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Mapping temperature service limits of ZnS Domes

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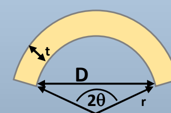
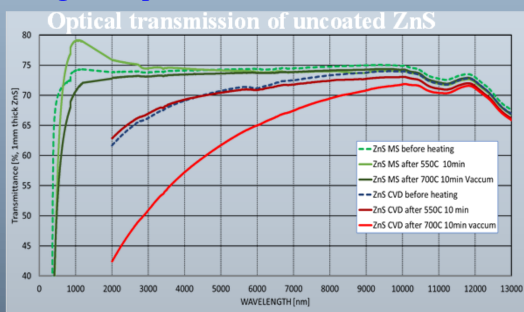
Research Motivation:

ZnS is the most popular Multi spectral material for missile domes.
Specifically, high speed missiles require IR material domes resistant to high temperatures and high heating rates.

The aerothermal heating characteristic to such applications can elevate the temperature of the dome well above 250˚C in a matter of seconds.
In this work we explore the service temperature upper limits of ZnS and thermal shock resistance of ZnS domes.

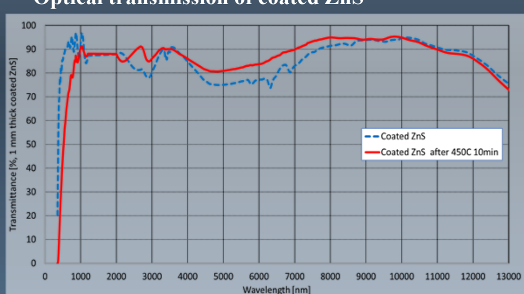


High Temperature resistance

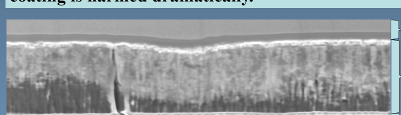


Optical Transmission of uncoated 1 mm thick multispectral and CVD grade ZnS samples before and after a 10 minute exposure to 550ºC in atmospheric pressure and to 700ºC under a vacuum of 10^{-6} Torr.
After exposure to 550ºC, transmission decreased in the VIS and increased in the NIR , due to the formation of an oxidation layer of ZnO (as identified by EDS), which partially functioned like an Anti-Reflection layer.
After exposure to 700ºC under vacuum, a large decrease is evident across the spectrum in CVD-ZnS. MS-ZnS showed only negligible transmission decrease in IR.

Optical transmission of coated ZnS

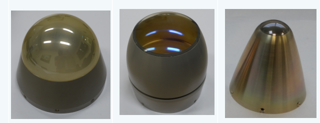


Optical Transmission of coated ZnS sample before and after a 10 minute exposure to 450ºC in atmospheric pressure, showing a decrease in the VIS caused by oxidation of the coating layers, as identified by Focus Ion Beam and EDS analysis. Above 500ºC the coating is harmed dramatically.



Thermal Shock resistance

Geometrical properties	Dome Assembly A	Dome Assembly B	Dome Assembly C
D, Base Diameter [mm]	120	90	40
r, Curvature radius [mm]	100	100	25
t, Thickness [mm]	4	3.6	2.5
2q, Included angle [˚]	165	70	90
Material Grade	CVD-ZnS	MS-ZnS	CVD-ZnS



Material properties	CVD ZnS	MS ZnS	Spinel	Fused SiO2
S, Strength [MPa]	100	70		
E, Modulus [GPa]	74	88		
a, CTE [1/K]	7.3e-6	6.5e-6		
n, Poisson's ratio	0.29	0.28		
k, therm. Conductivity [W/mK] @ 20°C-400°C	16.7-9.2	27		
R', Hasselman's Mild thermal shock merit function	2.6	2.1	1.9	3.4

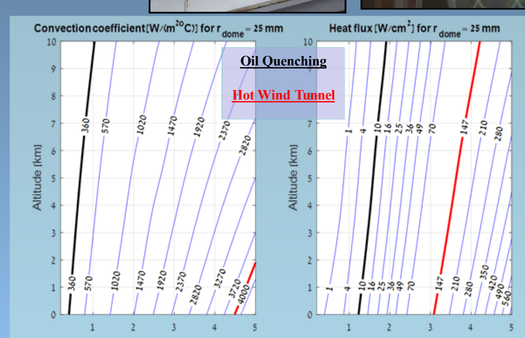
Biot number
Criterion for Mild thermal shock

$$\beta = \frac{th}{k} << 1$$

Hasselman's merit function for Mild thermal shock

$$R' = \frac{S(1-\nu)k}{\alpha E}$$

Thermal test conditions	Missiles	Oil Quenching	Hot wind tunnel
Velocity [Mach No.]	2-5		
Altitude [km]	0-25		
Max. temp. [°C]	250-400	350	400
Heating rate [°C/sec]	50-100	30-70	100-200
h, Coef. heat convection [W/m²K]	1000 typ [400-8000]	250-1000	4000
β, biot number	0.25 typ [0.01-5] Mostly mild	0.06-0.25 mild	1.1 Not mild nor severe
Thermal shock Resistance Test results		10 of 10 survived 10 A domes 10 B domes	4 of 4 survived 4 C domes



ZnS domes showed 100% resistance to mild thermal shock, characteristic to two different missile flight conditions.
Theoretical calculations according to Hasselman's and Klein's approaches indicate that ZnS has potential resistance to even tougher conditions.

Summary:

Temperature Limit	Optical performance	Visual inspection: Surface Roughness	Surface Bleaching	Coating intactness	Coating adhesion	Interferometer analysis PV, RMS
up to 10min @ 700˚C	Formation of ZnO oxidation layer under atmospheric pressure.	Signs of roughness	Negative effect			Negative effect Indication of Micro faceting
up to 10min @ 600˚C	Formation of ZnO oxidation layer under atmospheric pressure. **Under development: a new durable AR coating for 600ºC with oxidation prevention capability**	No effect	No effect			No effect
up to 10min @ 450˚C	Practical range 0.9-13 µm	No effect	Negative effect	No effect	No effect	No effect
up to 10min @ 400˚C	Practical range 0.45-13 µm	No effect	Slight Negative effect	No effect	No effect	No effect