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
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, \(<\pm 5\) V.).
- **Visible-NIR region**: (0.4 to 1.1 \(\mu m\)); **IR Region**: (2 to 45 \(\mu m\)).
- 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-\(\varepsilon\).
  - **Light** = IR-transparent. When in this state, IR is transmitted and reaches a highly IR-reflective layer (usually Au) that is low-\(\varepsilon\).

**Benefits**
- Flexible substrate
- Active control of \(\varepsilon\)-values
- Light weight: 1.6 kg/m\(^2\) vs. 4 to 10 kg/m\(^2\) for louver system.

- Requires minimal electrical power to operate.

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**Dark State (+0.2 V)**  **Light State (-1.0 V)**

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August, 10 2005
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/cm^2 for < 30 sec
  - Steady-state: < 40 μW/cm^2
**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 ($\varepsilon = 0.7$) allows for rejection of waste heat loads
- Low emissivity state ($\varepsilon = 0.15$ to 0.3) conserves waste heat for butane vaporization
- Thermal modeling indicates ED extends steady-state operation modes for large off-sun angles

![Micro-Inspector Thermal Modeling Results](image-url)
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.

• Acknowledgements: National Aeronautics and Space Administration, NASA Exploration Systems Research & Technology’s (ESR&T) Advanced Space Operations (ASO) Technology Maturation Program, NASA Small Business Innovation Research Program.