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Variable Emittance Electrochromic Thermal Control for Small Satellites

Variable Emittance Electrochromic Thermal Control Space Testing

Work performed on this contract was done at:
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Outline

- IR-ElectroChromic Device for active emissivity control
- EclipseVED™
- Performance
- Cold Mirror Additions
- MidSTAR1 Satellite test results
- Future Space Simulation Tests
- Small Satellite Uses
- Conclusions

Thermal Control & Technologies

Thermal control is required for satellites to keep the internal temperature around room temperature (300K)

Current technologies include:

- Paints
- Mechanical Louvers
- Heaters/Radiators
- Heat Pipes

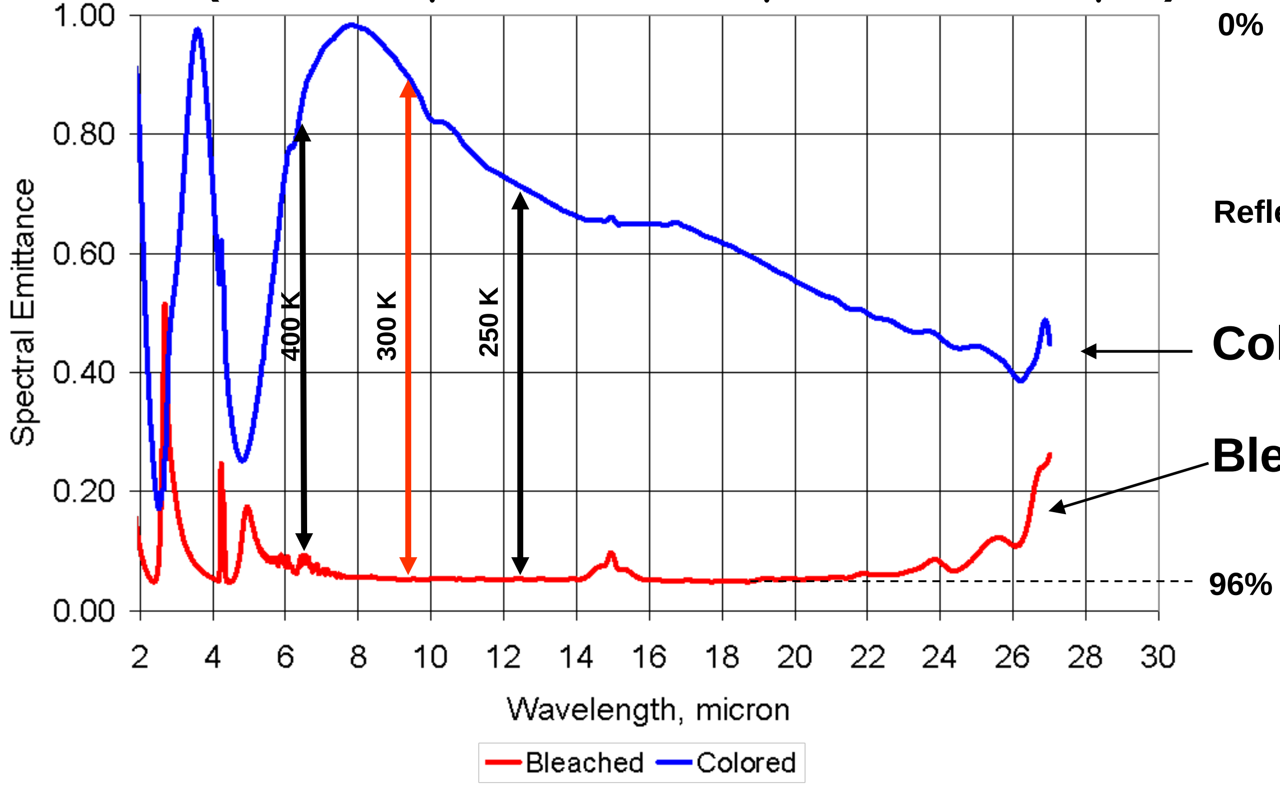
On the Horizon:

- **EclipseVED™**
- MEMS
- Electrostatic Flap
- Other ECD systems

Large Ratio IR Variable Emittance EC Device

Eclipse Thermal Control Device (EclipseVED™)

(400K 6.4 μm, 300 K; 9.5 μm, 250K 12.6 μm)



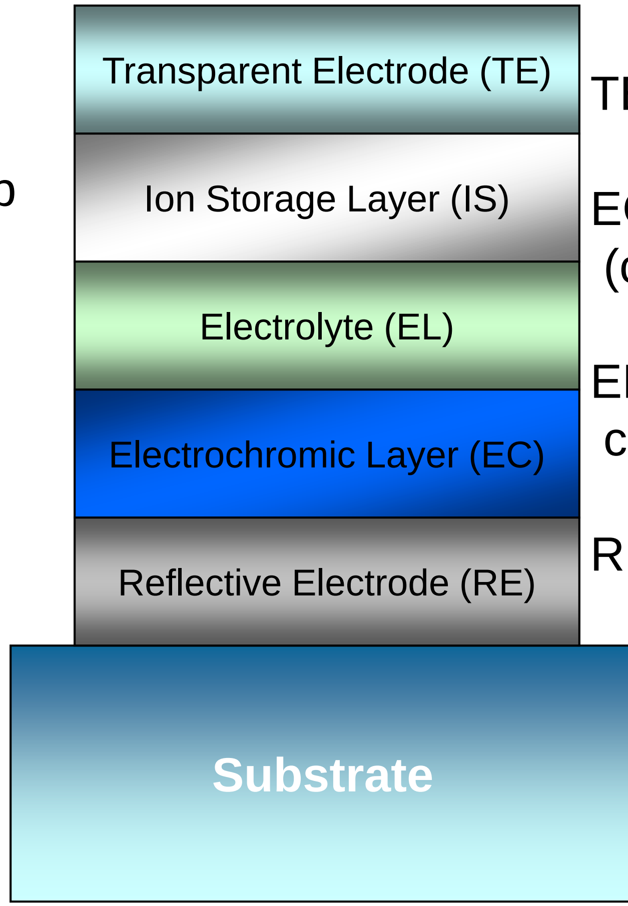
Electrochromic System Layers

Electrochromic coatings are a series of layered coating which include:

Optical Properties

Non-Absorb ↔ Absorb

Non-Absorb ↔ Absorb



Electrical Properties

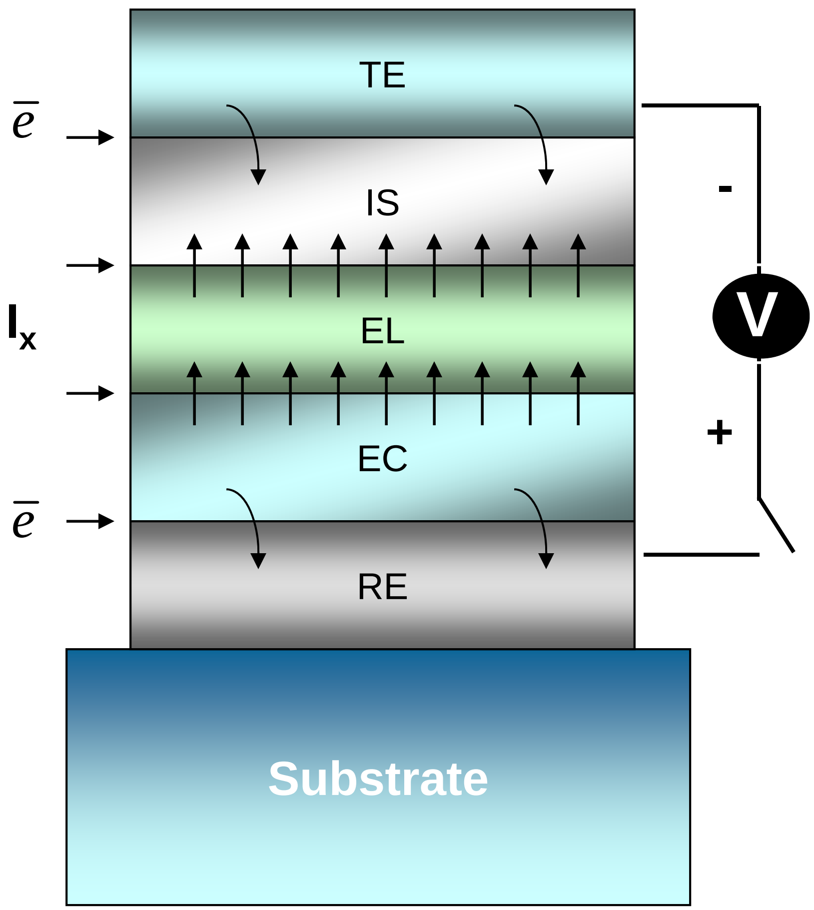
TE: Electrical Conductors

EC & IS Layers: Mixed conductors (conduct both electron and ion)

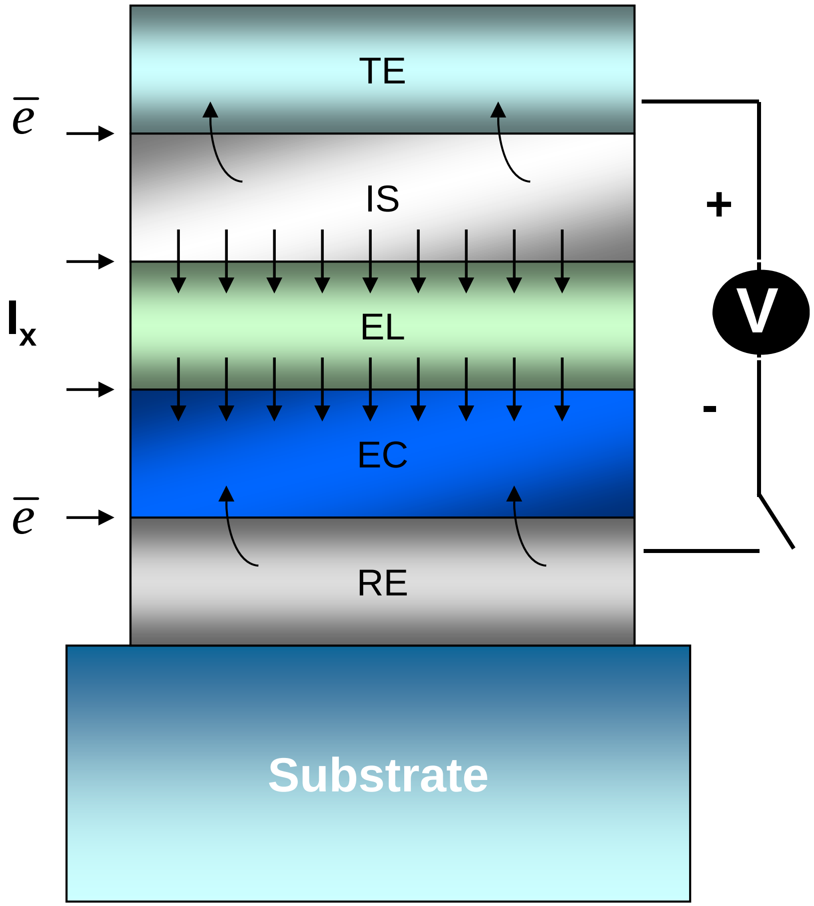
EL: Electronic insulator/ ion conductor.

RE: Electrical Conductors

ECD Operation: Bleaching



ECD operation: Coloring



Redox Layer Reactions

Anode reaction:

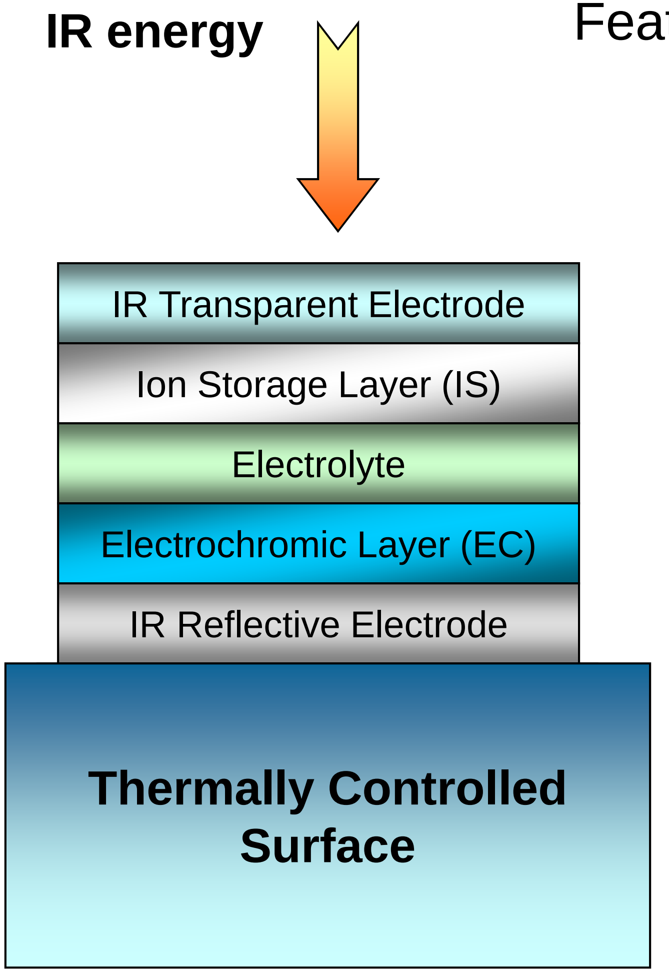
Red. (colored) $$I_xEC \underset{-1.6V}{\overset{+0.6V}{\rightleftarrows}} xI^+ + xe^- + EC$$ (bleached) Ox.

Cathode reaction:

Ox. (colored) $$IS + xI^+ + xe^- \underset{+1.6V}{\overset{-0.6V}{\rightleftarrows}} I_xIS$$ (bleached) Red.

Emissivity Control System

The IR transparent electrode is an Eclipse proprietary technology (EclipseTEC™) with sheet resistance of 5 Ohms/sq and an IR transmission of greater than 90%.



Features of VED:

- Ion loading
- Solid electrolyte
- Interface layers
- Ion Storage layer
- Metamaterial IR transparent electrode
- IR reflective electrode
- Monolithic all inorganic films
- Weight = $5 g/m^2$
- Activation V (Avg 1 V)
- Current (< 1 mA)
  - Density ($2 mA/cm^2$-$40 \mu A/cm^2$)
- $\mu W/cm^2 < P < 3 mW/cm^2$

EclipseVED™ Advantages

The EclipseVED™ is:

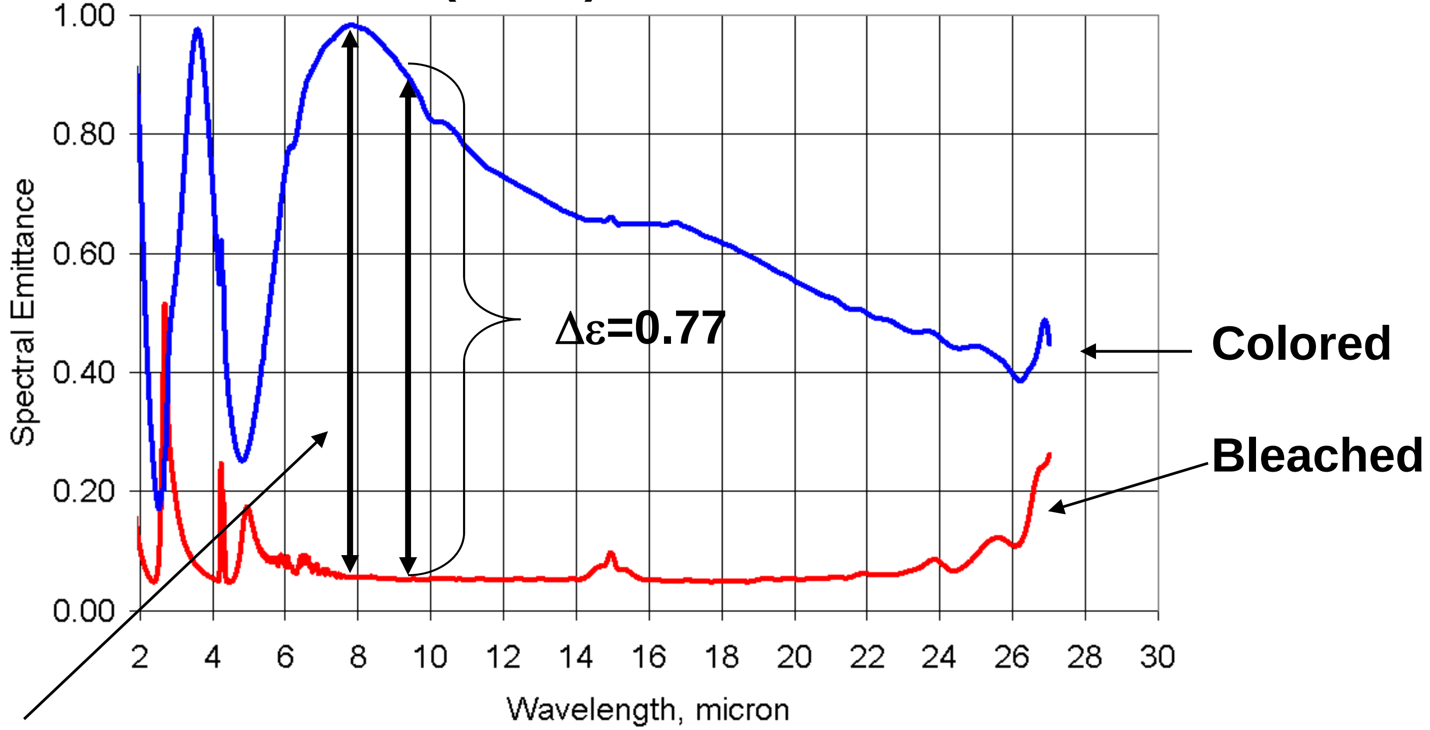
- Light weight ($5g/m^2$).
- Δe around 0.8.
- Full coloring is now under 4 min and as low as 1 minute bleaching.

Higher temperature region (T>300K) thermal control is possible.

- Emittance memory
- Metamaterial IR transparent continuous electrode.
- Low power consuming; $\mu W/cm^2$ to maintain a selected emittance.
- Cold mirror for protection and optical performance
- Electrical control without mechanical/moving parts.

Large Ratio IR Variable Emittance Device - EclipseVED™

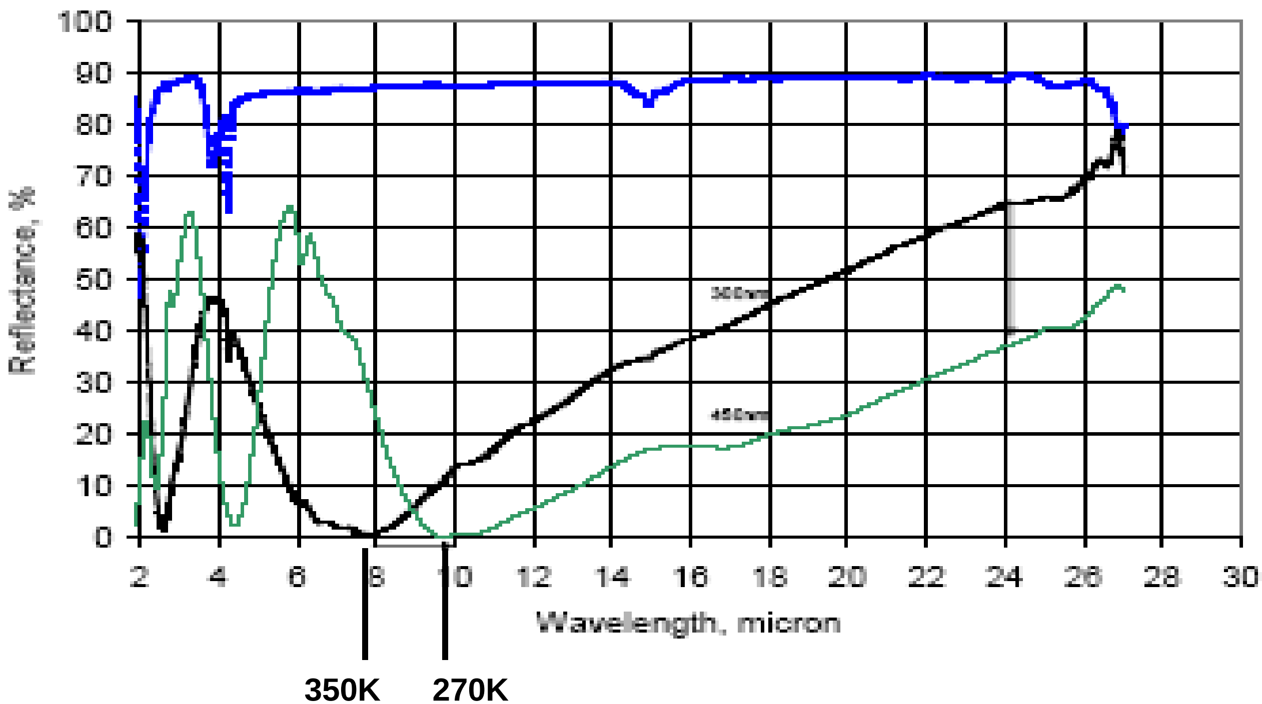
Eclipse Thermal Control Device - EclipseVED™
RT (300 K)



8μm(350K): Δε =0.93

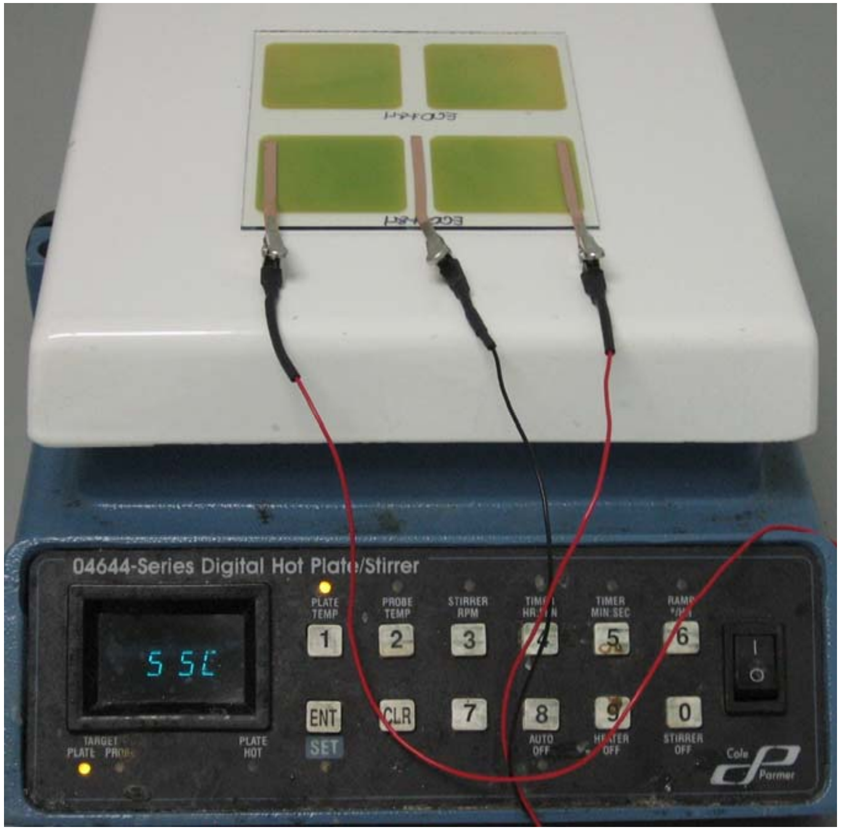
Spectral Emittance (ε=1-R)
Eclipse (9.5μm(300K)): Δε =0.77

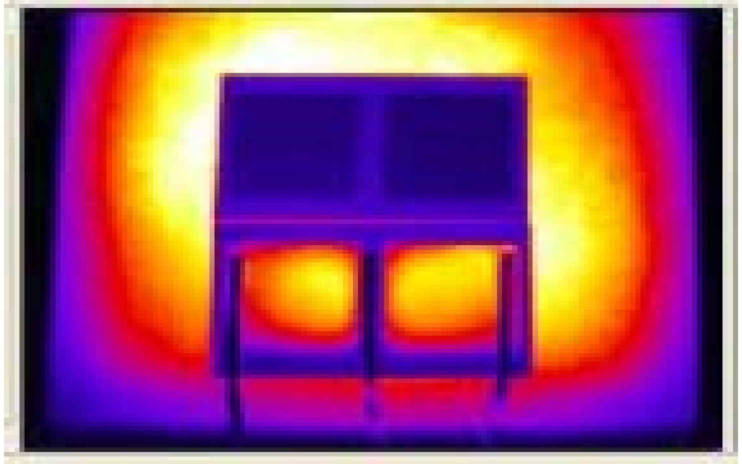
Current Black Body Heat Matching



Δe=0.7 in 4 minutes

Thermal and Optical Images

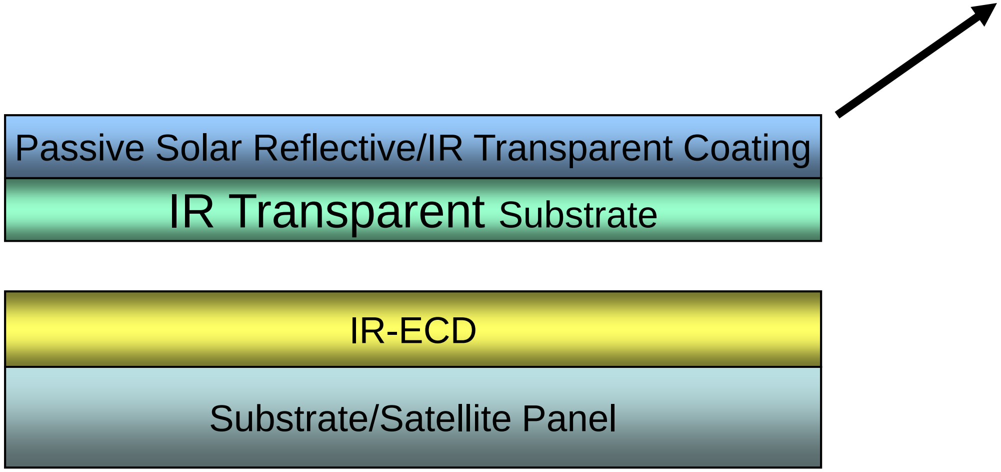




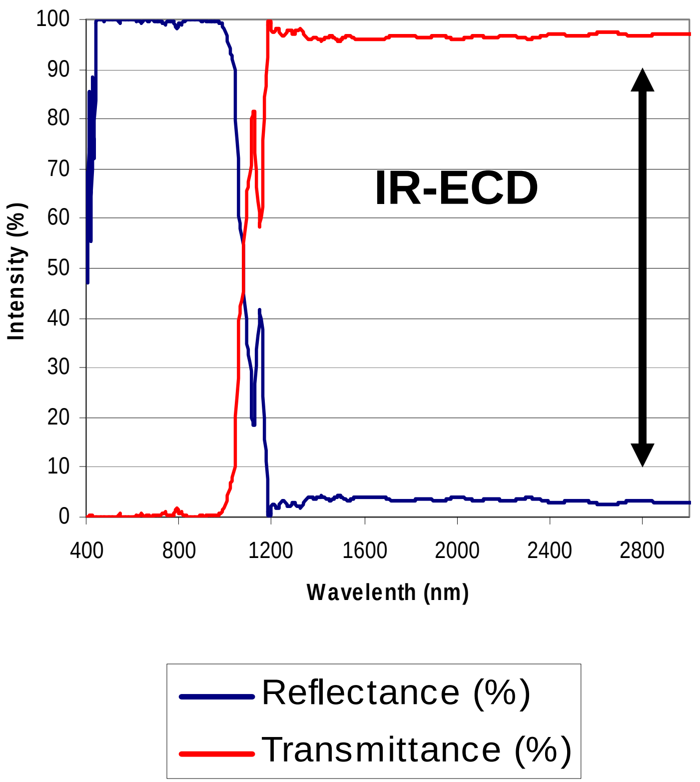
IR-ECD on 50 ^{0}C hot plate.
Low-e state (dark)
High-e state (yellow-red)

Cold Mirror Type 1 (Solid Substrate)

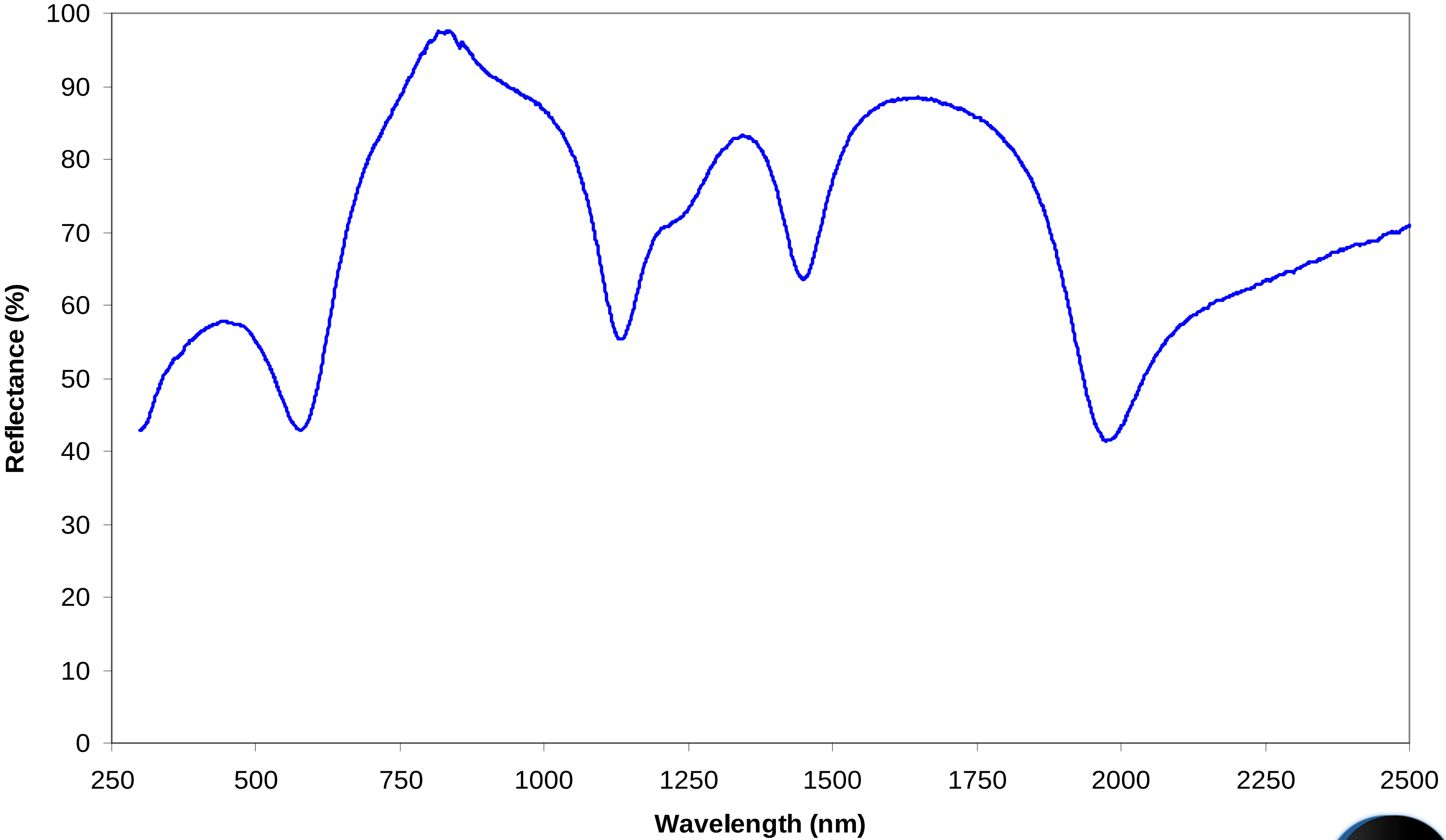
With a solar reflector the Eclipse IR-ECD modulator can regular heat In line-of-sight of the sun with the Rejection of the majority of the sun's Solar energy



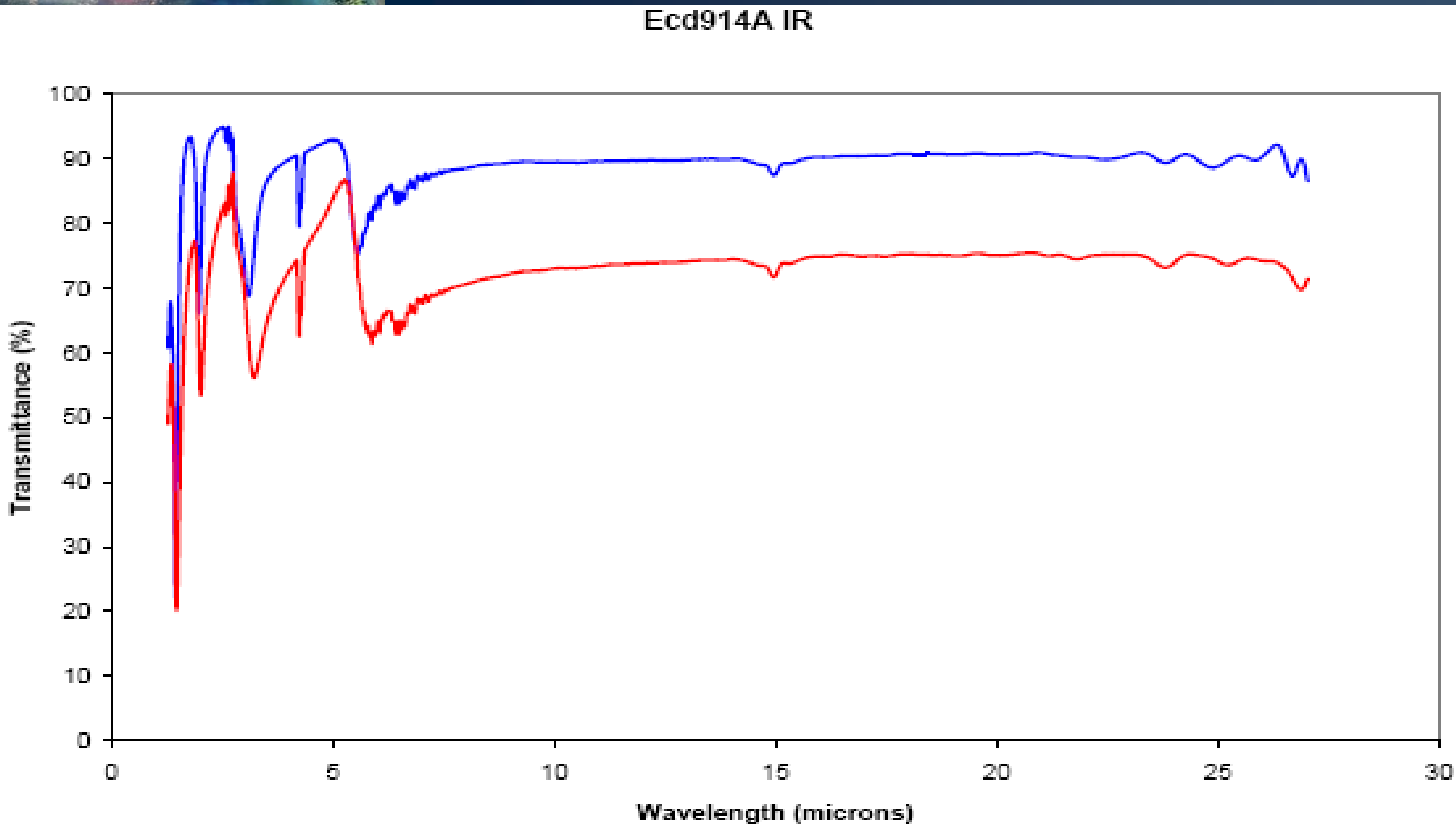
Solar Reflector Model



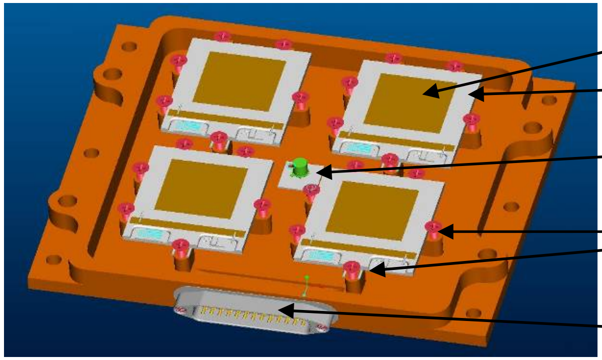
Cold mirror Type 2: Directly on ECD



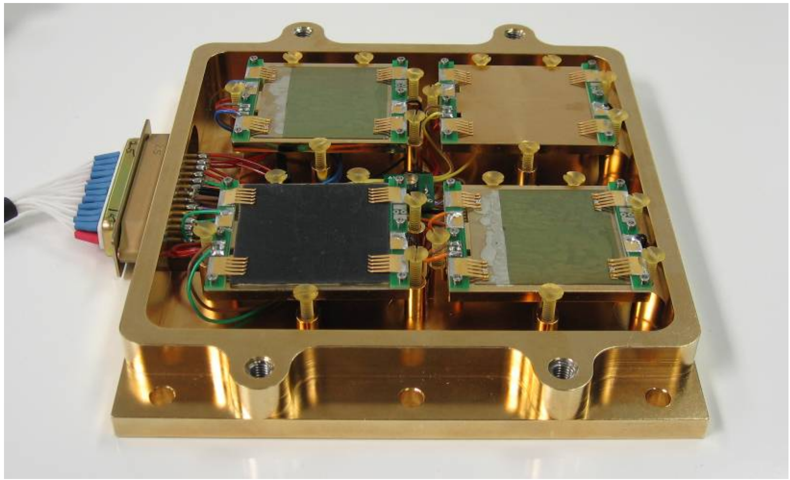
Cold mirror Type 2: Directly on ECD



Eclipse MidSTAR1 Experiment



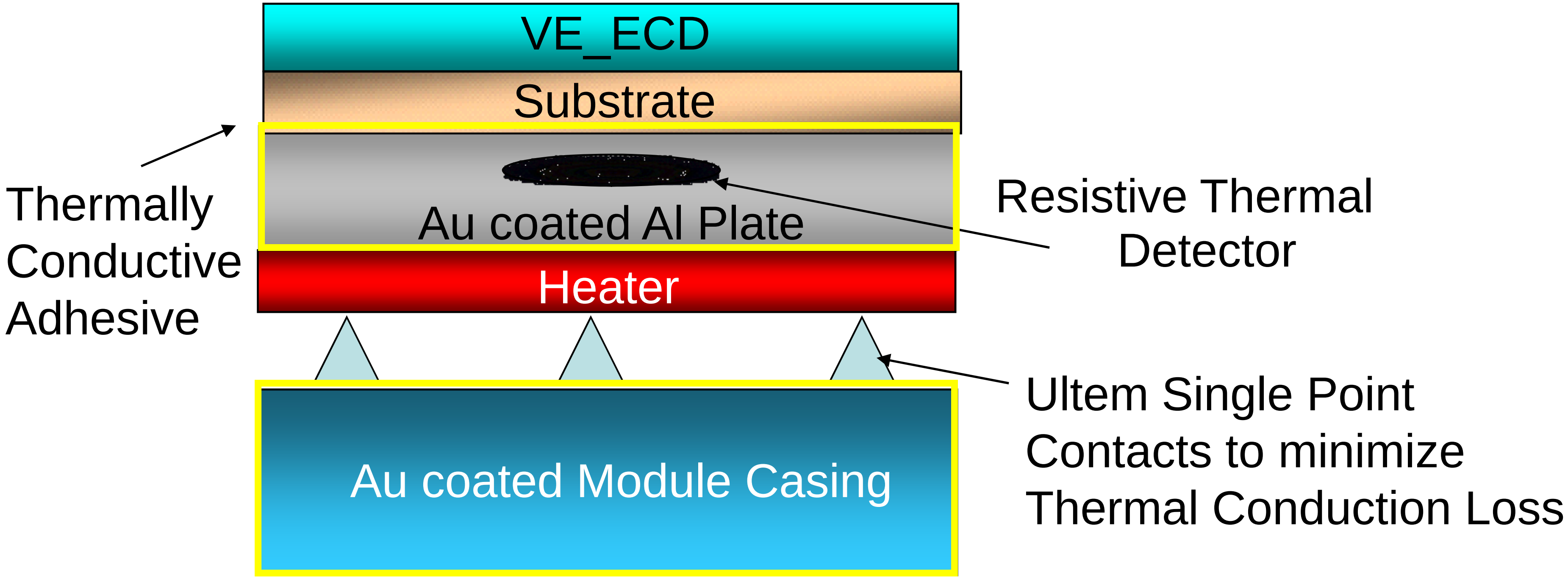
Drawing



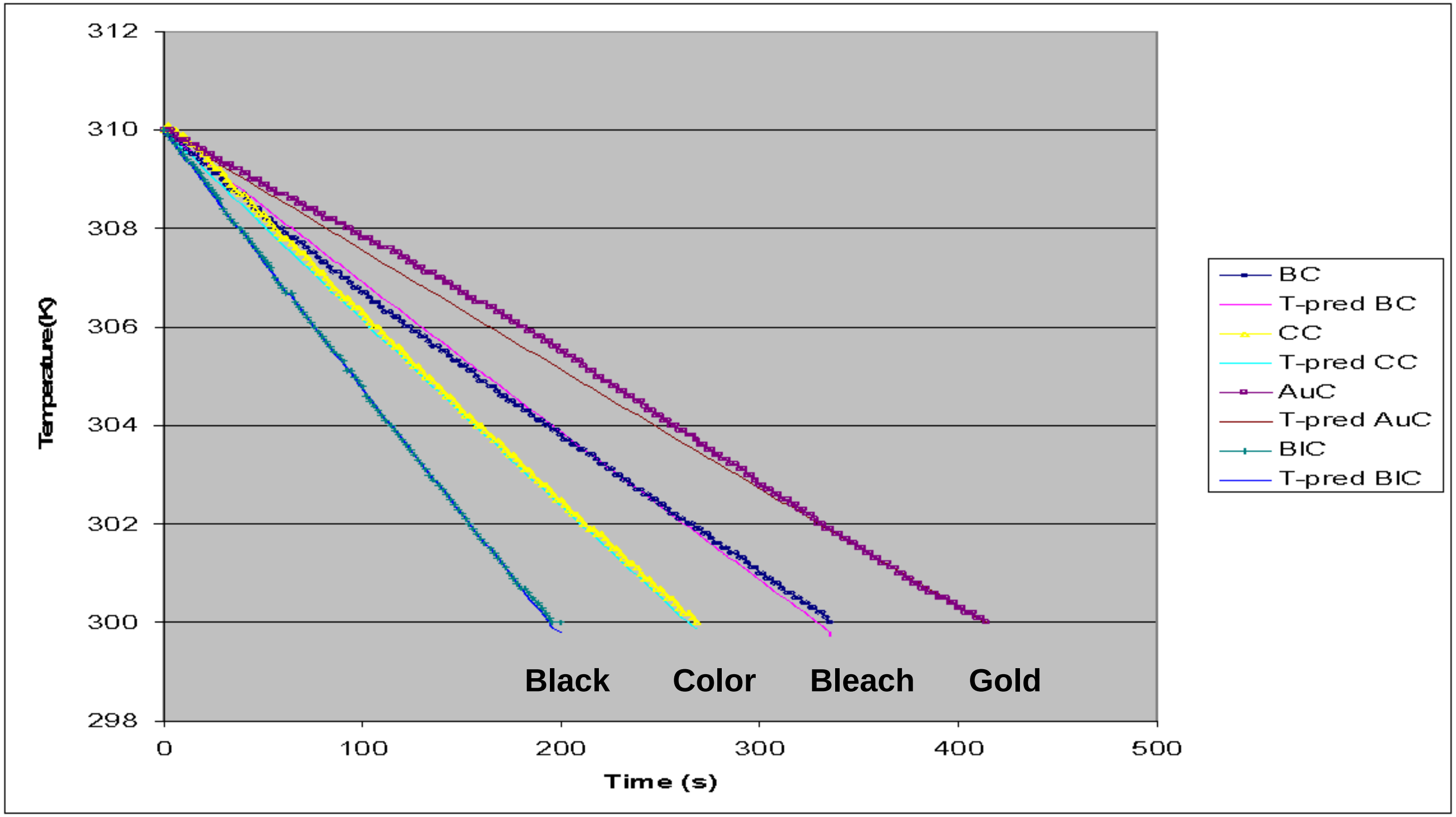
Test Module

- **Testing Unit**: An externally mounted module populated with two EclipseVED™s, a low emittance standard and a high emittance standard each connected to an on-board control module.
- **Purpose**: Identify the effect that the EclipseVED™ has on heat dissipation and absorption rates of a small thermal mass in the space environment.

Cross-sectional of MidSTAR1 Thermal Mass



MidSTAR1 Results

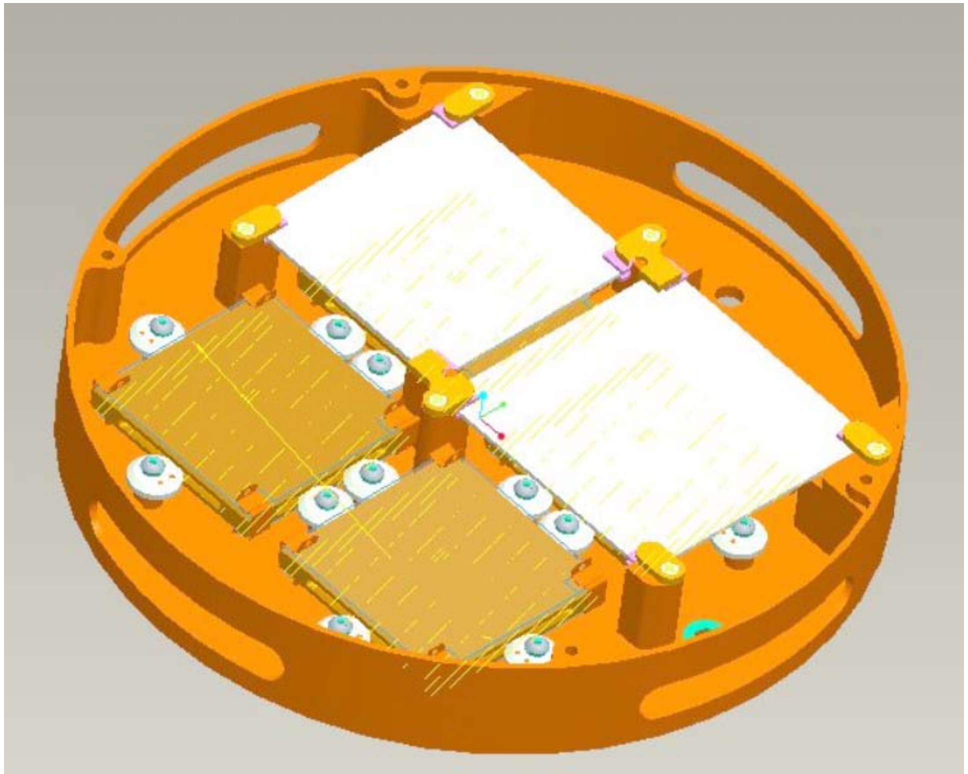


Conclusions on MidSTAR1 Experiment

- Heat dissipation rate on Au (low-e) surface is slowest.
- Heat dissipation rate on black (high-e) surface is fastest.
- Heat dissipation rate of the colored EclipseVED^{TM} is closer to that of the black surface.
- Heat dissipation rate of the bleached EclipseVED^{TM} is closer to that of the gold surface.
- Heat dissipation rate of the colored EclipseVED^{TM} is faster than that of its bleached condition.
- EclipseVED^{TM} controls the heat dissipation rate of the surfaces they are attached to.
- EclipseVED^{TM} works in the space-based conditions and can be remotely controlled from the earth.

Future Vacuum Testing

- Oxygen, Radiation, Solar Loading testing
- Each sample group of 4 devices has 1 of each of the following:
  - 1 uncovered sample
  - 1 sample with a sealed cleartran top plate with a type I cold mirror deposition on it.
  - 1 sample with direct deposit type II "cold mirror" coating
  - 1 sample sealed with a cleartran substrate (no cold mirror coating).



Vacuum Testing

- Atomic Oxygen Testing
  - TEST 1: Conduct atomic oxygen (AO) testing to a fluence of 2x1020 atoms/cm2 in the MSFC Atomic Oxygen Beam Facility (AOBF) as a screening test.
    - During the test, provisions will be made to periodically switch the emissivity state of the materials while in the vacuum chamber. The number of times the emissivity state will be switched will be agreed upon by both parties.
  - TEST 2: Following the screening test and any necessary modifications to the coatings a long term AO test in the AOBF will be conducted. The target AO fluence will be 3x1021 atoms/cm2.
    - During the test, provisions will be made to periodically switch the emissivity state of the materials as in the first test.

Vacuum Testing

- Radiation and Charge Particle Testing
  - TEST 1: Conduct a screening test in the solar wind test facility (SWTF) where protons, electrons, and UV light are combined to irradiate the material. Typical sample exposure area in the SWTF is 4.5” square. A one year exposure will be done for screening purposes to a dose for both proton and electrons of ~2 x1016 p+/cm2 and ~2 x1016 e+/cm2, respectively. The proton and electron energy will be determined based on the depth of penetration into the materials.
    - During the test, provisions will be made to periodically switch the emissivity state of the materials.
  - TEST 2: Following the screening test in the solar wind test facility, a second test will conducted if changes to the materials are required.
    - During the test, provisions will be made to periodically switch the emissivity state of the materials.

Vacuum Testing

- Thermal Property Demonstration
  - TEST 1: Conduct a test to demonstrate the thermal control material's ability to change infrared emittance under solar radiation.
    - During this test the X-25 solar simulator will illuminate the front side of the materials and the back side will face a cold (TBD °C) plate with a black highly emissive coating. While the X-25 is irradiating the sample, the temperature of the sample will be monitored.
    - At the appropriate time the sample emittance will be changed and the temperature will be monitored for any changes after switching the emittance.
  - TEST 2: Following the first test, a second test will be done after modifications to the materials have been made.

Thermal Control for Small and Nano Satellites

- Could be used for short mission, high variable heat/power load systems.
- Useable for thermal control on non-attitude controlled “rolling” satellites.

Looking to the future:

- When combined with photovoltaic cells could provide:
  - Simultaneous thermal control and solar cell use.
  - Longevity of the cells and batteries by minimizing continual power accumulation.
  - On the fly, fully automated power management system.

Conclusions

1. The EclipseVED™ is the first full functional ECD working in space.

2. The EclipseVED™ is extremely good emissivity modulator.

3. The EclipseVED™ will soon be tested by NASA for Space Qualification testing.

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