ELECTROCHROMIC RADIATORS FOR MICROSPACECRAFT THERMAL CONTROL

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Introduction

- **Thermal control challenges for microspacecraft**
  - limited thermal mass
  - limited electrical power for survival heating
- **Mature thermal control technologies**
  - relatively massive
  - power consumptive
  - difficult to scale to very small sizes
- **Mechanical Louvers**
  - used to modulate heat rejection from radiators
  - bulky mechanical devices, difficult to miniaturize
  - often opened and closed via a bi-metallic thermostatic actuator with a single temperature set point
- **Thin-film variable-emittance coatings offer the functionality of mechanical louvers but with decreased mass, cost, and mechanical complexity**

Mechanical Louvers

Variable-emittance Coating

Variable-Emittance Radiators

- **A controlled variation of the Infra-red emittance of a radiator can maintain the temperature or heat rejection in response to changing environment**
- **Effect of variability of infrared emissivity of a flat plate radiator with no solar irradiation:**
  - Stefan-Boltzmann Law: $Q = A\varepsilon\sigma T_1^4$
  - Constant Heat Rejection: $T_2/T_1 = (\varepsilon_1/\varepsilon_2)^{0.25}$
  - Constant Temperature: $Q_2/Q_1 = \varepsilon_2/\varepsilon_1$
- **Several variable-emittance technologies are being developed by DOD and NASA sponsored Small Business Innovation Research (SBIR) grants for potential space applications:**
  - Microelectromechanical (MEMS) machined microlouvers
  - Electrophoretic and Electrostatic surfaces
  - Electrochromic Coatings

Thin-film Electrochromic Coatings

- **An electrochromic film is composed of a number of layers which behave much like the anode, cathode, electrolyte and mutual electrodes in a battery**
- **Visible and IR reflective and/or transmissive characteristics of the film are changed by the application of a small activation electrical potential (usually DC, <± 5 V.)**
- **Visible-NIR region: (0.4 to 1.1 μm); IR Region: (2 to 45 μm)**
- **The two extreme conditions are called 'light' (or 'bleached') and 'dark' state**
  - Dark = highly IR-absorbing. IR is not able to reach the reflecting layer, surface is high-ε
  - Light = IR-transparent. When in this state, IR is transmitted and reaches a highly IR-reflective layer (usually Au) that is low-ε
- **Benefits**
  - Flexible substrate
  - Active control of ε-values
  - Light weight: 1.6 kg/m^2 vs.

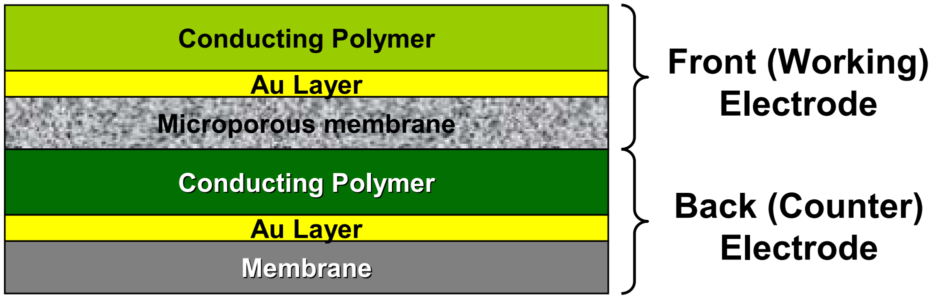
  4 to 10 kg/m^2 for louver system
- **Requires minimal electrical power to operate**

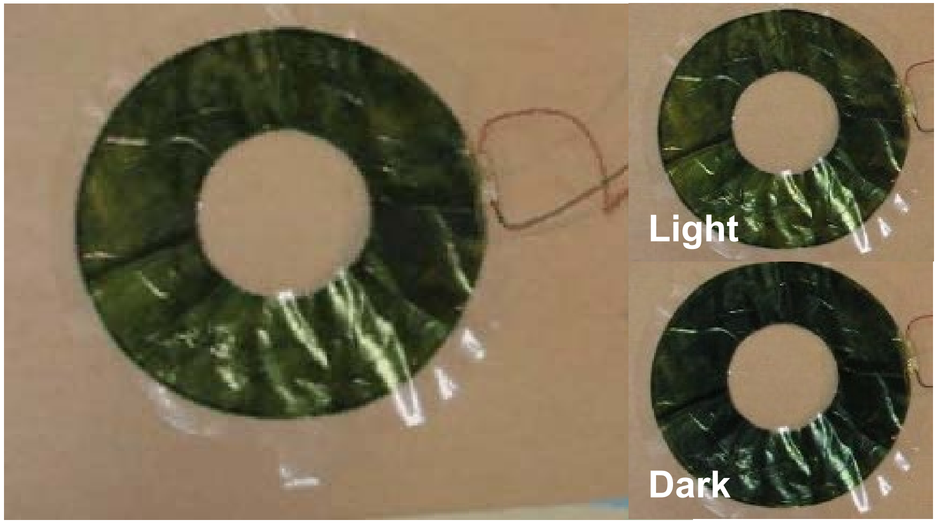
Dark State (+0.2 V)

Light State (-1.0 V)

Conducting Polymer-based Electrochromics

- **Ashwin-Ushas Corp. / NASA-JPL**
- **Operational principle:**
  - Active CP layer undergoes electrochemically-induced oxidation and reduction with an applied voltage.
  - Completely reduced state is IR-transparent. Partially oxidized state is highly IR-absorbing.
  - Uses an Ionic Electrolyte, also called “room temperature molten salt”. Liquid from –100°C to + 280°C
- **Performance:**
  - Emissivity change: ~0.55
  - Emissivity limits tailorable: 0.15 to 0.85
  - Solar Absorptance < 0.29
- **Thin (< 0.5 mm), flexible panel construction**
  - Can be affixed to any surface. Conform to any shape/size.
  - May be cut with scissors.
- **Light weight: ~ 0.8 kg/m^2**
- **Low power consumption:**
  - Peak Transient ~4 mW/cm2 for < 30 sec
  - Steady-state: < 40 μW/cm2





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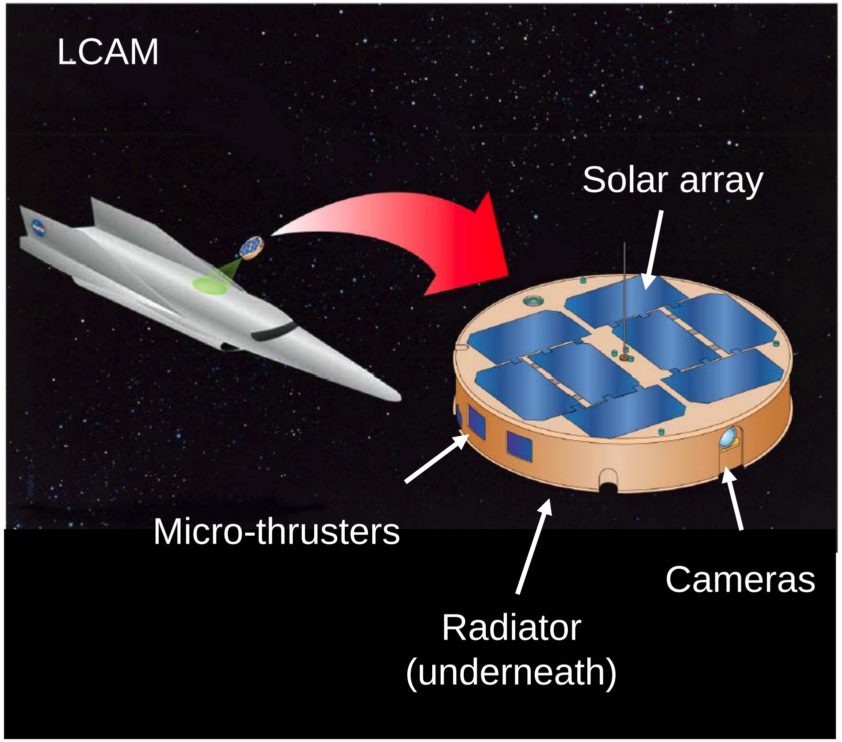
Microspacecraft Application

- **Micro-Inspector is a deployable, mobile camera platform intended for inspection of exterior surfaces of a host spacecraft**
- **Based on the Low Cost Adjunct Microspacecraft (LCAM) architecture**

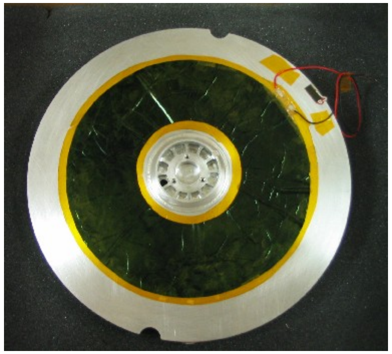
- **Attributes:**
  - Less than 3 kg and 25 cm3
  - Solar-powered
  - low pressure, liquid butane-based propulsion system

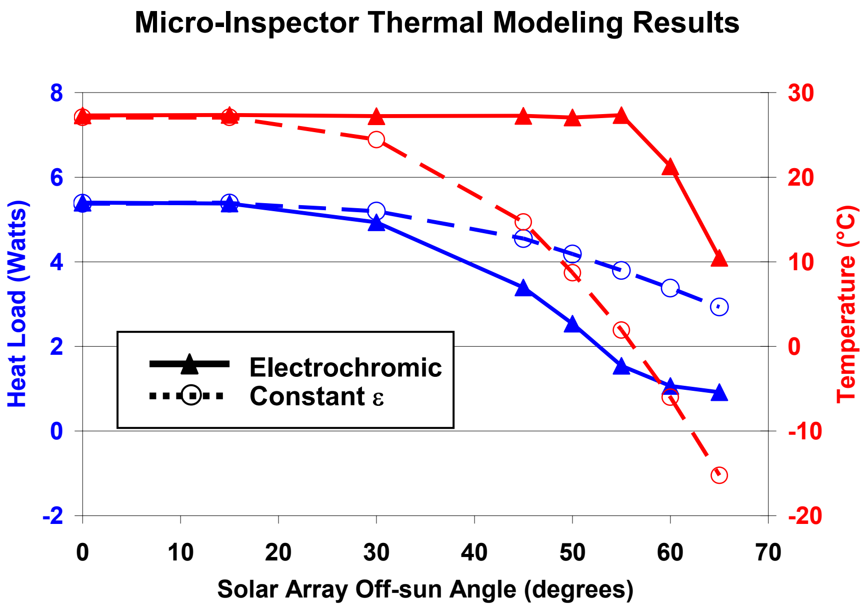
- **Thermal Control Requirements:**
  - maintain all avionics/instruments/batteries within allowable temperatures
  - utilize waste heat from avionics and instruments to vaporize propellant
  - manage the waste heat so that the butane propellant does not become over-pressurized



Micro-Inspector Electrochromic Radiator

- Electrochromic Device (ED) from Ashwin-Ushas applied to the underside thermal radiator
- ED consumes less than 20 mW steady-state power
- High emissivity state (ε=0.7) allows for rejection of waste heat loads
- Low emissivity state (ε=0.15 to 0.3) conserves waste heat for butane vaporization
- Thermal modeling indicates ED extends steady-state operation modes for large off-sun angles





Electrochromics Development Testing

- Ashwin-Ushas Electrochromic devices are currently being developed for increased reliability
- Development program entails testing a number of devices for performance, material compatibility, manufacturability, and durability.
- NASA SBIR program: environmental exposure (gamma radiation, UV, solar wind, atomic oxygen, hard vacuum, thermal cycling)
- Micro-Inspector project:
  - Calorimetric and reflectometer performance testing
  - Iso-butane propellant chemical compatibility tests
  - Long term storage in vacuum, open-atmosphere, and gaseous Nitrogen environments
  - System thermal vacuum performance testing

Summary/Future Work

- Conducting Polymer Electrochromic Devices developed by Ashwin-Ushas Corporation are being designed to extend the functionality of mechanical louvers to microspacecraft thermal control
- Thermal modeling of a Micro-Inspector spacecraft design indicates that electrochromic devices can maintain optimal hardware temperatures and decrease heat loss for spacecraft off-sun angles in excess of 45 degrees
- A technology development program is underway to assess and improve the performance, manufacturability, material compatibility, and lifetime of the electrochromic device technology.
- Further development testing as part of the Micro-Inspector project will include vibrational tests and thermal cycling tests to gauge environmental stress and system thermal vacuum tests to validate performance.
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