature and strength
Wafer Level Microprocessing

CAD drawing

Mask

Pattern & etch
Assembly & Packaging
Gas Turbine

- Gas Turbine components: fuel/air mixture, MEMS atomizer, fluidic check valves, 3 wire power feeds, slot nozzles, micropump chamber, fuel spray.
Test Setup

Malvern Mastersizer

Modified dry feed unit
Conclusions

• Analytical & computational tools Developed
• Design completed
• MEMS fabrication processes defined
• Atomizers built
• Testing underway
Contact Info

Mr. James Nabity, Principal Investigator
TDA Research, Inc.
12345 W 52\textsuperscript{nd} Ave
Wheat Ridge, CO 80033

(303) 940-2313
nabity@tda.com