Selective Absorber Coatings Based on Carbon Nanotubes

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Objectives

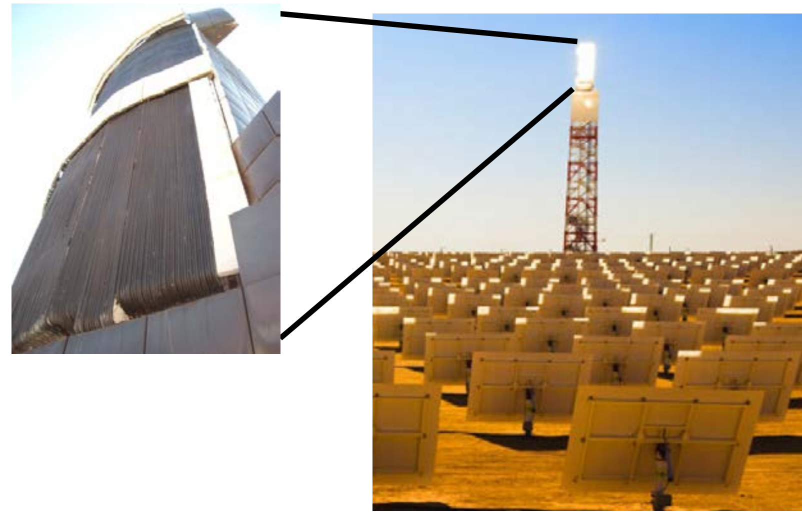
- **Development of high absorptance low emittance coating**

Methodology

- **Wet deposition (simple to apply also on site and on curved surfaces)**
- **Carbon nanotubes (CNTs) based**

First Generation – Hight Temp. Absorbers With BrightSource

Typical Formulation	%
Solvent/water	60-90
Matrix former	2-30
Dispersant	2
Wetting agent	1
Black pigment	2-20



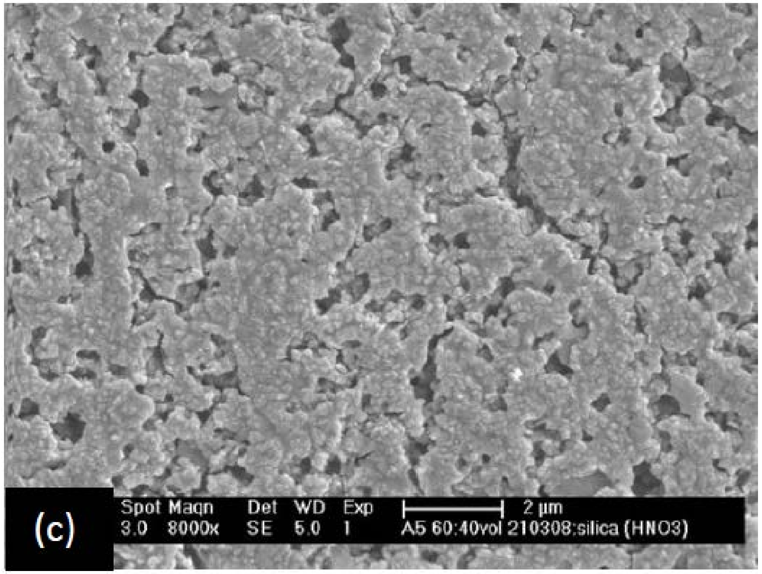
Application methodology:

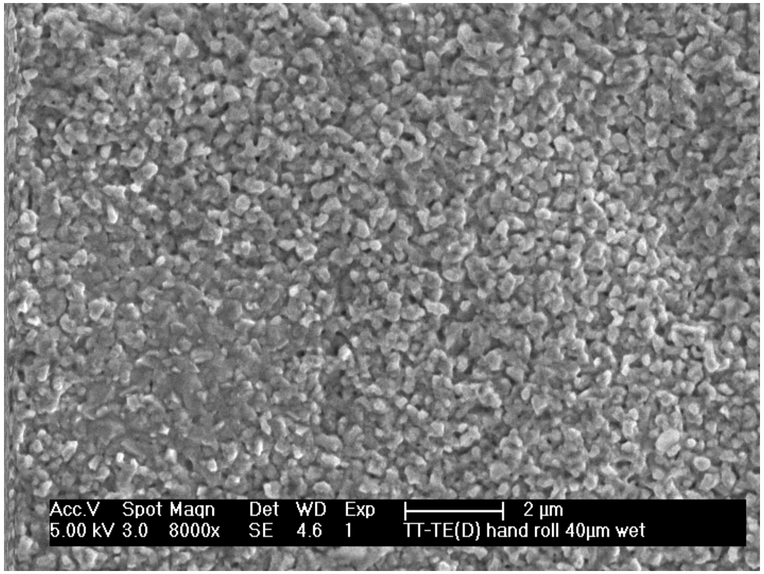
- **Substrate: Inconel (625, 718, 740) stainless steel (non-sand blasted)**
- **Coating method: hand roll, brush and spray coating**
- **Curing profile: 5 or 10 °C/min up to 750 °C - 2 hours**

The Coatings

1. Very high absorptance (>95%)
2. High thermal stability (>1000 hr at 750 °C)
3. Excellent adhesion
4. No corrosion

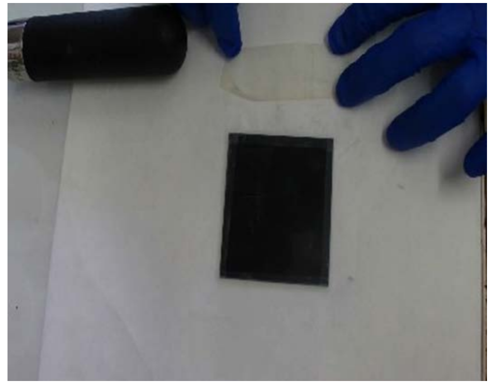
SEM of the coatings after curing



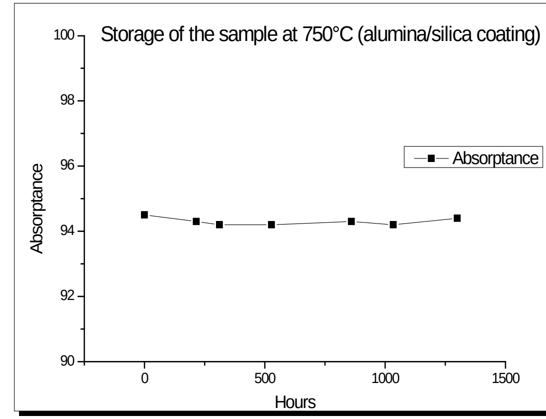


Research, Development and Implementation

Making the formulation



Adhesion complies with the ASTM standards



Testing the coating at 750 °C for 1300 hours

Coating BrightSource pipes

Receiver was exposed to high temperature of ca. 750 °C.

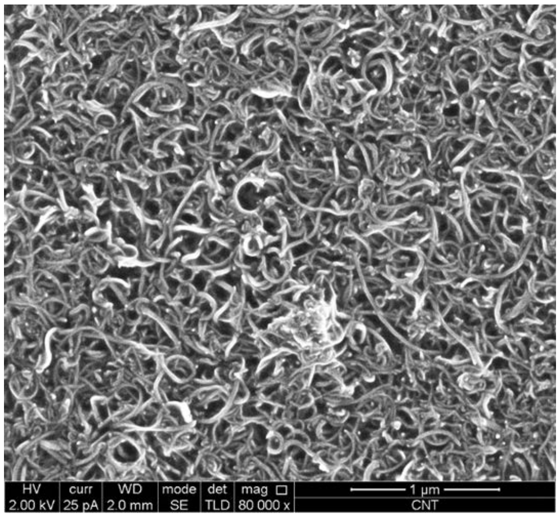
The Products

The Ivenpah CSP in California

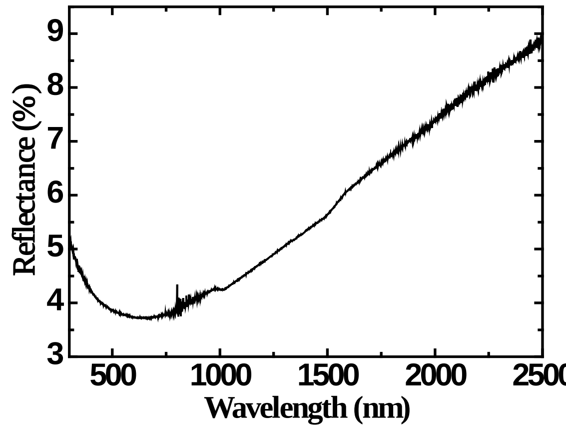
The Stirling receiver of Qnergy operating in Colorado

The Second Generation – Mid Temp Carbon Nanotubes (CNTs)

Carbon nanotubes – the most absorbing material

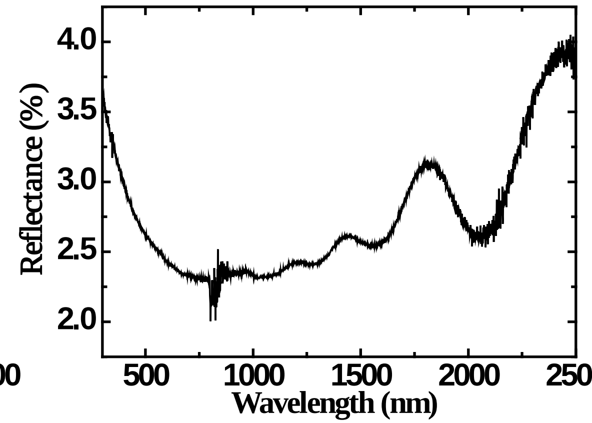


CNT/Polysiloxane



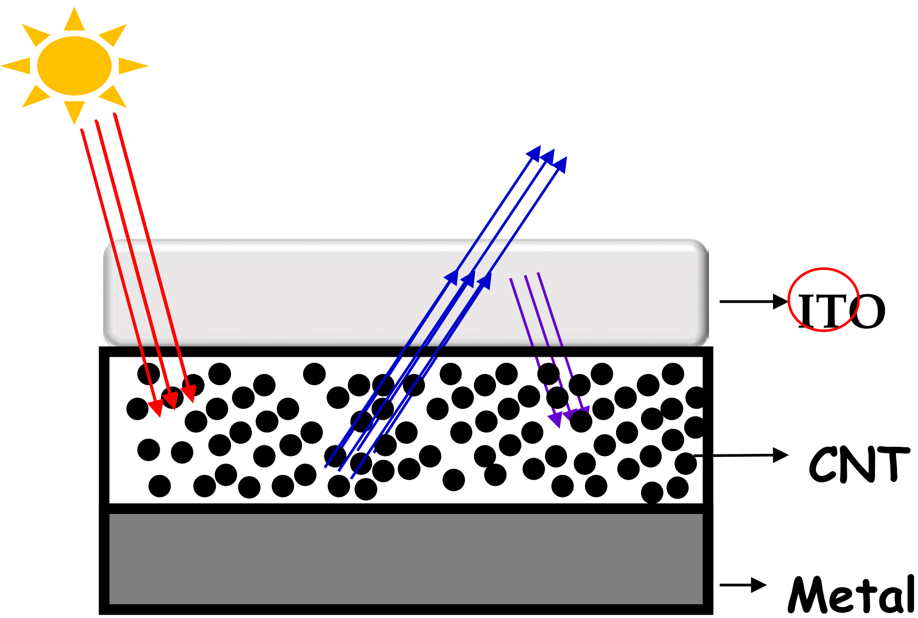
Absorptance: 0.94
Emittance: 0.80

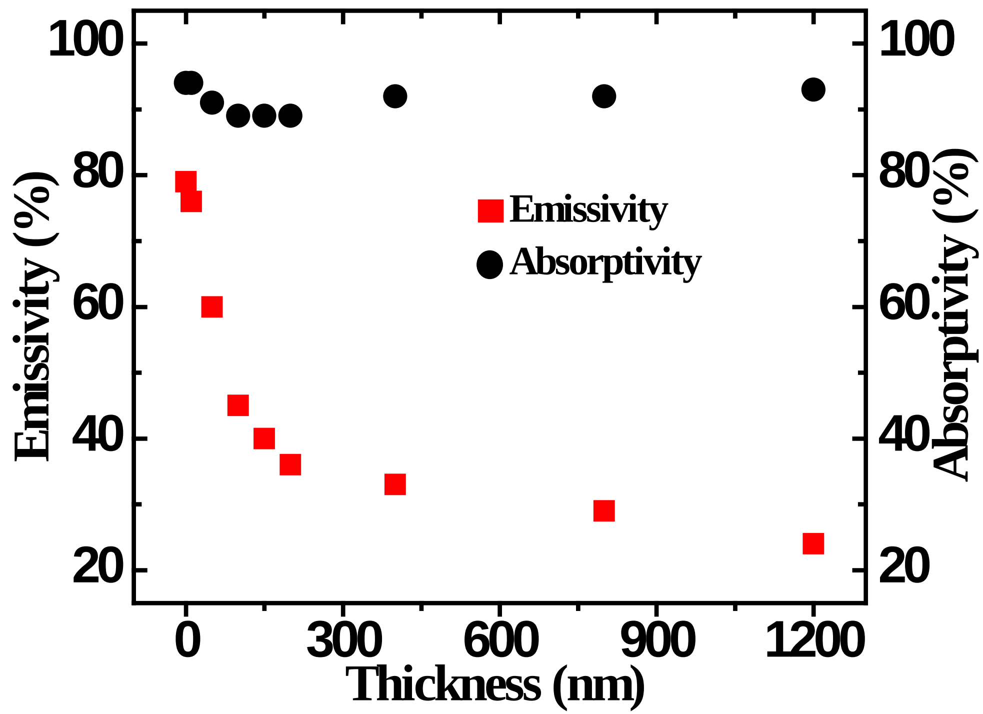
CNT/Alumina-TMS



Absorptance: 0.97
Emittance: 0.88

Reducing the Emissivity





At 1200 nm thickness:

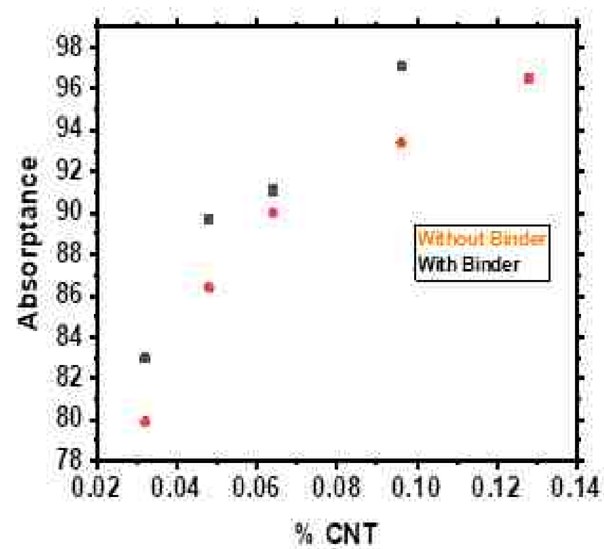
Absorptance: 0.94

Emittance: 0.24

The Problem of the Binder

Sample name	CNT conc.	Binder 10% AlOOH + MTMS (2:1)	α, %	ε
YL-RL-105-1	0.032%	-	79.9	0.29
YL-RL-105-4		+	83.0	0.78
YL-RL-109-4	0.048%	-	86.4	0.33
YL-RL-109-3		+	89.7	0.81
YL-RL-107-2	0.064%	-	90.0	0.32
YL-RL-103-2/1		+	91.1	0.78
YL-RL-109-2	0.096%	-	93.4	0.44
YL-RL-109-1		+	97.1	0.86
YL-RL-107-1	0.128%	-	96.1	0.54
YL-RL-103-1/1		+	96.5	0.81

- The binder is responsible for the high emittance.
- Addition of binders significantly increased the emittance.
- There was no significant change in the absorptance with and without binders.



The Effect Binder Concentration

Layer	Sample name	Binders 10%AlOOH :MTMS (2:1)	Short Multi-Wall CNT (Cheaptube) Outer Ø: 10-20 nm Length: 0.5-2.0 um			Multi-Wall CNT COOH (CheCharboxylated) Outer Ø: >50 nm Length: 10-20 um		
			α	ε	Adhesion	α	ε	Adhesion
Two layers	YL-RL-111/112-5	Binders (1:8.4)	91.5	0.61	Good Adhesion	94.0	0.60	Partially Adhesion
	YL-RL-111/112-6	Binders (1:4)	92.8	0.44	No Adhesion	95.6	0.48	No Adhesion
	YL-RL-111/112-7	Binders (1:2)	93.9	0.43	No Adhesion	93.4	0.42	No Adhesion
	YL-RL-111/112-8	Binders (1:1)	93.0	0.36	No Adhesion	93.1	0.38	Almost good adhesion

The Effect Binder Type and ITO

Sample name	Layer	Separate annealing for each layer	Separate annealing for each layer		
			α, %	ε	Adhesion
YL-RL-121-1	1-st	CNT (w/o binder)	94.4	0.37	no
	2-nd	ITO + Al-BEAA	80.9	0.32	no
YL-RL-121-4	1-st	CNT + binder	94.2	0.45	no
	2-nd	ITO + Al-BEAA	86.9	0.41	no
YL-RL-121-2	1-st	CNT (w/o binder)	94.0	0.40	no
	2-nd	ITO + Al-DBEAA	80.9	0.24	no
YL-RL-121-5	1-st	CNT + binder	92.6	0.41	no
	2-nd	ITO + Al-DBEAA	62.9	0.57	no
YL-RL-121-3	1-st	CNT (w/o binder)	92.9	0.35	no
	2-nd	ITO + Tyzor AA	75.3	0.49	Self-peeled coating
YL-RL-121-6	1-st	CNT + binder	92.5	0.41	no
	2-nd	ITO + Tyzor AA	89.5	0.74	no

Solvent-Based Binder

Sample name	CNT*:Binder ratio	α	ε	Adhesion
YL-RL-130-1	1:6**	81.5	0.25	Good
YL-RL-130-2	1:3	82.4	0.22	Good
YL-RL-130-3	1:1.5	86.2	0.23	Almost good
YL-RL-130-4	1:0.75	88.0	0.24	No
YL-RL-130-0	1:0	0.87	0.24	No

Conclusions and Perspectives

- ✓ Carbon nanotubes can be used very efficiently for non-selective coatings up to 350 °C (in air) and >500 °C in vacuum.
- ✓ Emissivity can be reduced by adding a second layer of transparent conducting materials, e.g., ITO.
- ✓ The binder in the CNT layer is responsible for the high emittance.
- ✓ More to come…