Solar-Selective Absorbers using Sub-Wavelength Gratings

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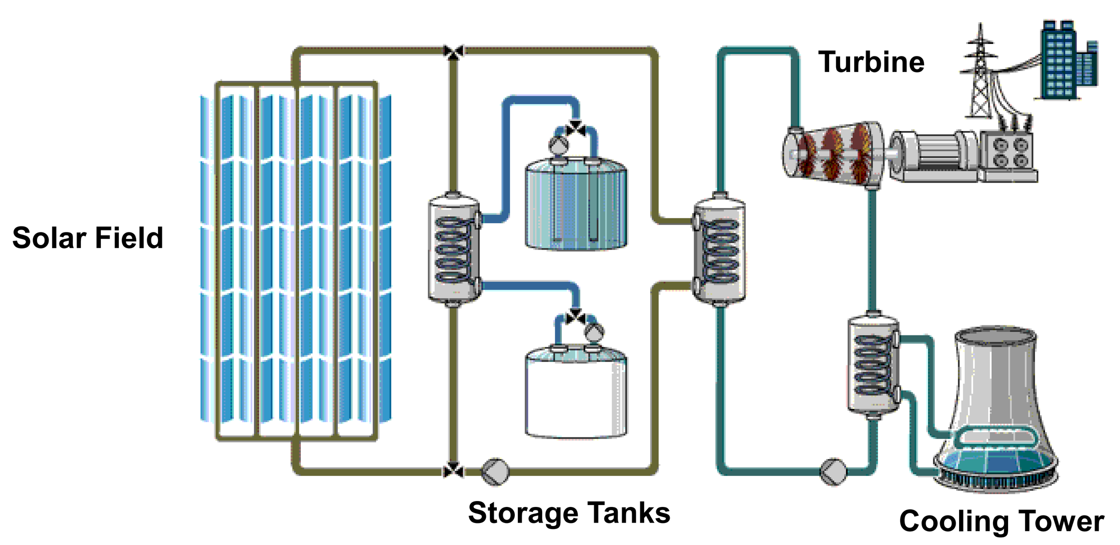
Introduction to Concentrated Solar Thermal (CST)

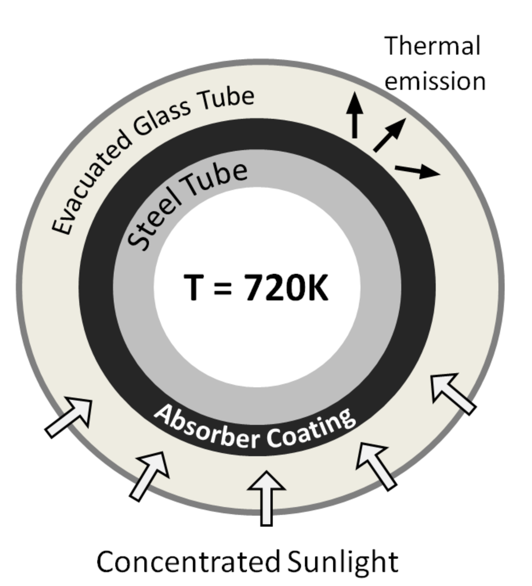
In the **trough configuration**, sunlight is concentrated by parabolic mirrors onto a heat collection element (HCE). The HCE is an absorber tube which runs along the focal point of the trough. The absorbed heat can be stored for several hours in thermal storage tanks. The heat can then be converted into steam to drive a turbine and generate electrical power.



Advantages of CST:

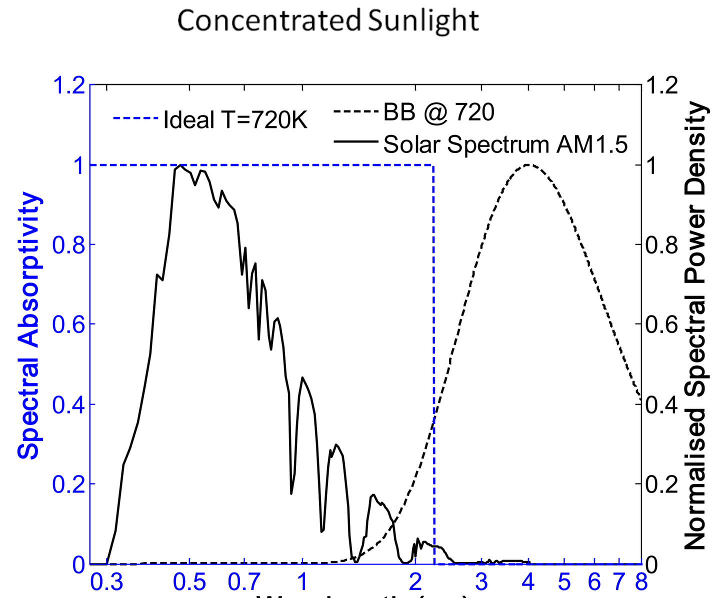
- Converts the **full spectrum** of solar radiation into heat.
- **Storage** capacity → High capacity factor (>40%)
- **Cost- effective**
- Lifetime > 20 years
- Effective for **large scale** generation (>50MW)
- Can supply steam for an industrial process or heating
- Can be used to **retrofit** an existing fossil fuel fired power plant

Optimizing a Solar-Selective Absorber



The heat collection element or absorber tube is coated with a solar-selective absorber which has two functions:

- **Maximize** the **solar absorptivity**
- **Minimize thermal emission** from its surface



Solar Spectrum (AM1.5) and black body (BB) radiation at 720K have little spectral overlap.
→ **Spectral Selectivity**

Ideal absorber

- Absorptivity α**=1** for $\lambda<\lambda_c=2.24\mu m$
- Emissivity ε**=0** for $\lambda>\lambda_c=2.24\mu m$

Acknowledgment
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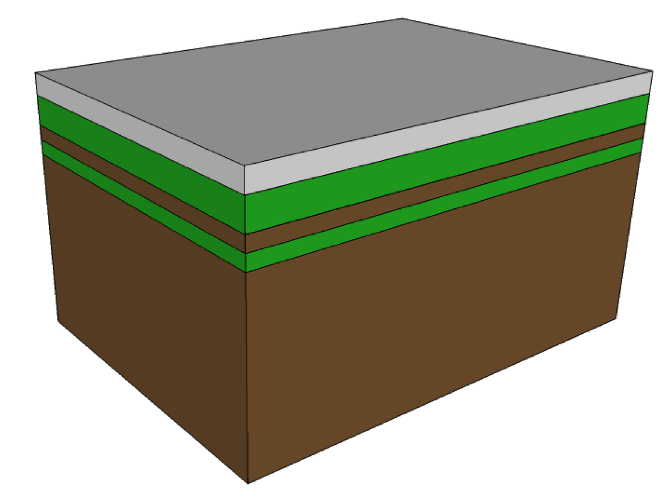
References

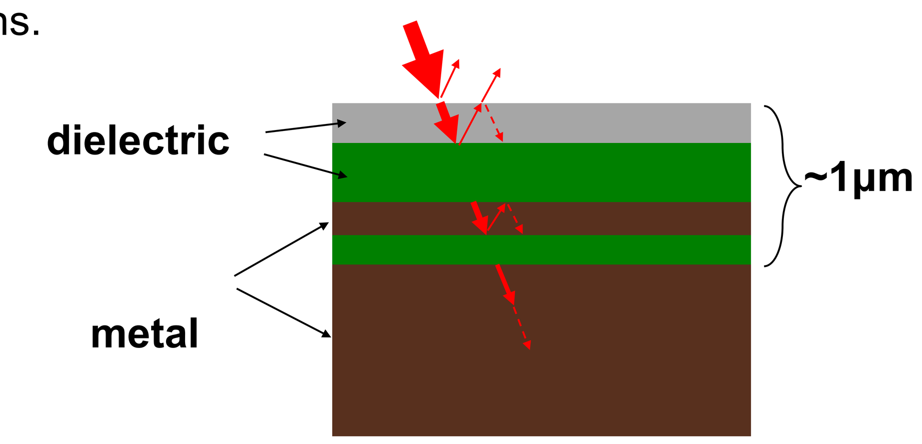
N.P. Sergeant et. al., *Design of wide-angle solar-selective absorbers using aperiodic metal-dielectric stacks*, **submitted**
N.P. Sergeant et. al., *Design of selective coatings for solar thermal applications using sub-wavelength metal-dielectric structures*, **Proc. SPIE Vol. 7410, 74100C (2009)**
N.P. Sergeant et. al., *Solar Selective Absorbers using coated V-grooved Sub-Wavelength Gratings*, **in preparation**

Metal-Dielectric Stacks on Planar Substrate



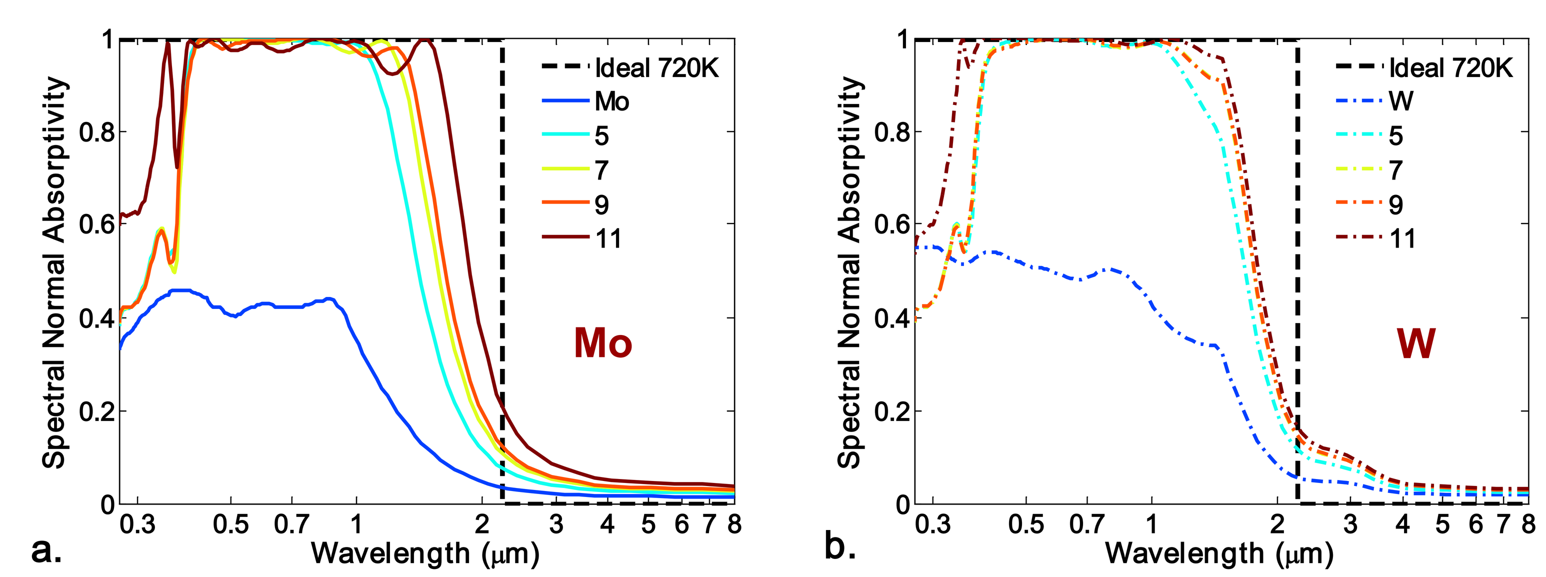
Interference Effects

When light is impinging on a metal-dielectric stack, it is reflected and transmitted at every interface. The metallic absorbing layers are spaced by dielectric layers creating constructive interference and enhancing absorption at specific wavelengths.



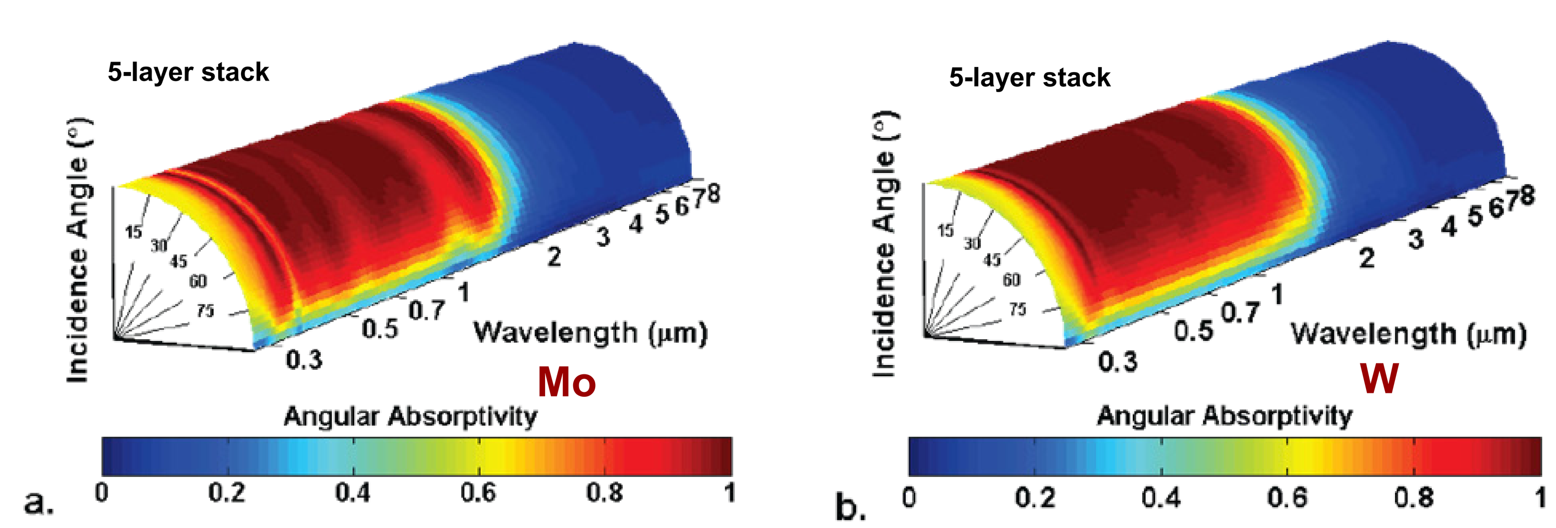
Simulation Results

We simulated stacks using the transfer-matrix method and optimized them with a **needle optimization** technique. We used **W** and **Mo** as metals, and $\mathbf{MgF_2}$ and $\mathbf{TiO_2}$ as the dielectric spacer layers. Layer thicknesses vary from 5 to 100nm.

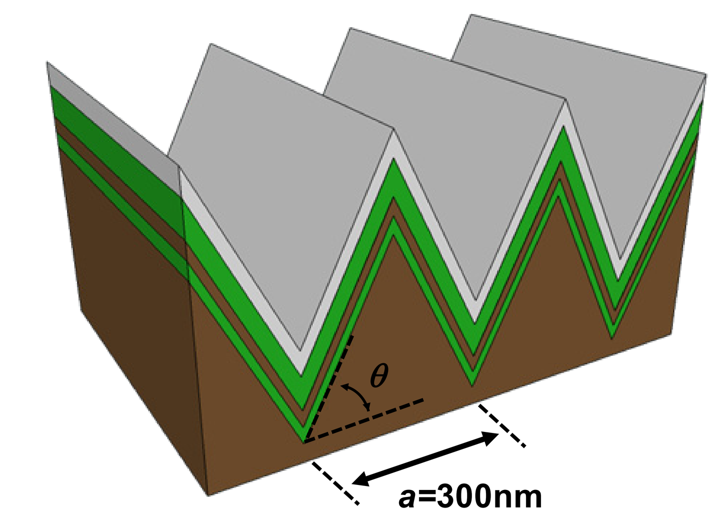


Angular Dependence

The metal-dielectric stacks are **wide angular** selective absorbers.



Metal-Dielectric Stacks on V-grooved Substrate



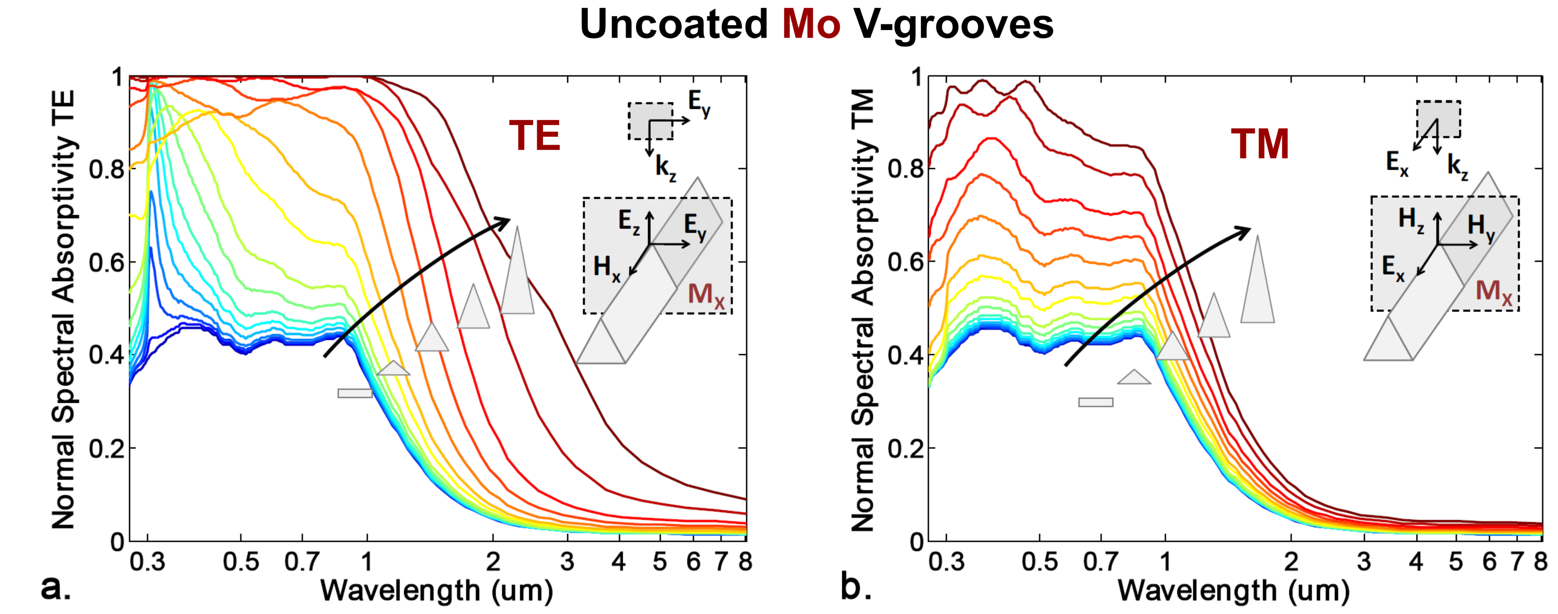
Impedance Matching and Interference Effects

A sub-wavelength grating (SWG) provides an impedance matching mechanism, since the refractive index changes gradually from air to that of the bare metal. This enhances absorption for wavelengths of the order of the grating. Since the V-grooves are coated with a metal-dielectric stack, interference effects are also governing the spectral behavior.

Simulation Results

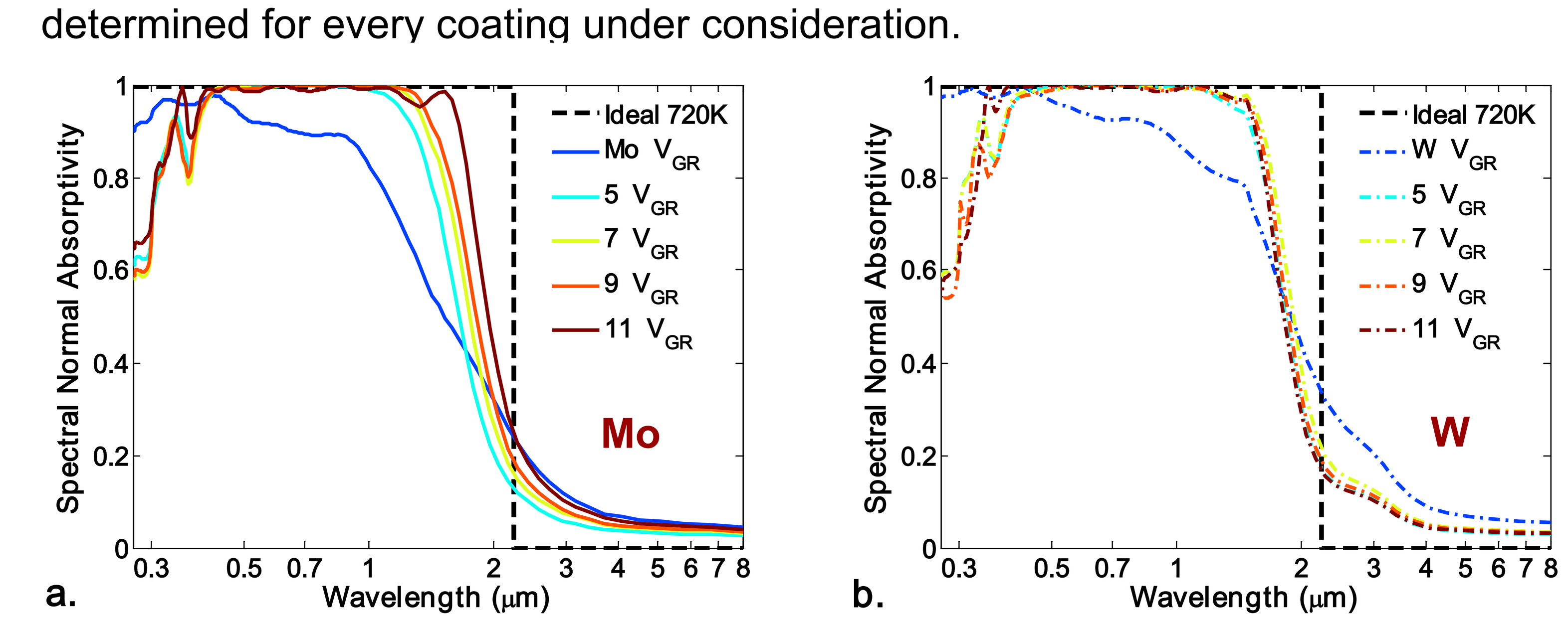
We simulated coated V-groove gratings using **RCWA**.

Uncoated Mo V-grooves



Optimal Coated V-grooves

The period *a*=300nm was kept constant and the optimal V-groove angle θ was determined for every coating under consideration.



Conclusion

Optimal coatings for **planar geometry** were modeled to have a **thermal emissivity <7%** at 720K while **absorbing >94%** of the incident light .
The **coated sub-wavelength V-groove gratings** can further enhance **solar absorptivity to >95%** while still keeping **thermal emissivity <7%.** These structures are predicted to have excellent spectral selectivity and thus good candidates for next generation solar thermal absorbers.