Plasma-deposited W/SiCH Nanocomposite Multilayers as High Temperature Air-Stable Solar Selective Absorber Coatings for Concentrated Solar Power Receivers

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High Temperature Air-stable Solar Selective Absorber Coatings for CSP receivers

All solar receivers need **high optical performance**

- **High solar absorptance** α_S to increase absorbed solar input $\alpha_S CI$
- **Low thermal emittance** $\varepsilon(T)$ to limit radiative thermal losses $\varepsilon(T)\sigma T^4$

→ High solar-to-heat conversion (heliothermal) efficiency

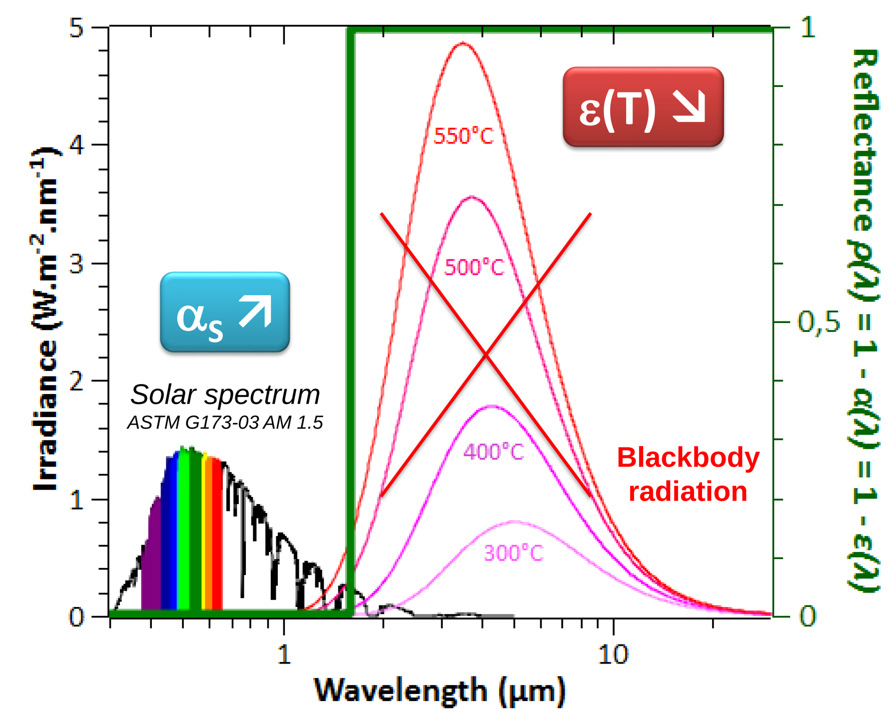
$$\eta_{heliotherm} \propto \alpha_S - \frac{\varepsilon(T)\cdot\sigma T^4}{C\cdot I}$$

→ Metallic pipes covered with **Solar Selective Absorber Coatings**

New generations also need **high thermal stability/durability in air**
i.e. **resistance or adaptation for long durations** to:

- high temperatures > 500°C → oxidation, atomic diffusion, etc.
- high thermomechanical stress & thermal shocks → fatigue, creep, etc.
- concentrated solar irradiance

Solar selective absorber coatings



For an ideal solar receiver, **spectral reflectance** $\rho(\lambda)$

- is low in solar range
- is high in IR range
- increases steeply at $\lambda_{cutoff} \approx 1.5 - 2$ µm (depends on T)

Complex behavior only achievable using **metal-ceramic coatings** (composites, multilayers)

NanoPlaST project: W-SiCH nanocomposite absorbers

"**Nano**composite **Pla**sma coatings for concentrated **S**olar **T**hermal energy conversion" (2019-2024)

This project funded by the French National Agency for Research (ANR) aims at developing **new nanocomposite absorber coatings** for CSP synthesized by vacuum plasma techniques, including **durability studies in representative working conditions**. Visit nanoplast-project.cnrs.fr

Partners and synergy:

- ***PROMES (coordinator)** specializes in CSP processes & materials, solar aging, thermo-optical characterization*
- ***PROMES, ICCF** and **HEF-IREIS** develop plasma processes & coatings*
- ***IMN** has expertise in optical and nanomaterials characterization*
- ***CEMHTI** has expertise in high temperature materials characterization*

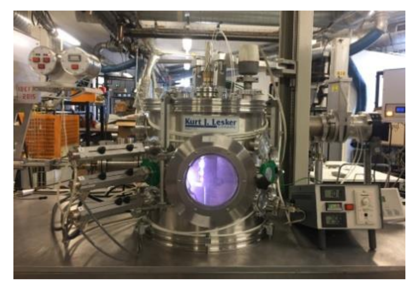
Project objective

Solar selective absorber coating

- **W-SiCH nanocomposite absorber**
  - SiCH absorptive ceramic
  - W refractory metal
- Protective antireflective coating (ARC)

→ **High optical performance**
→ **High thermal stability/durability in air**

Deposition technique

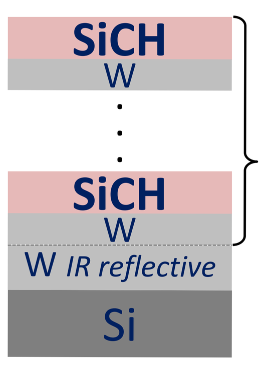


Vacuum plasma reactor

- SiCH: Ar/Si$(CH_3)_4$ PECVD
- W: PVD (sputtering)

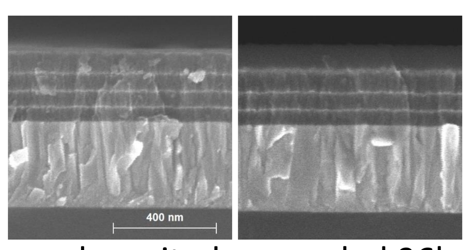
Investigated methods to synthesize W-SiCH nanocomposites
Option 1. Annealing of W/SiCH periodic multibilayer coatings
Option 2. Reactive sputtering of W target in Ar/Si$(CH_3)_4$ plasma

Optical Performance of W/SiCH and W-SiCH multilayer absorbers



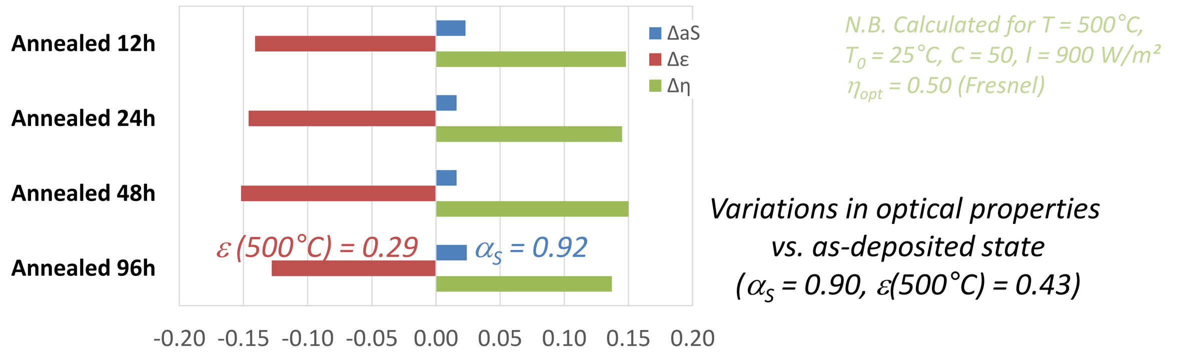
***Option 1.* Annealing of W/SiCH periodic multibilayer coatings**

4 W/SiCH bilayers annealed
@ 500°C in air for 12h to 96h



as-deposited **1 at.% O** — annealed 96h **12 at.% O**

- **Composition**: %O ↗ + W diffusion *(RBS, EDS, XPS, FTIR)*
- **Optical performance**: α_S ↗, $\varepsilon(500°C)$ ↘↘, $\eta_{heliotherm}$ ↗↗



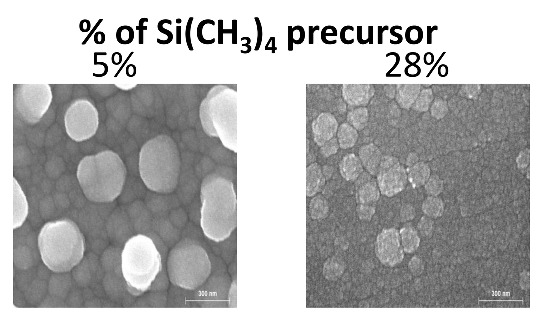
N.B. Calculated for T = 500°C, T_0 = 25°C, C = 50, I = 900 W/m², η_{Carnot} = 0.50 (Fresnel)

Variations in optical properties vs. as-deposited state (α_S = 0.90, $\varepsilon(500°C)$ = 0.43)

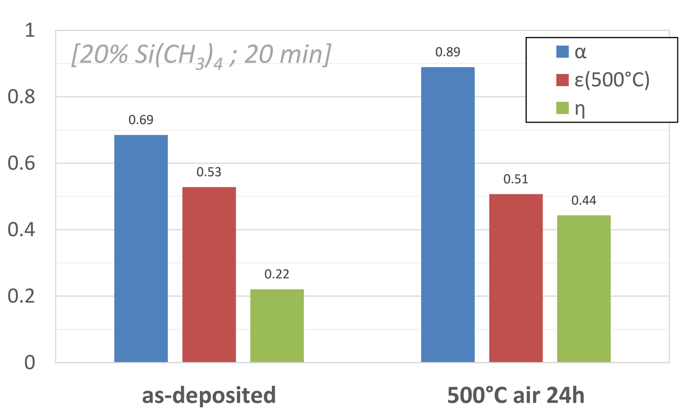
- Short annealing strongly improves optical performance before it stabilizes → **curing step**
- Oxidation gives protective & low-n optical effects

Option 2.* Direct synthesis of W-SiCH nanocomposites *by microwave-assisted reactive sputtering

[D. Ngoue, PhD thesis U. Perpignan, 2021]



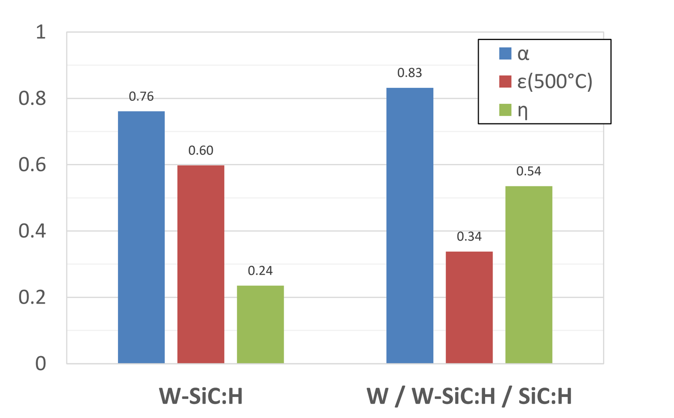
Nanograins containing W *(EDS, KFM)*
% Si$(CH_3)_4$ ↗ ⇔ size of nanograins ↘



- **Spectrally selective behavior** if > 20% of precursor
- **Thermal annealing** @ 500°C in air → further improvement of optical performance (α_S up to 0.92)

Towards nanocomposite multilayer coatings

First complete architecture (not optimized)



W IR-refl. sublayer + SiCH antirefl. top layer
→ further improvement of optical performance

Next generation

Complementary developments may even further improve performance

- **Metallic support** (IR-reflective, adapted to CSP)
- **Curing step** (thermal annealing in air)
- **Design optimization** by optical simulation (architecture and layer thicknesses)

Conclusions and further work

- Plasma deposited (W, SiCH) solar selective absorber coatings with good optical performance and thermal stability in air at 500°C were developed for CSP technologies.
- W-SiCH nanocomposite absorber layers can be synthesized from thermal annealing of W/SiCH multilayer absorbers or directly by microwave-assisted sputtering.
- Their insertion in multilayers with W IR-reflective sublayer and SiCH antireflective top layer lead to enhanced optical performance.
- Further developments are underway to further improve their optical performance (e.g. metallic support, curing, optical design).

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