Advanced Monopropellants Combustion Chambers and Monolithic Catalyst for Small Satellite Propulsion

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Small and cube satellites require propulsion system which provides high-velocity changes and rapid control.

Ionic liquids (HAN, ADN) based monopropellants offer many advantages over hydrazine: low toxicity, higher Isp, low freezing point and higher density-Isp. Also provide the ability to preload fuel before system integration.

However, advanced monopropellants have higher decomposition temperature, aggressive combustion and intermediate products.

Current granular catalysts degrade at the higher temperature: the catalyst support sinters and loses surface area, poor iridium adhesion leads to catalytic metal depletion, granule attrition causes void formation and thruster flooding.

Catalyst bed plates erode at the higher temperature.
## Monopropellants Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hydrazine</th>
<th>HAN (AF-M315E)</th>
<th>ADN (LMP-103S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{sp}$, sec</td>
<td>233</td>
<td>266</td>
<td>252</td>
</tr>
<tr>
<td>Density, g/cc</td>
<td>1.01</td>
<td>1.46</td>
<td>1.24</td>
</tr>
<tr>
<td>Melting point, ºC</td>
<td>1</td>
<td>-22</td>
<td>-6</td>
</tr>
<tr>
<td>Combustion Temperature, ºC</td>
<td>883</td>
<td>1893</td>
<td>1608</td>
</tr>
</tbody>
</table>

AF-M315E developed by Air Force Research Laboratory

Catalyst and Combustion Chamber for AF-M315E monopropellant

- Ir/Re combustion chambers proved for bipropellant thrusters: Aerojet/Ultramet and NASA/Aerojet/PPL
- Ir/Re combustion chambers proved for monopropellant thrusters: ECAPS/PPL
- Ir/Re combustion chambers electro-formed from molten salts using (EL-Form®) technique
- Monolithic catalyst based on metal foams being developed
Monolithic Catalyst Bed
Advantages

- Low pressure drop
- Better thermal shock and attrition resistance
- Uniform flow distribution and mass/heat transfer
- Shorter diffusion length

Previous Development:
E. W. Schmidt – Alumina coated metal foams, 1969-1973
R. LaFerla, R.H. Tuffias – Iridium and rhenium coated carbon foam, ceramic foams, 1988-1993
C. Kappenstein - Alumina coated ceramic honeycomb and ceramic foams, 2006-2012
Production of High-Temperature Structures using EL-Form® Process

- EL-Form® is electrodeposition in a non-toxic molten salt electrolyte
- Inert atmosphere enables the processing of oxygen sensitive materials such as refractory metals: W, Re, Mo, Nb, Ta, Hf, B and noble metals: Ir, Rh, Ru, Pt
- Ability to produce high purity components utilizing scrap/refined material as the precursor due to electrochemical refining
- Provides tight tolerances and high material utilization rate
- Modulated current improves metal distribution
- Electroconductive porous substrates used as precursor
Identification and Significance of Innovation

- Most In Space chemical propulsion systems use hydrazine propellant. Hydrazine is highly toxic & dangerously unstable.
- Non-toxic HydroxylAmmonium Nitrate (HAN) AF-M315E monopropellant has 12% higher Isp and 60% higher density-Isp than hydrazine monopropellant.
- HAN’s combustion temperature is significantly higher at 2083°K.
- The Phase I Ir/Re chamber demonstrated pulse and 10 sec firings.
- New foam catalyst developed to ignite HAN AF-M315E.

Technical Objectives and Phase II Work Plan

- Develop a non-toxic HAN based monopropellant thruster to replace hydrazine.
- Pursue improvements to Phase I foam catalyst and injector.
- Demonstrate ignition of non-toxic AF-M315E.
- Test life and response time of the thrust chamber assembly.
- Analyze post test thruster and catalyst.
- Make multiple thrust chambers for commercial partners Aerojet, Dynetics, AMPAC-ISP, & Pratt & Whitney Rocketdyne
- Commercialize “green” thruster
- Increase to TRL 5-6

NASA and Non-NASA Applications

- Mono- and Bi-propellant rocket engines for commercial and military satellites
- Reaction Control Systems for commercial and military satellites
- Apogee Engines for commercial and military satellites
- Jet engine restarters and auxiliary power units
- Divert and Attitude Control Systems for missile interceptors

SBIR Industrial Partner: Aerojet

Firm Contacts
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Monolithic catalyst substrates and bed plates developed to replace granular catalysts.
Iridium Microcrystal Catalyst

Innovative technique for deposition of adherent iridium microcrystals developed.

SEM images of Ir crystals

Magnification is 50X

Magnification is 5000X
Thrust chamber and metal foam monolithic catalyst were tested with advanced AF-M315E monopropellant. Ignition and sustained combustion was demonstrated. Clean, colorless exhaust observed.
Phase II Development

- Development, manufacturing and testing of 1N AF-M315E thruster for replacement of hydrazine fueled MR-142 thruster in Aerojet CubeSat High-Impulse Adaptable Monopropellant Propulsion System (CHAMPS)

- System will use four green propellant thrusters to provide pitch, yaw and roll attitude control as well as single axis $\Delta V$ for orbit transfer and station-keeping

CHAMPS integrated into standard 1U Frame
Aerojet Green Monopropellant
CHAMPS

- Employs non-toxic AF-M315E Monopropellant
- Will provide three axis attitude control and single axis ΔV
- Can be integrated in 1U, 3U, and 6U CubeSat configuration
- Extended attitude control for up to several years
- Ability to deploy CubeSat from GTO-bound lunch vehicles and move back to selected orbits in LEO
- Capability to deorbit CubeSats at higher altitudes
Plasma Processes has developed and manufactured for ECAPS 1N high-temperature combustion chambers and injectors heads since 2005

- Iridium/rhenium composition provides excellent oxidation protection and long life
- EL-Form® technology is maturing for mass production
- More than 50 combustion chambers were manufactured and delivered to ECAPS
Electroforming of 1N LMP-103S Combustion Chamber

- Rhenium deposit on mandrel
- Flange electroforming
- Machined Chamber

Ir/Re Interface
LMP-103S Monopropellant Thruster

Electroformed Ir/Re Combustion Chambers

ECAPS 1N Thruster Assembly
1N LMP-103S Thruster Firing

Qualification life test with propellant throughput of 24 kg and 25 hours firing time.
In Space Demonstration

PRISMA Mango Satellite
ECAPS 1N High Performance Green Propulsion System (HPGP)

- Employs non toxic LMP-103S monopropellant
- The thrust range with 0.3 to 1.3N
- The minimum impulse bit with 0.01 to 0.043 Ns
- 6-12% higher Isp than hydrazine
- Catalyst bed preheat temperature 340ºC. Required 9.25W.
- Long life Oxidation resistant high temperature combustion chamber
- ATK licensed to blend propellant and sell ECAPS thrusters in the United States

1N HPGP Thruster assembly
4 lbf iridium/rhenium/iridium thruster was designed and manufactured for non-toxic AF-M315E monopropellant.

A metal foam based monolithic catalyst was developed and fabricated.

Ignition of AF-M315E monopropellant was demonstrated.

The thruster was successfully tested for pulses and then 10 second burn.

1 N Thrust Chambers for LMP-103S monopropellant developed and manufactured

EL-Form® technology matured for mass production of 1N iridium/rhenium thrusters

Electroformed Ir/Re thrusters flight qualified onboard PRISMA satellite