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Front Surface Spectral Control Development for TPV Energy Conversion (a Presentation)

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Front Surface Spectral Control Development for TPV Energy Conversion

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Overview:

Update of the results presented in DEC2001 and DEC2003

Introduction to the potential of alternative materials that provide higher temperature stability than current materials

Outline:

Review briefly the importance of spectral control

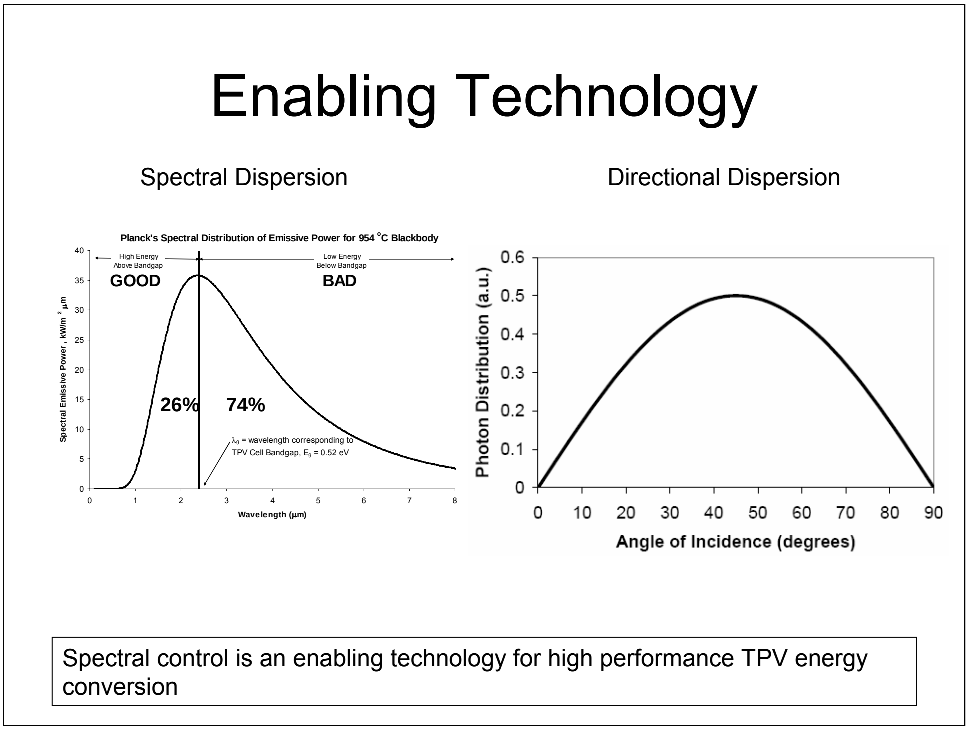
Provide current results

Introduce the temperature stability issue

Describe the requirements for alternate materials

Present alternative materials

Conclusion



Enabling Technology

Spectral Dispersion

Directional Dispersion

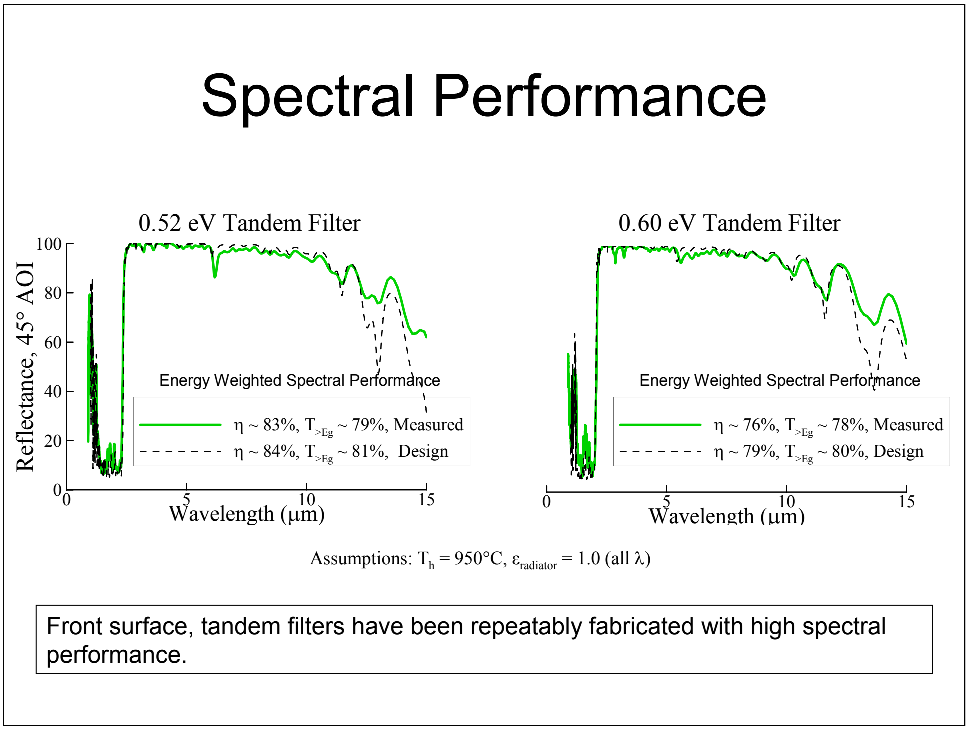
Spectral control is an enabling technology for high performance TPV energy conversion

Why the problem is important

Spectral control is a key enabling technology for high efficiency TPV energy conversion

Source is spectrally and directionally dispersive

Without spectral control, TPV conversion efficiency would be 5-7% instead of >20%



Spectral Performance

Assumptions: $T_h = 950°C$, $\varepsilon_{radiator} = 1.0$ (all λ)

Front surface, tandem filters have been repeatably fabricated with high spectral performance.

Tandem filter status

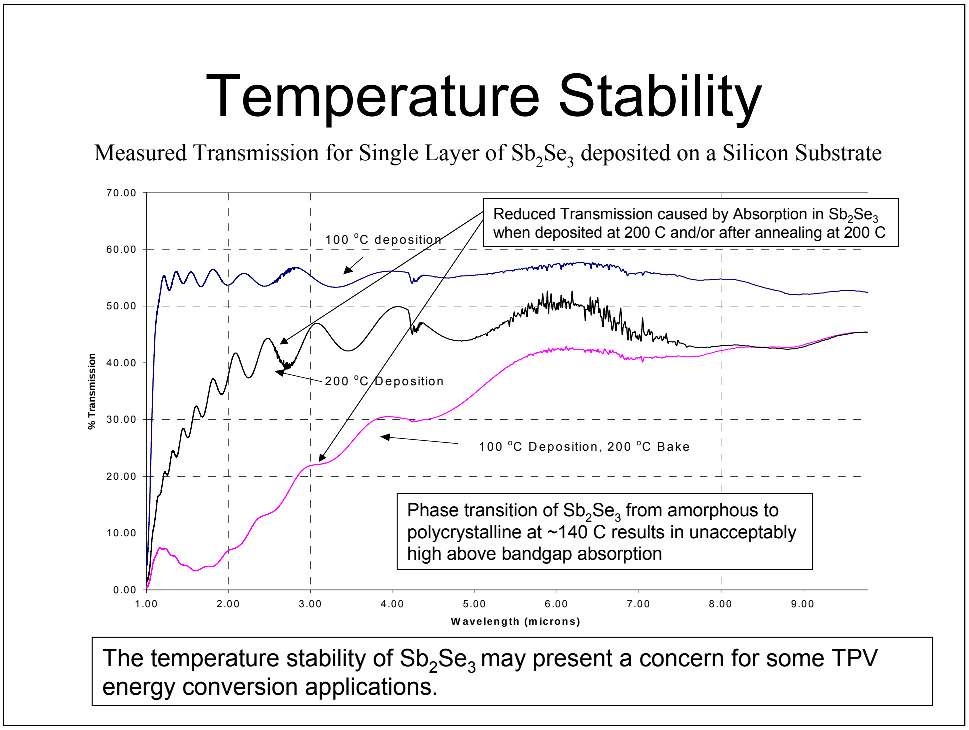
Last year (DEC2003):

0.52eV: spectral efficiency 80% and 79% (unchanged) above Eg transmission

0.60eV: spectral efficiency 75% and 75% above Eg transmission

DEC2001

0.52eV spectral efficiency 77% (above Eg transmission not reported)



Temperature Stability

Measured Transmission for Single Layer of Sb_2Se_3 deposited on a Silicon Substrate

Reduced Transmission caused by Absorption in Sb_2Se_3 when deposited at 200 C and/or after annealing at 200 C

Phase transition of Sb_2Se_3 from amorphous to polycrystalline at ~140 C results in unacceptably high above bandgap absorption

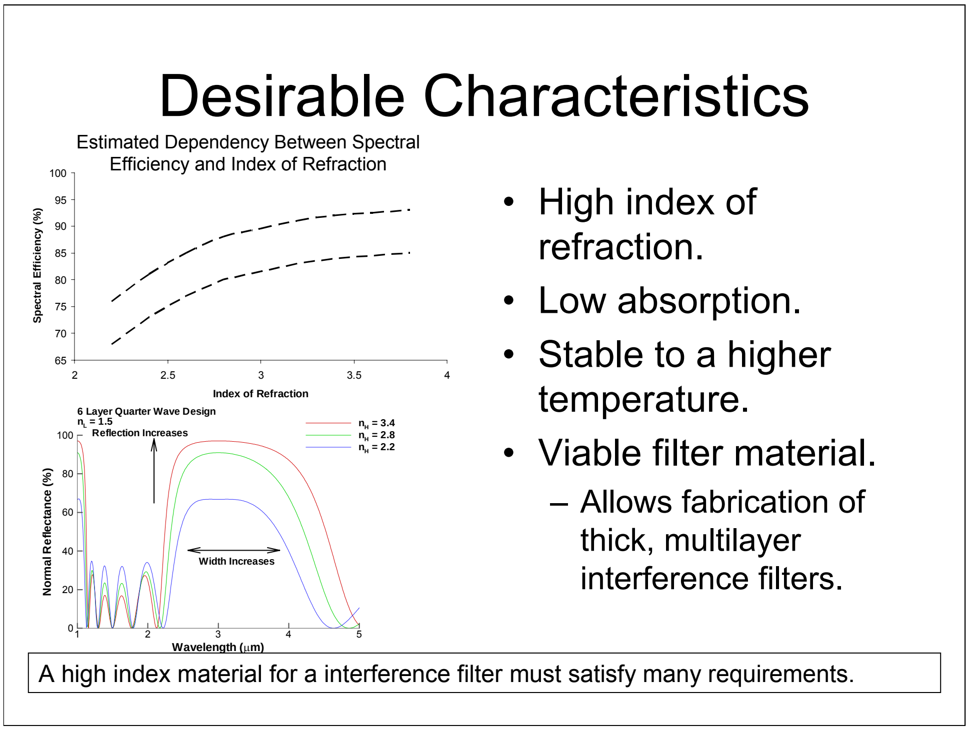
The temperature stability of Sb_2Se_3 may present a concern for some TPV energy conversion applications.

<u>What the problem is</u>

Antimony selenide experiences a phase transformation at about 140C

Time-temperature studies are underway to better quantify the conditions for the phase transformation

Stability at a higher temperature could decrease size, weight, and complexity of the heat rejection system in some applications.



Desirable Characteristics

- High index of refraction.
- Low absorption.
- Stable to a higher temperature.
- Viable filter material.
  - Allows fabrication of thick, multilayer interference filters.

A high index material for a interference filter must satisfy many requirements.

Antimony selenide combined with any alternate material must satisfy several stringent requirements to yield the high spectral efficiency achieved to date.

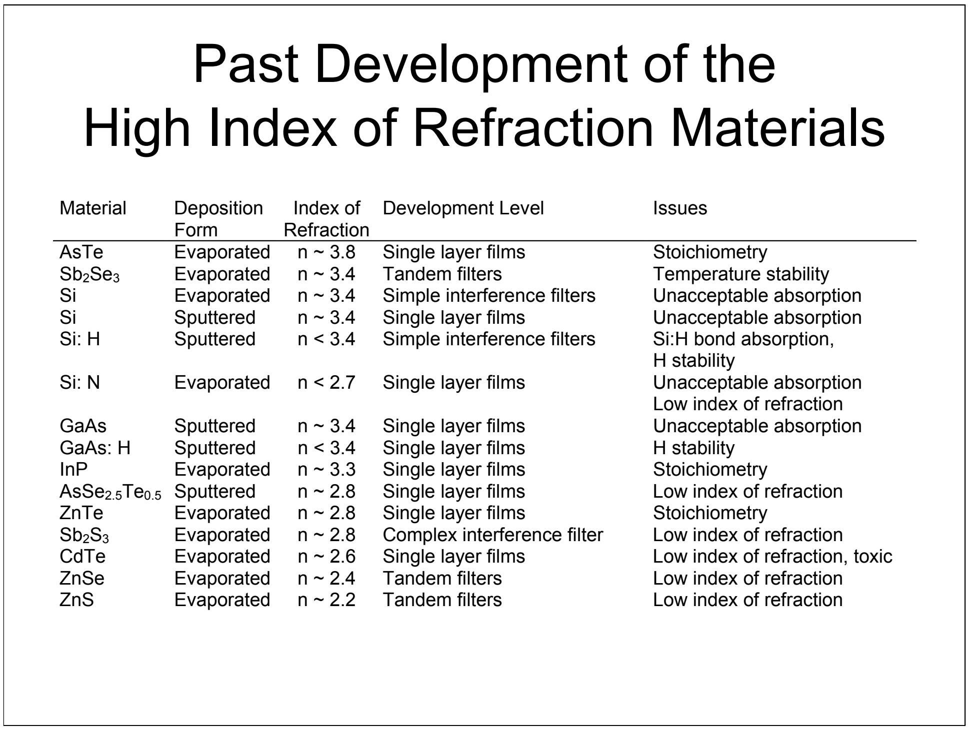
The index of refraction contrast between the materials comprising the filter determines the complexity. The complexity increases as the contrast decreases.   For a given set of alternating layers, the width of the reflection band and the magnitude of the reflection are dependent on the index of refraction contrast.

Very low absorption (0.0001) is required to maintain the power density available from the radiating surface.

The temperature stability must be higher than antimony selenide; otherwise just use antimony selenide.

An alternate material must work within the fabrication process to be a viable filter material. The characteristics include but are not limited to the following:

- Evaporable
- Residual stresses can mitigate through design or fabrication techniques
- Deposition variables, such as temperature, incidence angle, and rate must all be compatible with other material in the stack

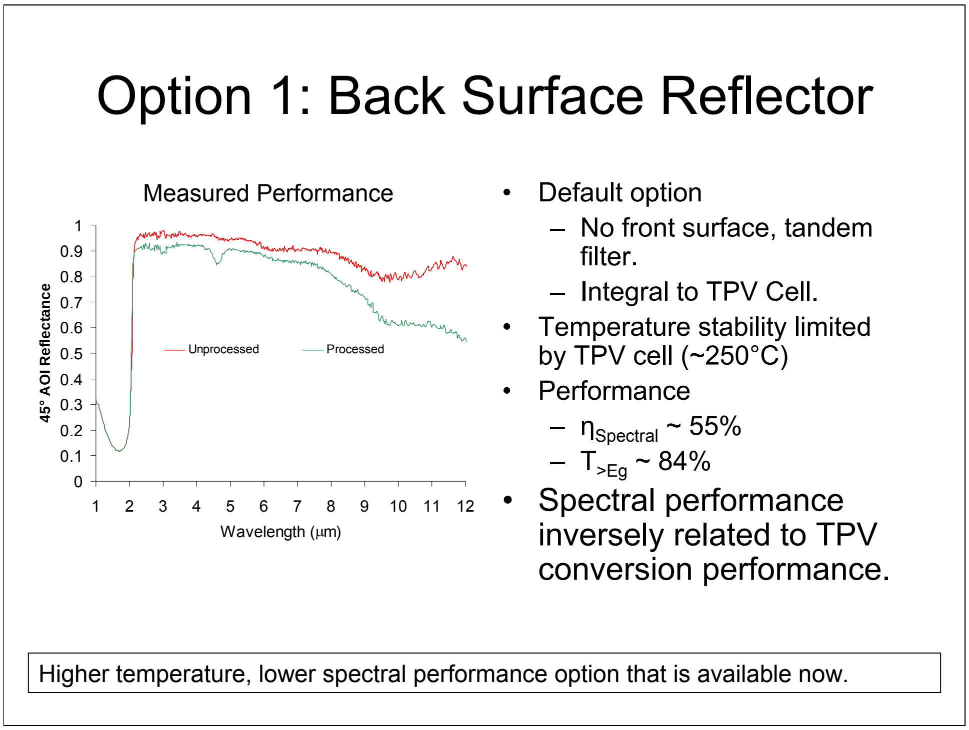


Past Development of the High Index of Refraction Materials

Material	Deposition Form	Index of Refraction	Development Level	Issues
AsTe	Evaporated	$n \sim 3.8$	Single layer films	Stoichiometry
Sb_2Se_3	Evaporated	$n \sim 3.4$	Tandem filters	Temperature stability
Si	Evaporated	$n \sim 3.4$	Simple interference filters	Unacceptable absorption
Si	Sputtered	$n \sim 3.4$	Single layer films	Unacceptable absorption
Si: H	Sputtered	$n < 3.4$	Simple interference filters	Si:H bond absorption, H stability
Si: N	Evaporated	$n < 2.7$	Single layer films	Unacceptable absorption Low index of refraction
GaAs	Sputtered	$n \sim 3.4$	Single layer films	Unacceptable absorption
GaAs: H	Sputtered	$n < 3.4$	Single layer films	H stability
InP	Evaporated	$n \sim 3.3$	Single layer films	Stoichiometry
$AsSe_{2.5}Te_{0.5}$	Sputtered	$n \sim 2.8$	Single layer films	Low index of refraction
ZnTe	Evaporated	$n \sim 2.8$	Single layer films	Stoichiometry
Sb_2S_3	Evaporated	$n \sim 2.8$	Complex interference filter	Low index of refraction
CdTe	Evaporated	$n \sim 2.6$	Single layer films	Low index of refraction, toxic
ZnSe	Evaporated	$n \sim 2.4$	Tandem filters	Low index of refraction
ZnS	Evaporated	$n \sim 2.2$	Tandem filters	Low index of refraction

We have studied many materials as the result of a literature review of a large set of materials.

Additional development of these and other materials could yield useful results for a given application.



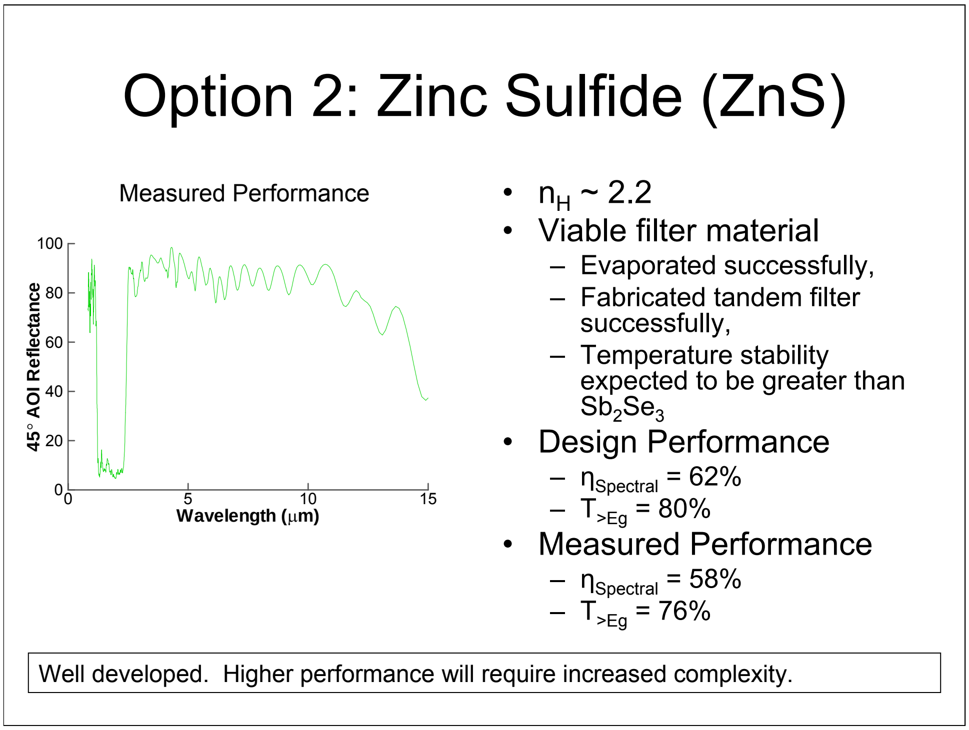
Option 1: Back Surface Reflector

- Default option
  - No front surface, tandem filter.
  - Integral to TPV Cell.
- Temperature stability limited by TPV cell (~250°C)
- Performance
  - η_{Spectral} ~ 55%
  - $T_{>Eg}$ ~ 84%
- Spectral performance inversely related to TPV conversion performance.

Higher temperature, lower spectral performance option that is available now.

<u>Potential Solutions to the problem</u>

High TPV efficiency (17% vs. 5%) can be achieved without front surface, tandem filters, using a BSR.



Option 2: Zinc Sulfide (ZnS)

- $n_H \sim 2.2$
- Viable filter material
  - Evaporated successfully,
  - Fabricated tandem filter successfully,
  - Temperature stability expected to be greater than Sb_2Se_3
- Design Performance
  - $\eta_{Spectral} = 62\%$
  - $T_{>Eg} = 80\%$
- Measured Performance
  - $\eta_{Spectral} = 58\%$
  - $T_{>Eg} = 76\%$

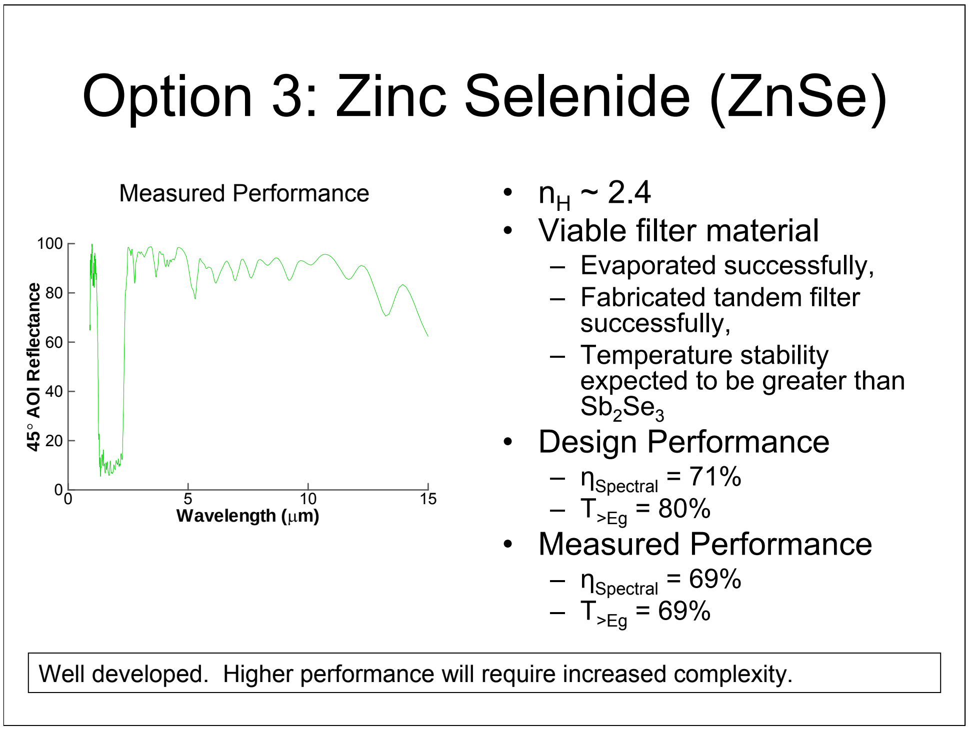
Well developed. Higher performance will require increased complexity.

Potential Solutions to the problem

Viable filter material since filters have been fabricated.

No test data for temperature stability, but sublimation temperature and melting temperatures for ZnS are nearly twice the temperatures of Sb_2Se_3

Higher performance will require more complex designs and more complex fabrication processes.



Option 3: Zinc Selenide (ZnSe)

Measured Performance

- n_H ~ 2.4
- Viable filter material
  - Evaporated successfully,
  - Fabricated tandem filter successfully,
  - Temperature stability expected to be greater than Sb_2Se_3
- Design Performance
  - $\eta_{Spectral}$ = 71%
  - $T_{>Eg}$ = 80%
- Measured Performance
  - $\eta_{Spectral}$ = 69%
  - $T_{>Eg}$ = 69%

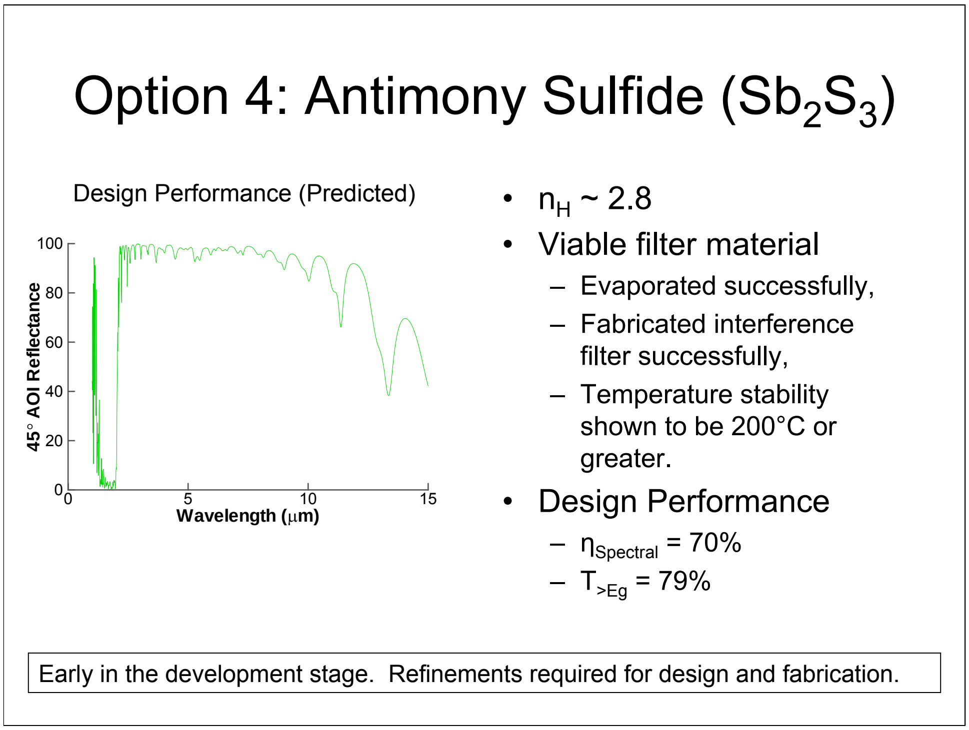
Well developed. Higher performance will require increased complexity.

Potential Solutions to the problem

Viable filter material since filters have been fabricated.

No test data for temperature stability, but sublimation temperature and melting temperatures for ZnSe nearly twice the temperatures of Sb2Se3

Higher performance will require more complex designs and more complex fabrication processes.



Option 4: Antimony Sulfide (Sb_2S_3)

Design Performance (Predicted)

- $n_H \sim 2.8$
- Viable filter material
  - Evaporated successfully,
  - Fabricated interference filter successfully,
  - Temperature stability shown to be 200°C or greater.
- Design Performance
  - $\eta_{Spectral} = 70\%$
  - $T_{>Eg} = 79\%$

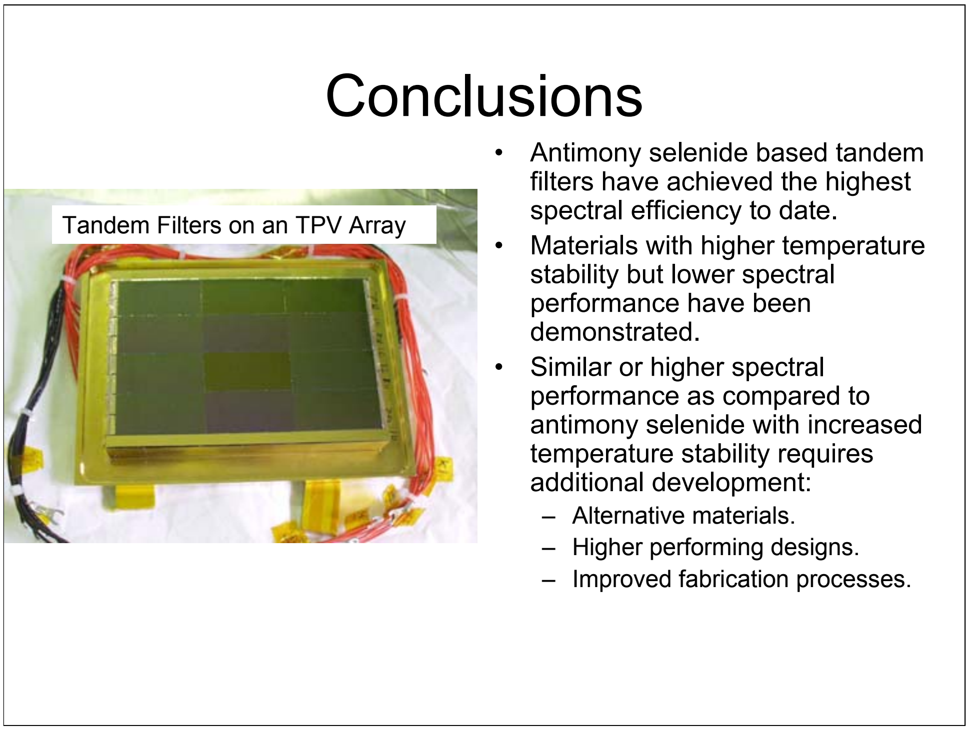
Early in the development stage. Refinements required for design and fabrication.

<u>Potential Solutions to the problem</u>

Viable filter material since an interference filter has been fabricated.

Sb_2S_3 as a single layer and interference filter shown to survive 200C for 2 hours.

Higher performance will require more complex designs and more complex fabrication processes.



Conclusions

Tandem Filters on an TPV Array

- Antimony selenide based tandem filters have achieved the highest spectral efficiency to date.
- Materials with higher temperature stability but lower spectral performance have been demonstrated.
- Similar or higher spectral performance as compared to antimony selenide with increased temperature stability requires additional development:
  - Alternative materials.
  - Higher performing designs.
  - Improved fabrication processes.

Antimony selenide has achieved the highest spectral efficiency to date.

Several materials expected to have higher temperature stability have been shown to be viable.

So far, with limited development, the performance of the these materials is lower than Antimony selenide.

Additional development will be required to achieve similar or higher performance.