A general introduction for the use and needs of TCMs

Functional Glasses

Siracusa, Sicily, January 6-11 2013

D. Lamine, Thin film department

Saint-Gobain Recherche

SAINT-GOBAIN

RECHERCHE

Agenda

- Presentation of Saint-Gobain and Saint-Gobain Recherche
- Introduction / Applications we are addressing with TCM
  - How TCM can functionalize glass ?
  - Physical principles
  - Applications in building and automotive
- Transparent electrodes for active glazing
- Summary

Saint-Gobain, one of the world's top one hundred leading industrial corporations

OPERATIONS IN
64
COUNTRIES

SALES
€42.116bn

Nearly
195,000
EMPLOYEES

2011	€ bn
Sales	42.1
Recurring net income	1.7
Capital expenditure	1.9
Free cash flow	1.4

Saint-Gobain, proud of its history

The origins of a multinational company

17th century — Louis XIV and Colbert decide on an economic recovery plan for France

1665 — Creation of the Manufacture royale des glaces

1688 — Invention of the process of glass poured on a table, Saint-Gobain becomes the undeniable leader

1850-1900 — Saint-Gobain expands into Europe starting up activities in Germany, Italy, Belgium, and Spain

1900-1950 — New markets and new products appear, making Saint-Gobain a diversified Group

1970 — Merger between Pont-à-Mousson and Saint-Gobain

1970-2007 — Refocus on materials with a high technological content and entry into building distribution and plasterboard

Today — Saint-Gobain focuses its strategy on Habitat

SAINT-GOBAIN and Glass

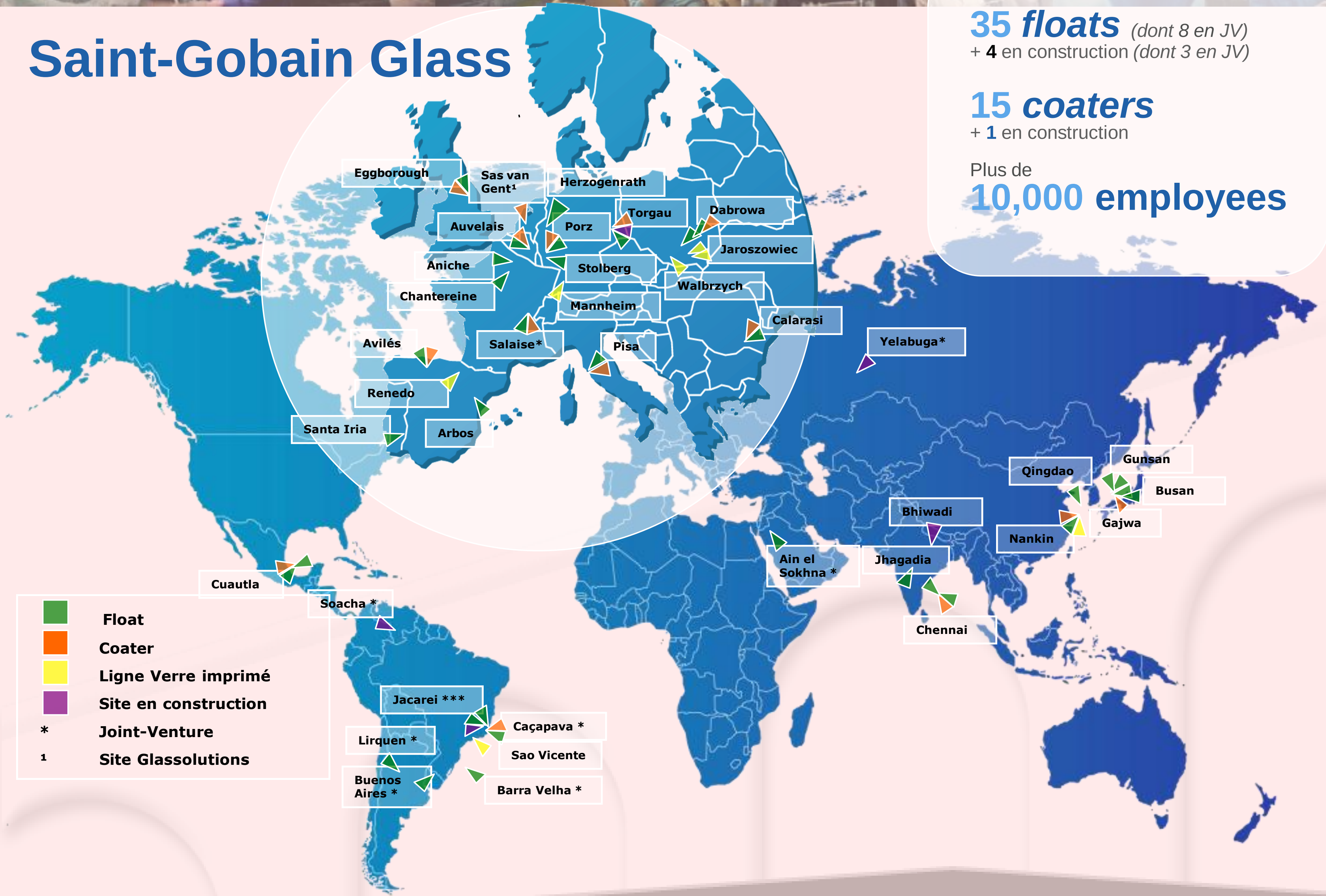
- SAINT-GOBAIN
  - Distribution
  - Innovative materials
    - High performances materials
    - Glass
      - Flat Glass — SAINT-GOBAIN GLASS
      - Transformation For habitat — GLASSOLUTIONS SAINT-GOBAIN
      - Transformation For automotive — SAINT-GOBAIN SEKURIT
      - Solar Energy — SAINT-GOBAIN SOLAR
  - Construction products
  - Packaging

Saint-Gobain Glass

35 floats *(dont 8 en JV)*
+ **4** en construction *(dont 3 en JV)*

15 coaters
+ **1** en construction

Plus de
10,000 employees



Research & Innovation

6 Main R&D centers

3,500 employees

396 patents filed in 2011

12 Research centers and about 100 development units worldwide

1 in 5 Saint-Gobain products sold today was developed in the last five years

R&D open to the outside world

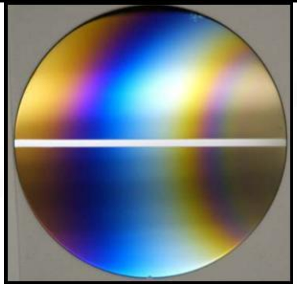
- Partnerships with start-ups: NOVA External Venturing
- University partnerships

SGR in charge of key competencies

GLASS

- Products: Flat glass, fibers, bottles, glass ceramics…
- Process: Melting, forming, spinning
- Driver: Emission reduction, energy consumption

SURFACES



- Products: Building, automotive, Photovoltaic, lighting
- Process: CVD, PVD, sol gel
- Driver: Building energy performance, renewable energy

BUILDING MATERIALS

- Products: Polymers, gypsum, cement, mortar
- Process: Drying, curing, coating
- Driver: Cost reduction, energy saving

HABITAT

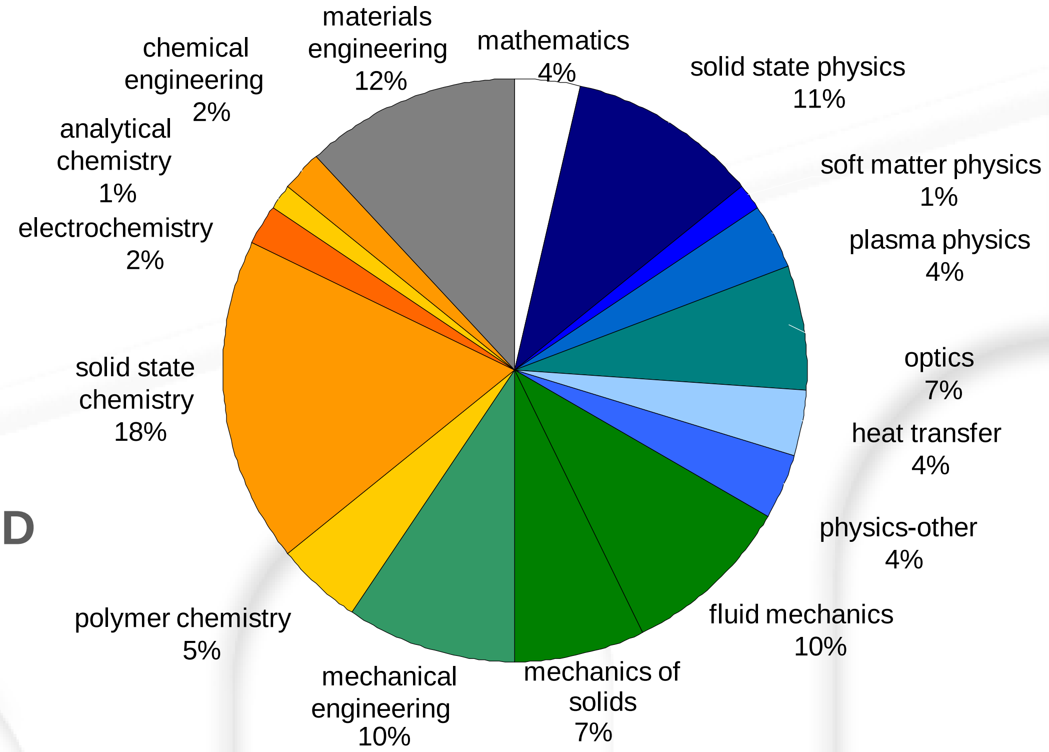
- Products: Virtual reality
- Driver: Thermal efficiency and comfort

SGR: Place for exchanges

Attractive place for talented researchers

- Scientific disciplines represented at SGR

- **465** employees
- **36** years old average
- **37%** of women
- **19** nationalities
- **83%** of researchers with PhD
- **86** patents in 2011



Agenda

- **Presentation of Saint-Gobain and Saint-Gobain Recherche**
- **Introduction / Applications we are addressing with TCM**
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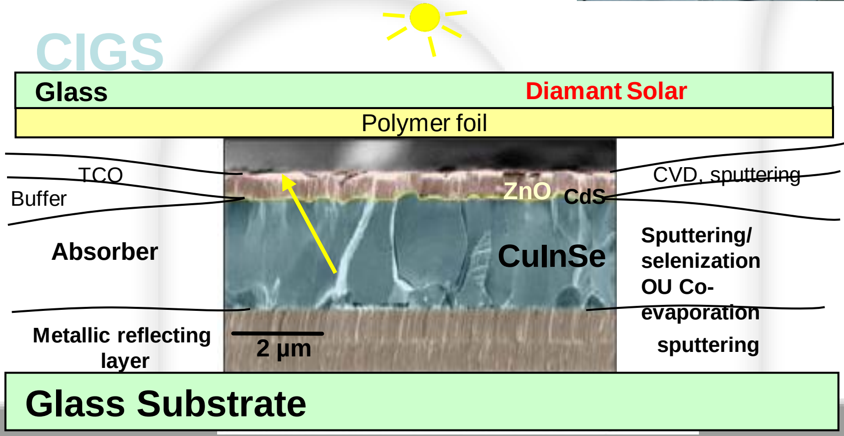
Transparent conductive materials as a way to improve…

- Heat preservation

- Sun management

- Safety and Comfort

- Transparent electrodes…

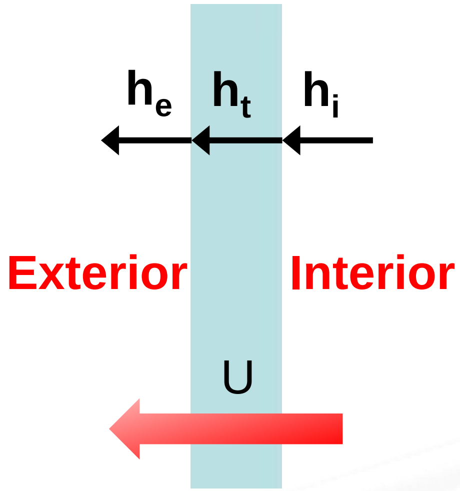


Windows reinforced thermal insulation: principles

Thermal transfert coefficient U

Heat quantity passing through a surface unit for a ΔT of 1K

$$\frac{1}{U} = \frac{1}{h_e} + \frac{1}{h_t} + \frac{1}{h_i} \qquad \text{(EN 00673)}$$



. **h_e** : External superficial thermal exchange coefficient (convective, depend on wind) around $\underline{20\ W.m^{-2}.K^{-1}}$

. **h_i** : Internal superficial thermal exchange coefficient , (convective and radiative)

$h_i = h_r + h_{conv}$

. h_{conv} is around $\underline{4\ W.m^{-2}.K^{-1}}$

. For bare glass, $h_r \approx \underline{5\ W.m^{-2}.K^{-1}}$

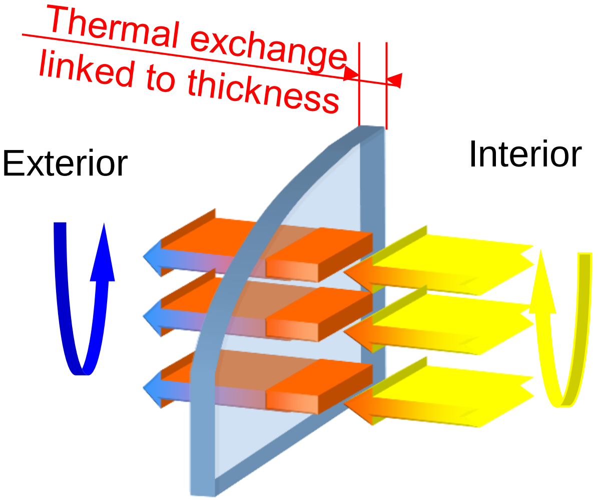
. **h_t** : thermal conductance of the glazing unit. For a sheet of glass of 4 mm thickness , $h_t = \underline{250\ W.m^{-2}.K^{-1}}$

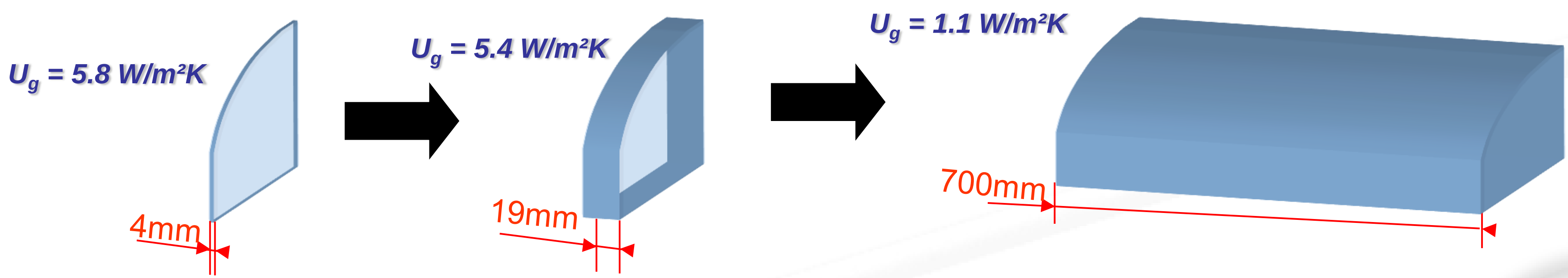
To increase the thermal insulation,
we need to decrease U, and thus h_i and h_t

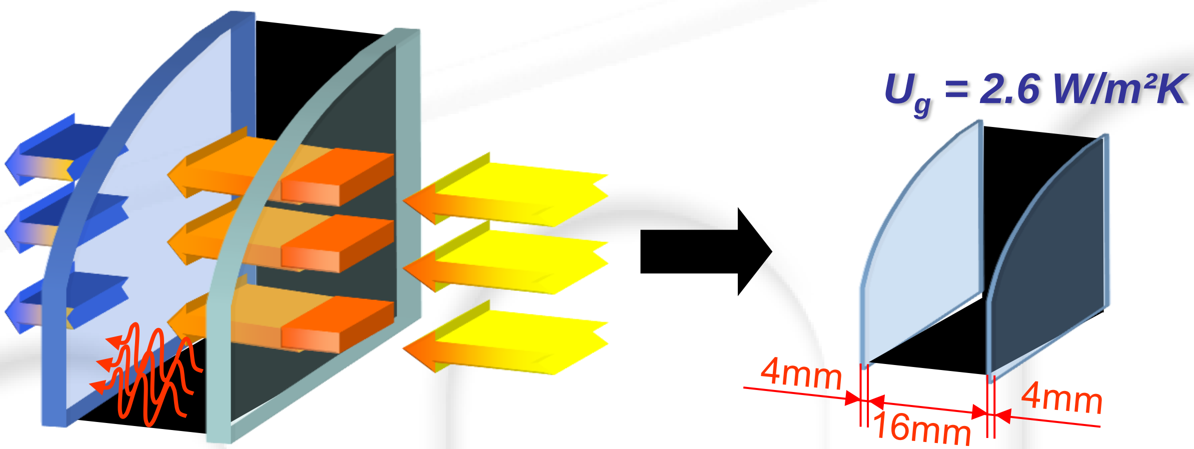
From simple glazing to double glazing

In a **single glazing**, thermal transfers are normalized and linked to the glass thermal conduction:

Insulation is only dependant on glass thickness





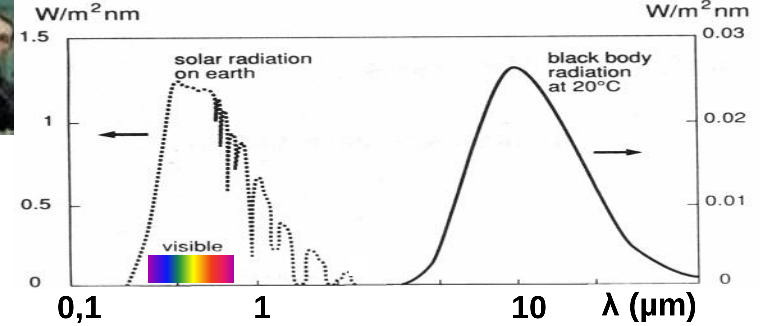


In a **double glazing**, thermal transfers are linked to

→The gas nature

→The gap thickness

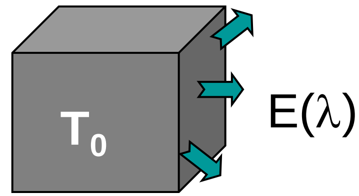
Emissivity

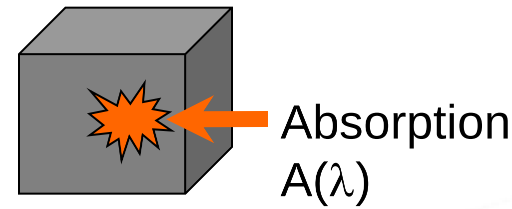


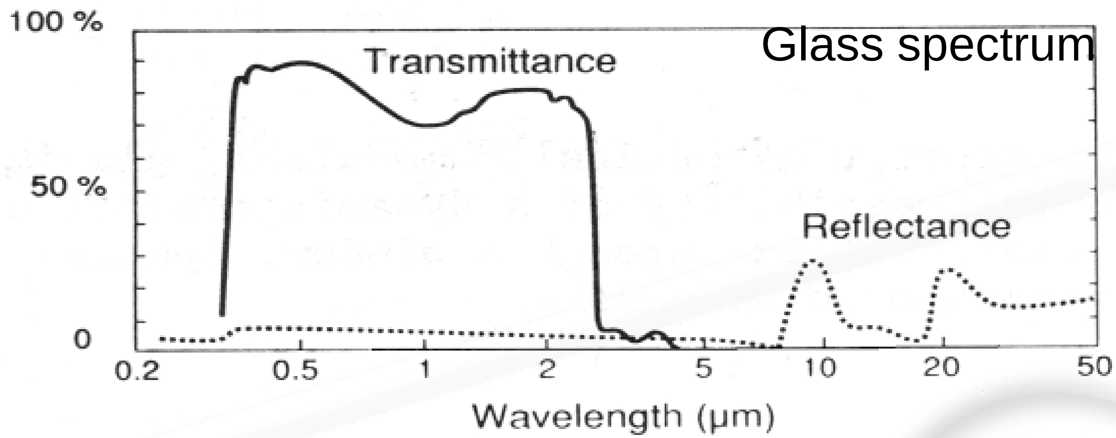
- **Emissivity ε**

  $E(\lambda) = \varepsilon(\lambda) \, . \, E_{BlackBody}(\lambda)$

  Kirchhoff law's : $\varepsilon(\lambda) = A(\lambda)$

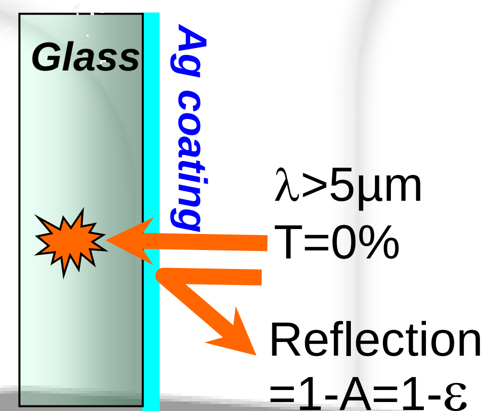






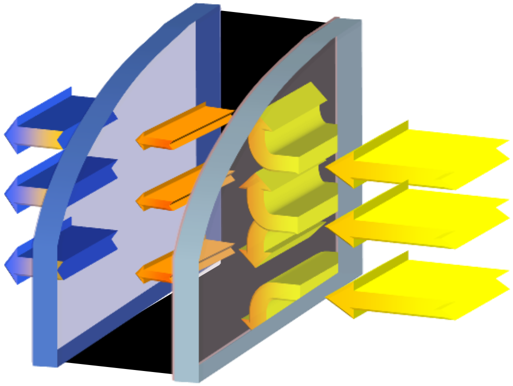
- **Measurement of ε for a coated glass**

  For $\lambda > 5 \mu m$, $T \sim 0 \rightarrow \varepsilon = A = 1 - R$



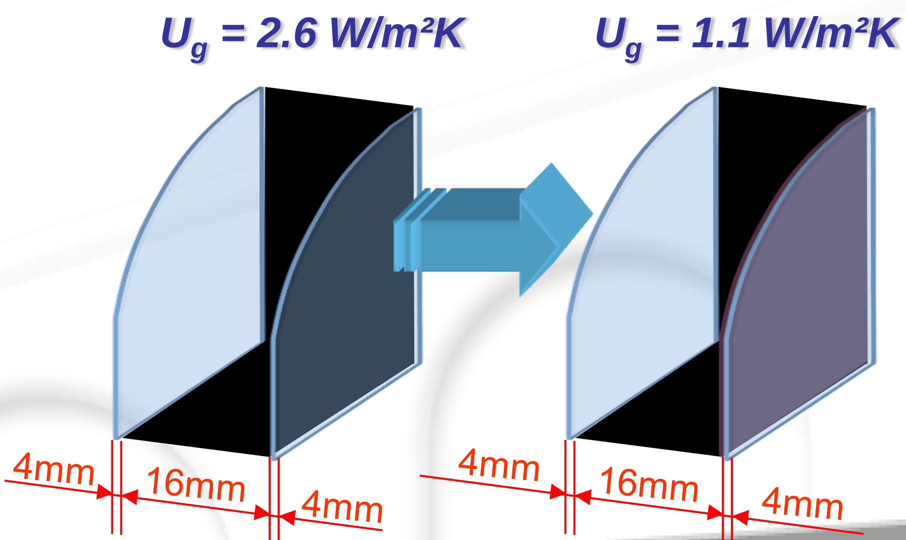
In a bare double glazing, the thermal transfer is related to the radiation at 70%

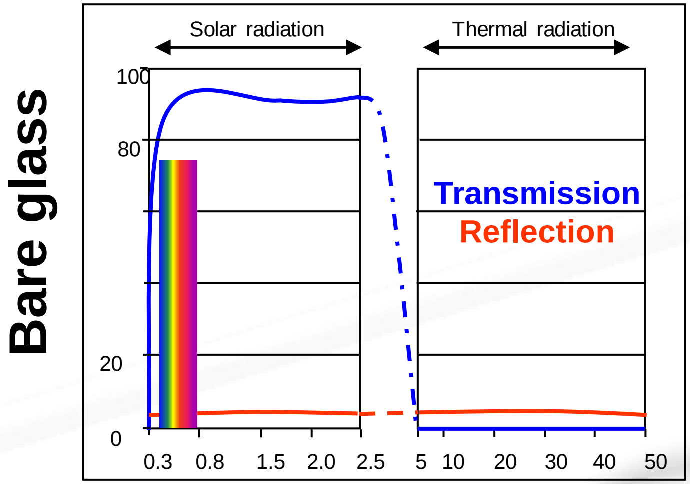
Thermal insulation: low emissivity glazing

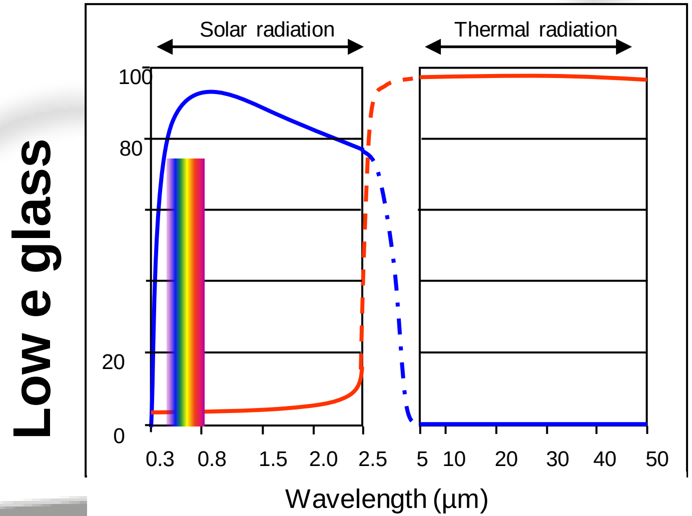


Low emissivity ⇨ lower radiation transfer

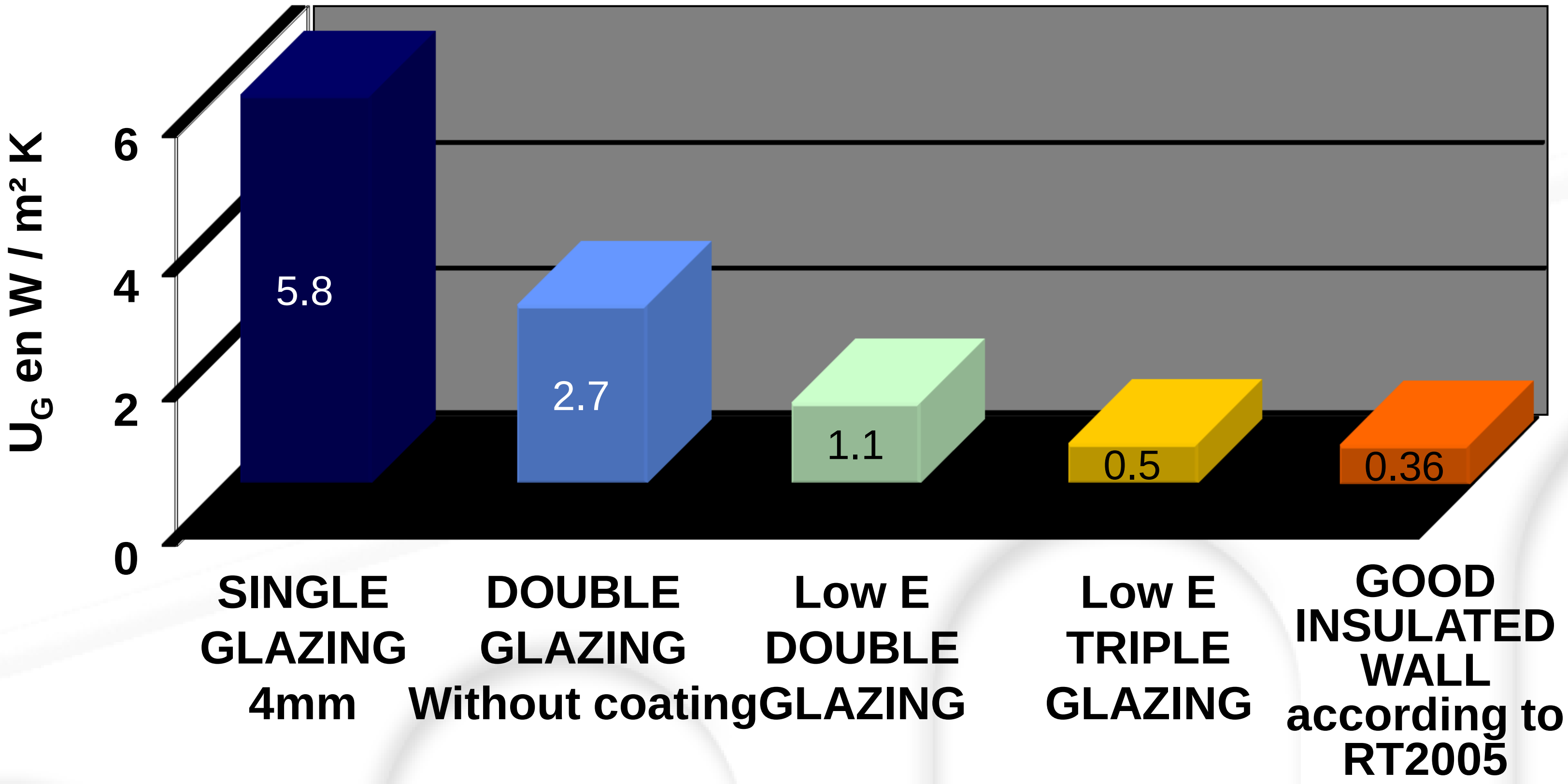
- A **low emissive layer** is added which is reflective in the far IR and highly transparent in the visible







Improvement of thermal insulation of glazing:



Emissivity is leading us back to conductivity, thus to TCMs

At $\lambda > 3$ µm, glass is opaque, thus emissivity $\varepsilon(\lambda) = 1 - R(\lambda)$

- Drude and Maxwell equations give us:

$$n^2 - k^2 = 1 - \frac{\omega_p{}^2 \tau}{\omega(1+\omega^2\tau^2)} \qquad 2nk = \frac{\omega_p{}^2 \tau}{\omega(1+\omega^2\tau^2)}$$

- The reflectivity of a metallic layer is:

$$R = r^2 \frac{\left|1 - \exp(\mathrm{i}\alpha N)\right|^2}{\left|1 - r^2 \exp(\mathrm{i}\alpha N)\right|^2} \qquad r = \frac{n+1+\mathrm{i}k}{n-1+\mathrm{i}k}$$

$$N = n + \mathrm{i}k$$

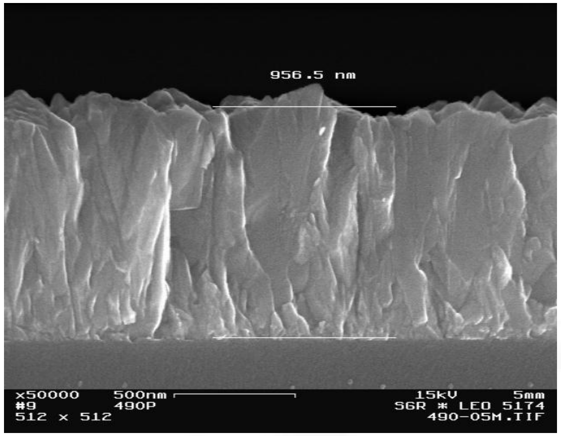
- Finally, with some approximations (over thickness and indexes)

$$R = 1 - \frac{4\varepsilon_0 c}{e} \frac{1}{N_e d\mu} = 1 - 4\varepsilon_0 c \times R/\mathrm{sq}$$

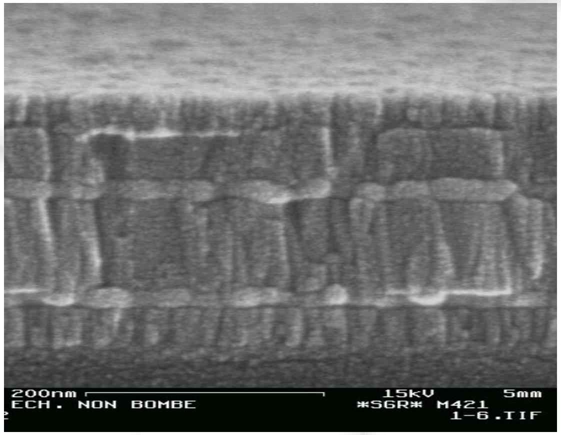
Independent of λ

ε (%) = 1.06×*R*/sq

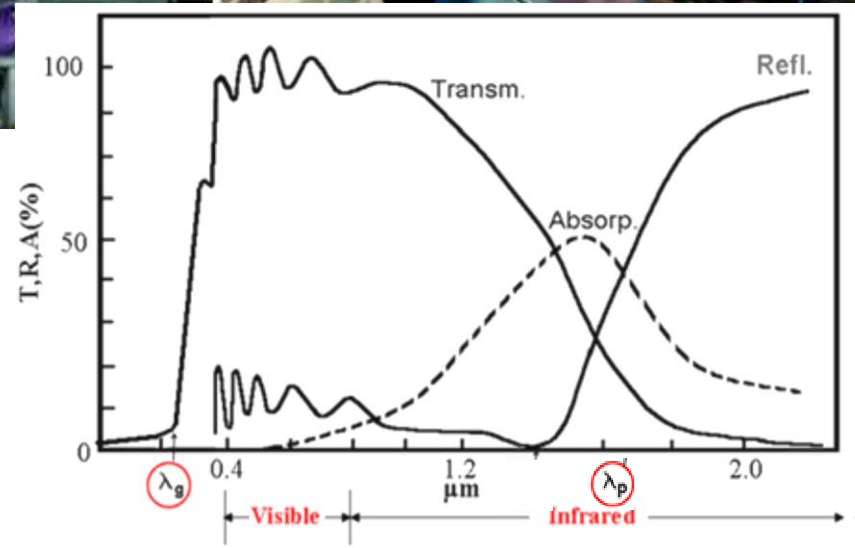
Low e with TCO and metallic TCC



- **Transparent, oxide conductors (TCO)**
  - SnO_2: F, ZnO: Al, In_2O_3:SnO_2 (ITO) ...
  - CVD, PECVD, sputtering, ALD, ...
  - Robust (for some)
  - Relatively easy to coat
  - Hot treatment necessary to achieve low conductivities



- **Transparent coating systems with metallic conductors (TCC)**
  - Ag, Nb, Mo, ..., embedded in an anti-reflective coating system
  - Sputtering
  - Very small, specific resistivity even with a coating on a cold substrate
  - Corrodible



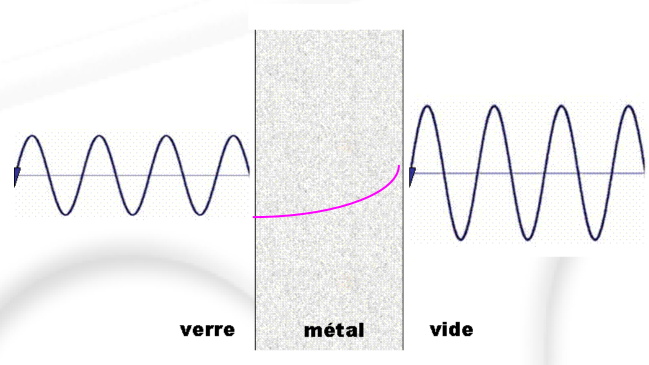
TCO

- n-oxide semiconductor
- Relatively thick layers are necessary in order to increase conductivity
- R/square > 5 ohms

We use the transparency of the TCO when $\omega > \omega_p$ (in the visible) and reflective in the far infrared ($\omega < \omega_p$)

Metallic conductors (TCC)

- High electron density, very good conductivities
- Very thin layers
- High reflectivity: Antireflective interference coatings are required

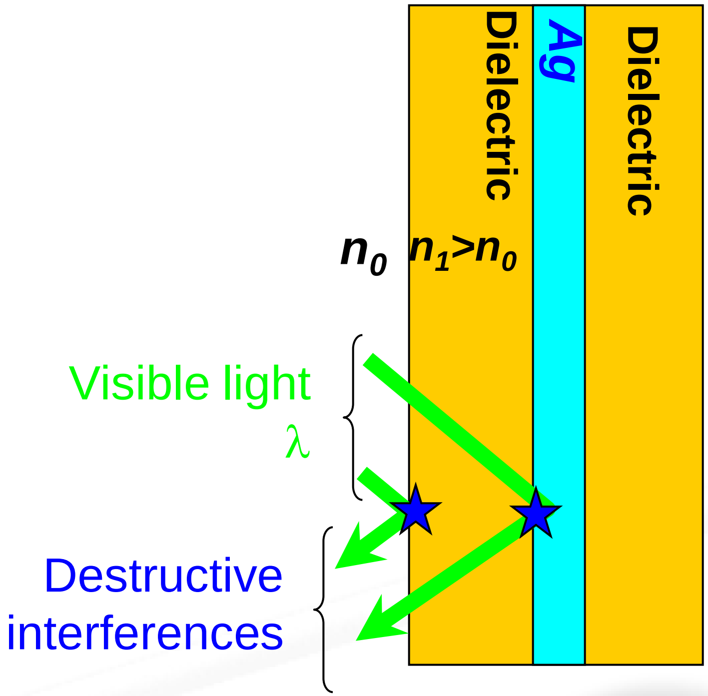


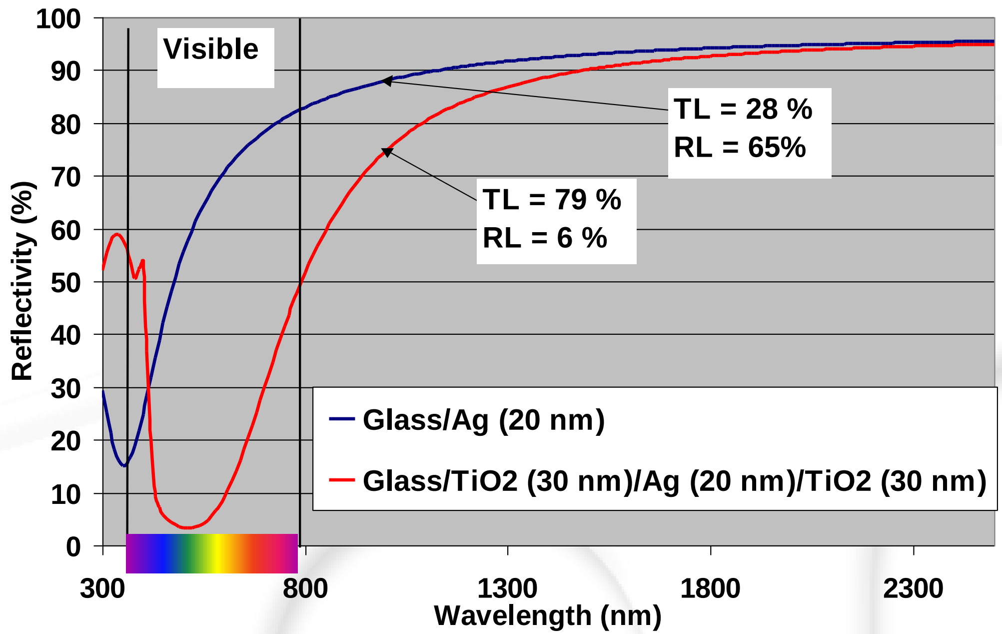
$\omega < \omega_p$, metal is always reflective:
A very thin layer (~skin depth) transmit partially the light.
Finally, we need a metal that transmit more in the visible than in the IR…

Principle of silver thin films IR reflection

For TCC-Ag : Anti-reflection in the visible

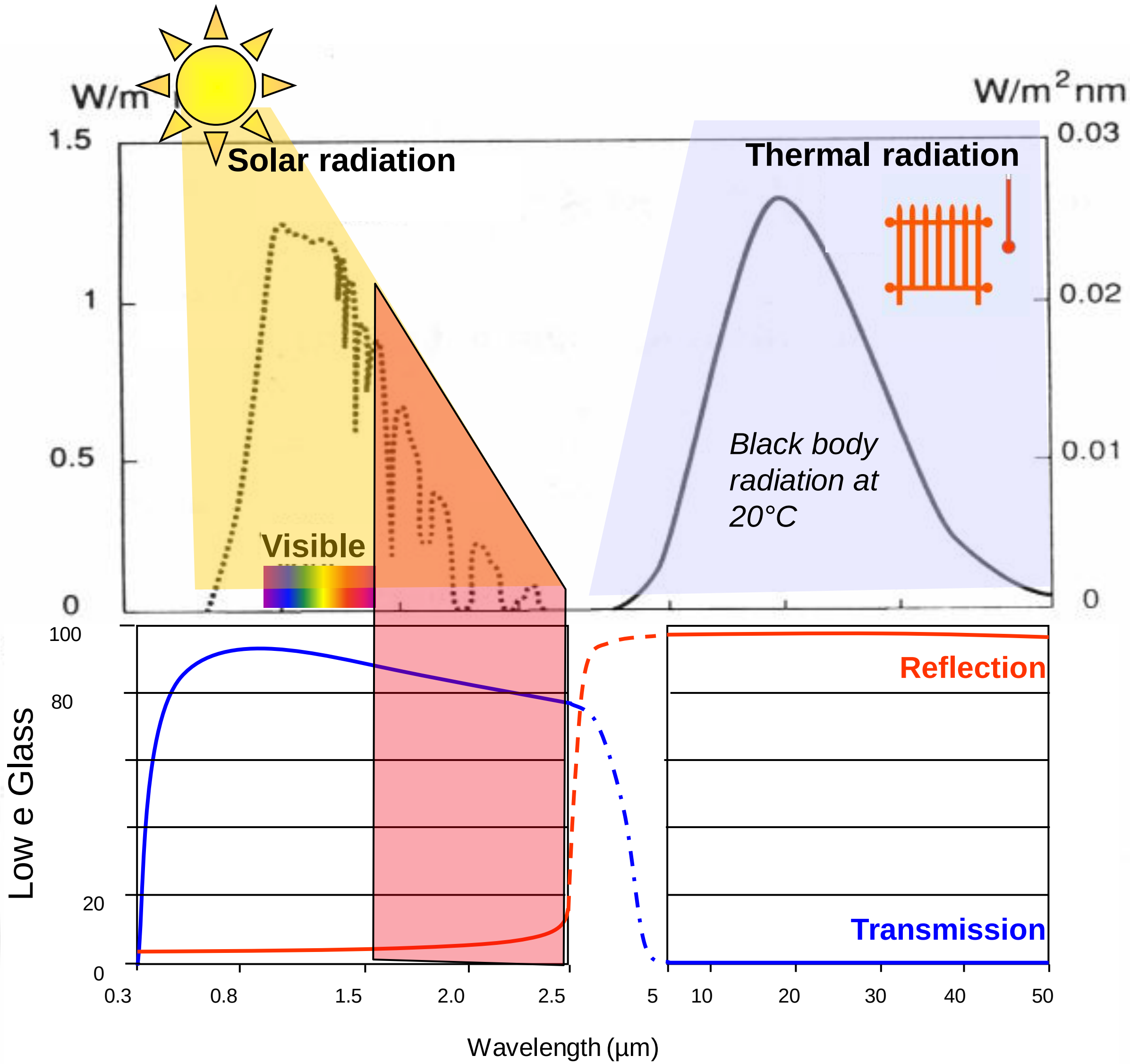
Silver is encapsulated between two dielectric layers

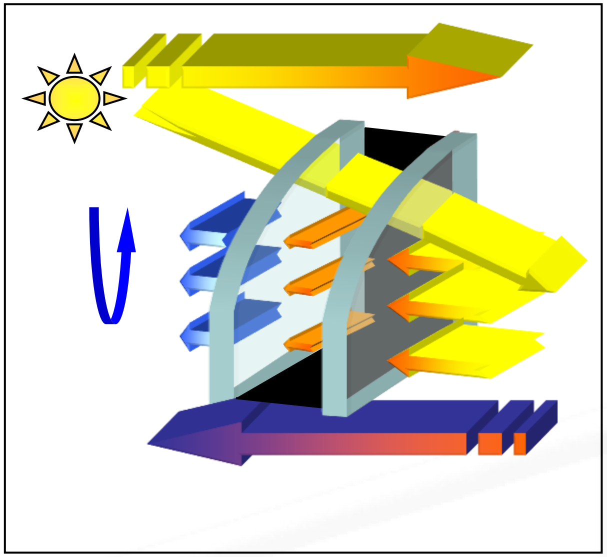




What are the low-e layers requirements?

- **The lowest emissivity as possible**
- **Transparent in the visible + near infrared**

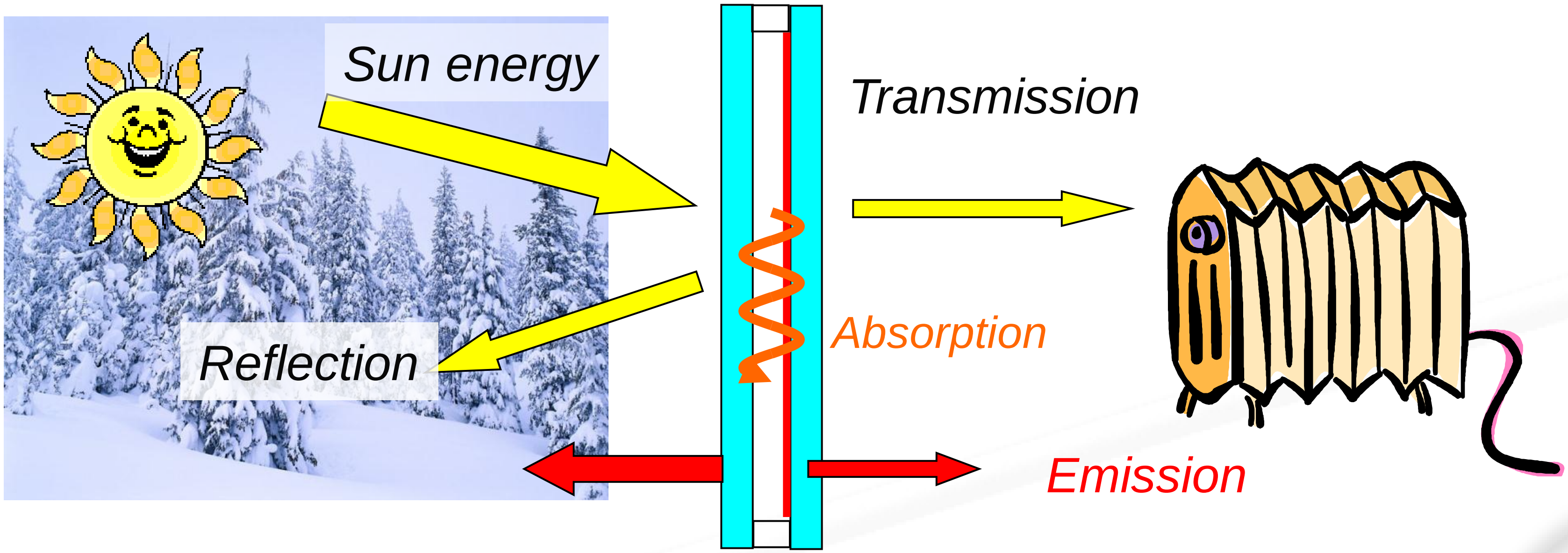




Solar radiation: 45% Near IR

Low emissive glass = transparent in the NIR

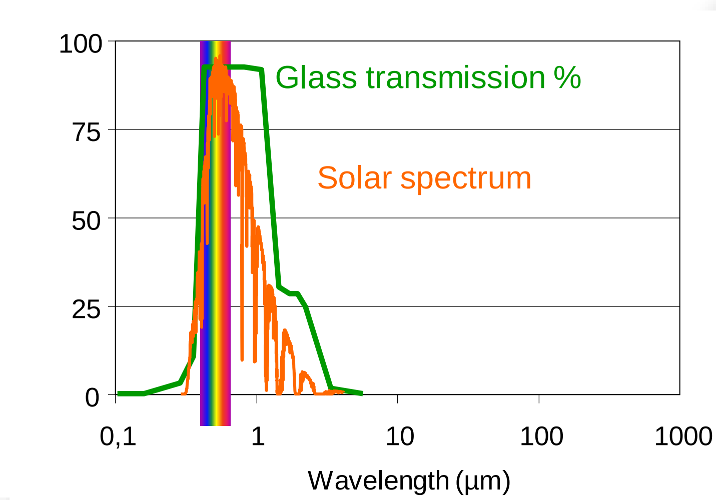
Measuring sun's input energy: the g-value



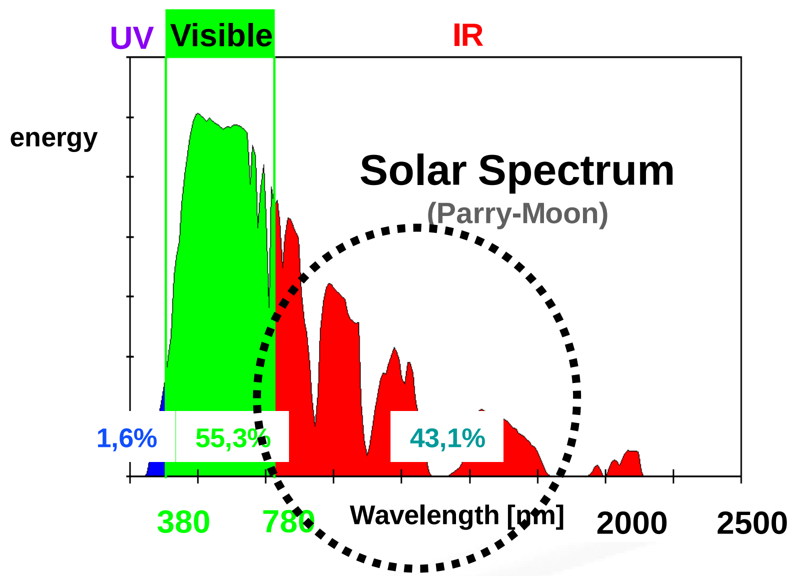
Energy transmission
(g-value)

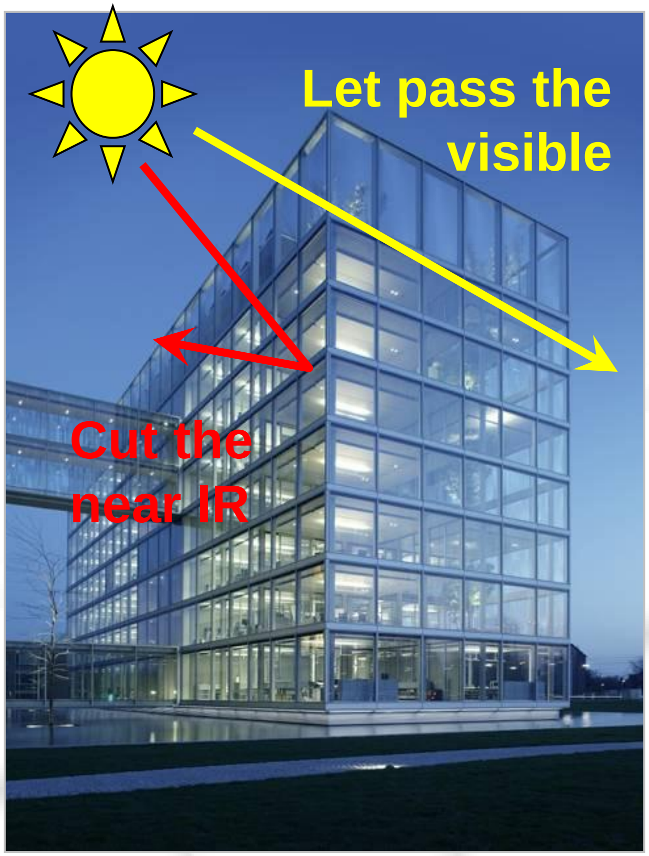
=

$$\frac{\textit{Transmitted + Re-emitted}}{\textit{Total Sun incident Energy}}$$



Solar management

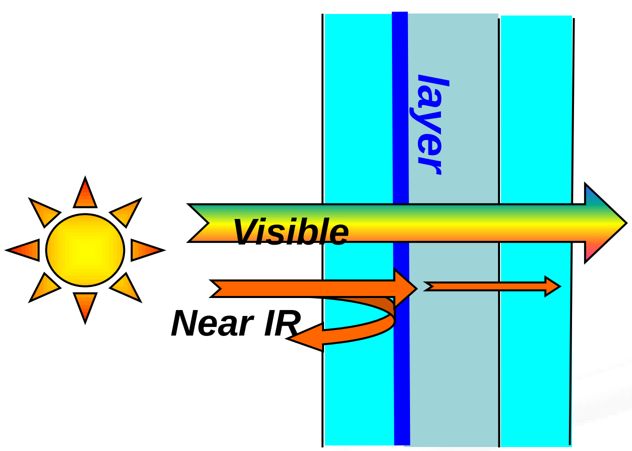


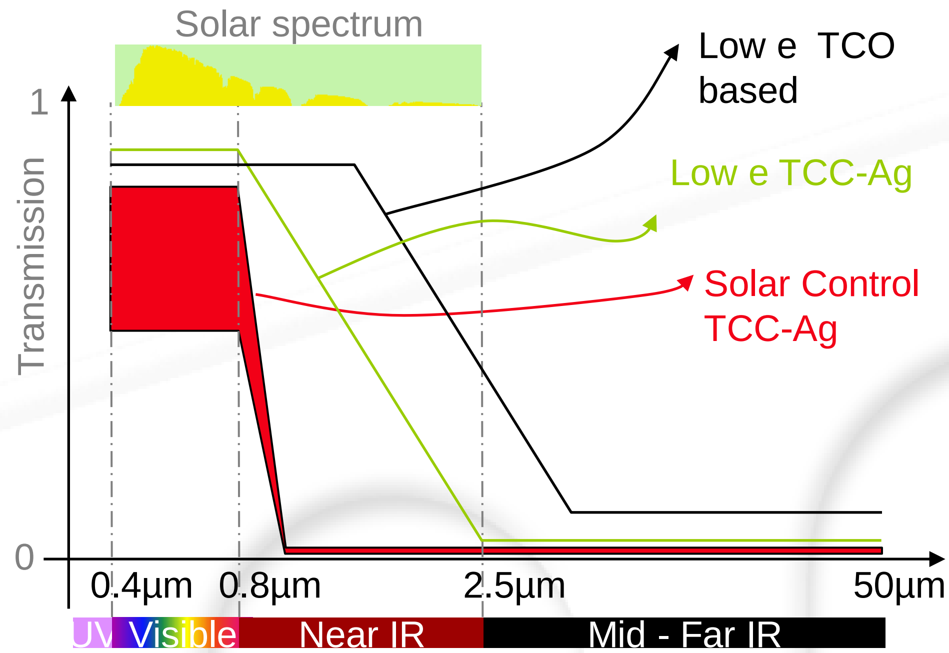


… but it may become also too hot

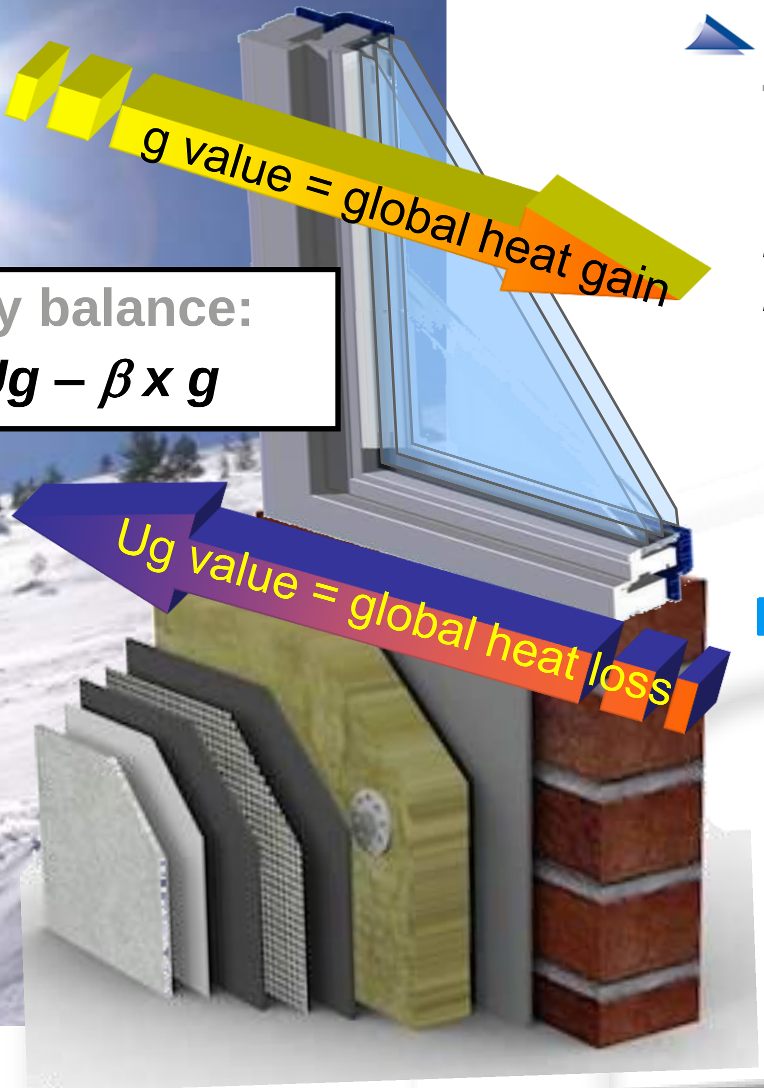
Solar control solutions

Solar control by reflection





…Performance is the energy balance between heat loss and solar heat gain



Energy balance:

$$\alpha \times Ug - \beta \times g$$

- **Low E coatings are transparent to solar radiation:**

  Increase of solar Heat gain: g

- **Low E coatings stop exchange by radiation:**

  Reduction of Heat Loss: Ug

GLAZINGS BECOME MORE ENERGY EFFICIENT THAN WALLS!

- **Triple Glazed units with high solar factor are more energy efficient than walls, also on North orientation!**

DONAU UNIVERSITÄT KREMS

	South	East West	North	Wall
Solar Heat Gain	+115	+69	+49	0
Heat Loss	- 56	- 56	- 56	- 10
Energy Balance kWh/m²	**+ 59**	**+13**	**- 7**	**- 10**

Triple glazed Unit with SGG **PLANITHERM MAX** in **Salzbourg**

Ug = 0.6W/m²K & g = 0,60

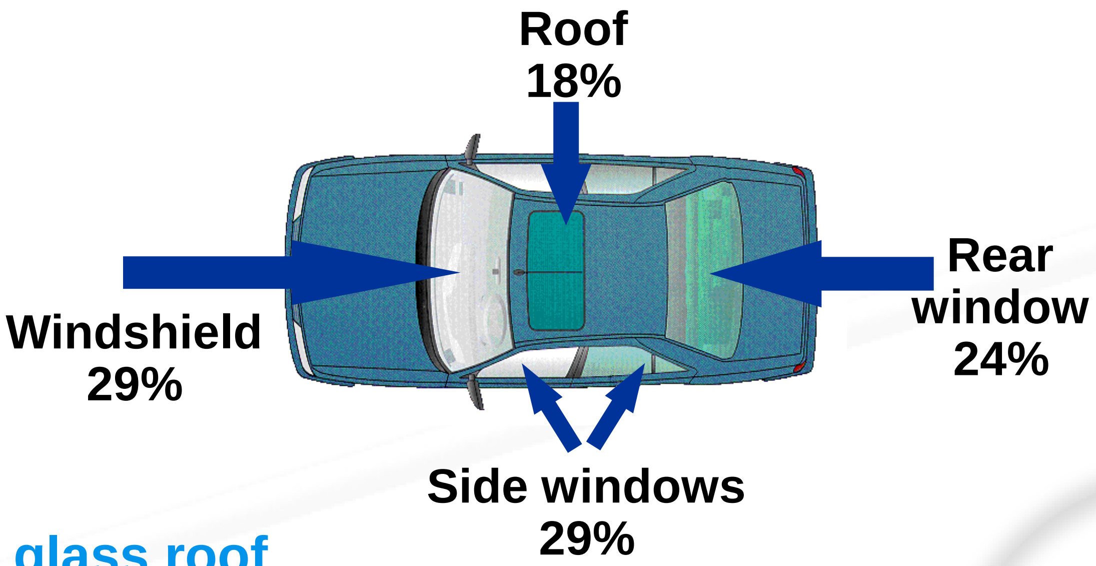
Wall:

U = 0.12W/m²K

The same solar input management is possible for cars

- **The solar energy input into the car is done primarily through the glazing**

Relative distribution of the glazing component (Example)



- **Example: Limousine with glass roof**
  - **Glass roof with low-e (ca 20%) coating**
- **Hot summer:**
  - **Entry Sun 1000W / m**
  - **Outdoor temperature 40 ° C**
  - **Interior regulated at 22 ° C**

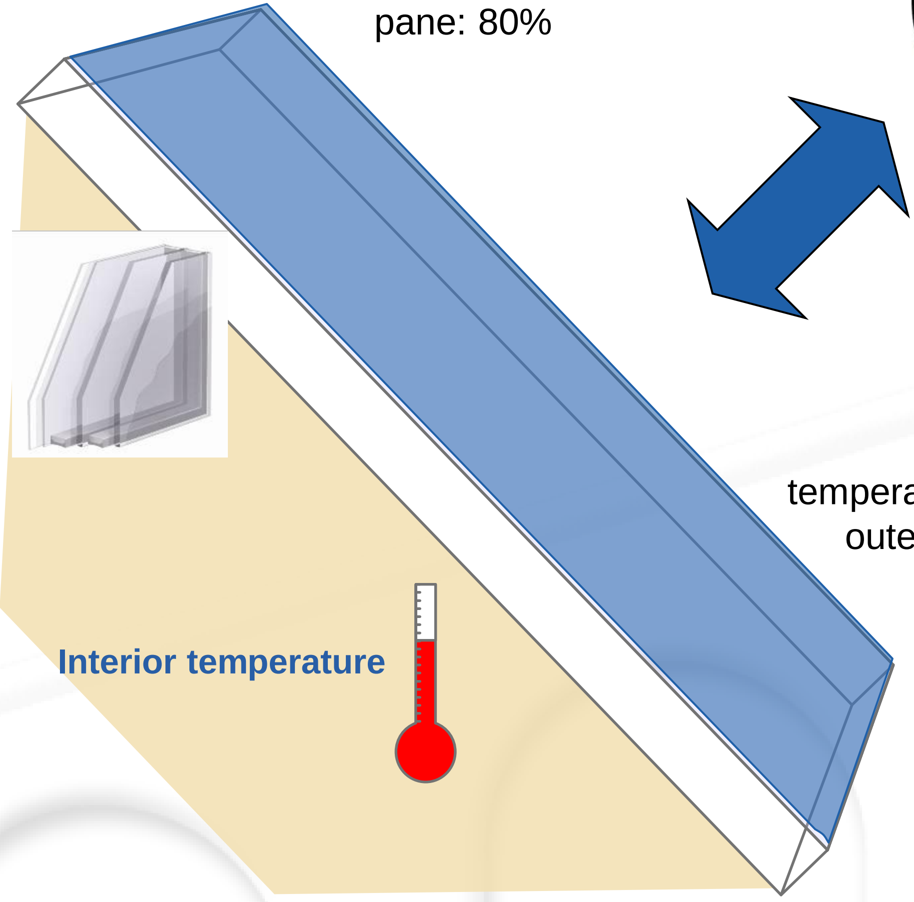
CO2 reduction

- **Heat input is reduced by 17%**
- **CO2 reduction: about 1.77 g / km**

TCC for low-e coatings: Anti-condensation

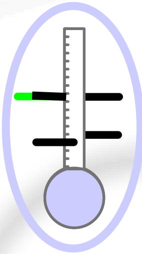
Condensation becomes an issue for high performance insulating glazing units - DGU and TGU


Emissivity of the outer pane: 80%



radiation exchange

temperature of the outer pane

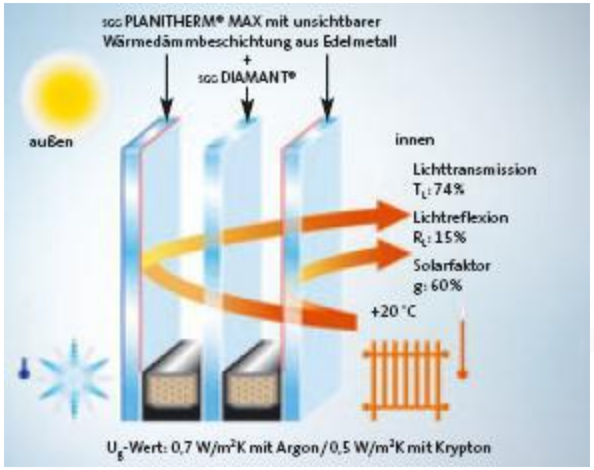


Low-e Coating

$T_{\text{Outdoor pane}} < T_{\text{Dew point}}$

- $T_{glass} > 0°C$ Fog
- $T_{glass} < 0°C$ Frost

Requirements for TCM ?



Coating inside insulated glazing

- Coating is well protected against chemical or mechanical stress but should be compatible with all the tranformation steps
- Metal coating systems achieve very low emissivities and with controled selectivity

Coating outside insulated glazing

- Coating must be chemically and mechanically stable (sometimes versus bending and tempering)
- Metal coating systems are either not chemically stable (Ag), very expensive (Au) or have a low conductivity
- Using a TCO is required

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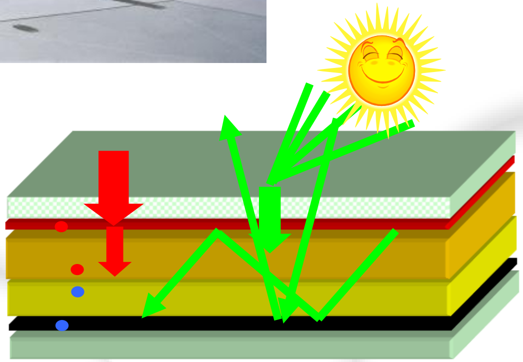
- **Summary**

Transparent electrodes for active glazings

- Accumulated experience on TCC use and issues enabled us to use them for active system as electrodes. They assume different roles with different characteristics :

  - Joule effect
  - Charge injection/collection



  - Polarization

Example of Joule effect :
To solve the automotive glazing icing problem: heat the glass (SG ClimaCoat)

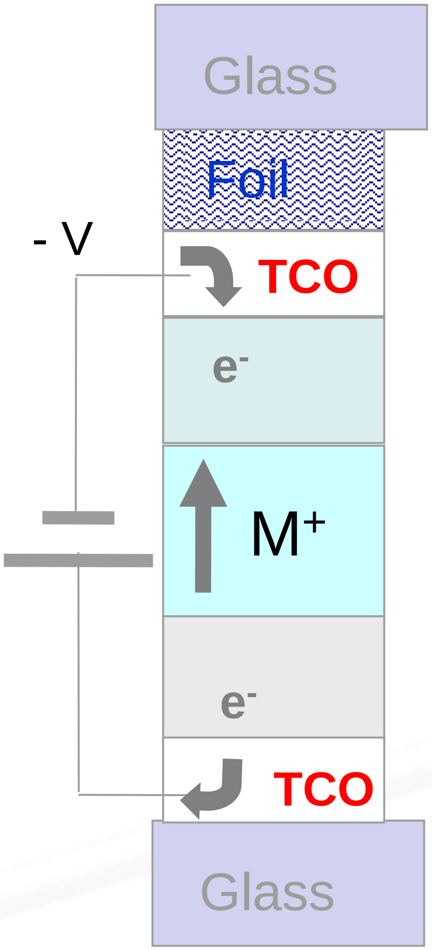
- Windshield (WSS) with a transparent conductive coating
- Coating is highly selective:
  - heat reduction in summer

without

- WSS can be heated by the coating (14V power port)
- Rapid de-icing and fogging

with

Injection/Collection: Electrodes for Electrochromic glazing



clear

WO_3

Electrolyte

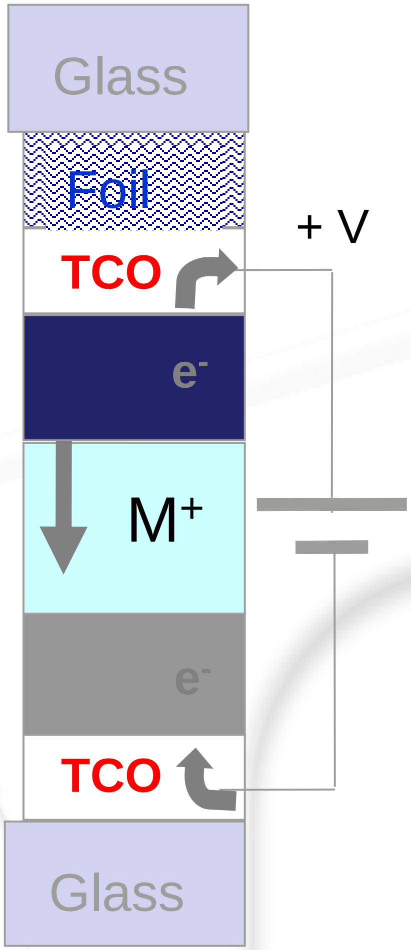
M : H^+, Li^+

M_xCE

CE : counter electrode

Behaves like a thin film battery

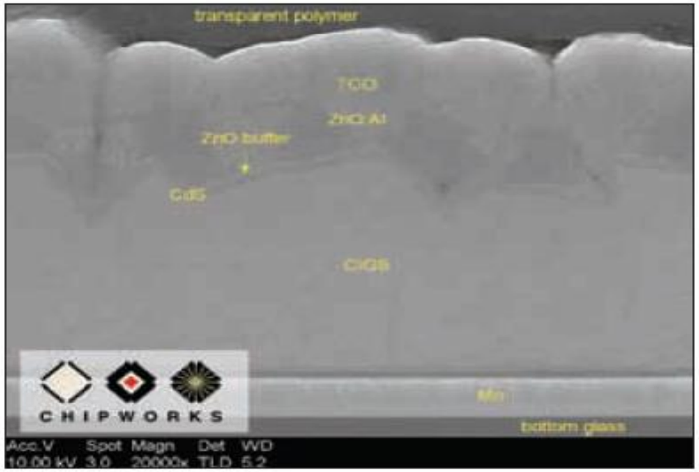
blue

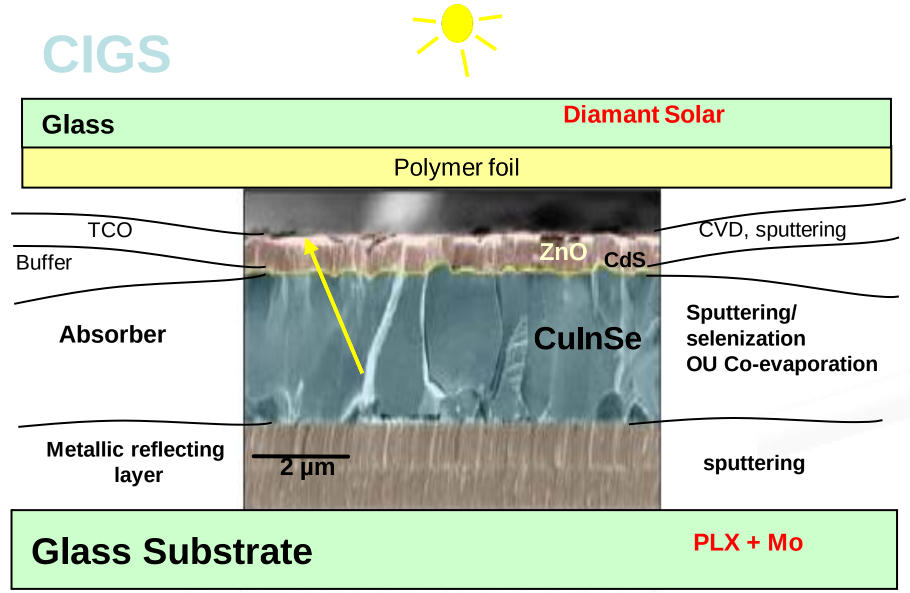


Electrodes needs:

highly conductive, highly transparent (including in the near infrared), chemically stable

Injection/Collection: Electrodes for PV-CIGS



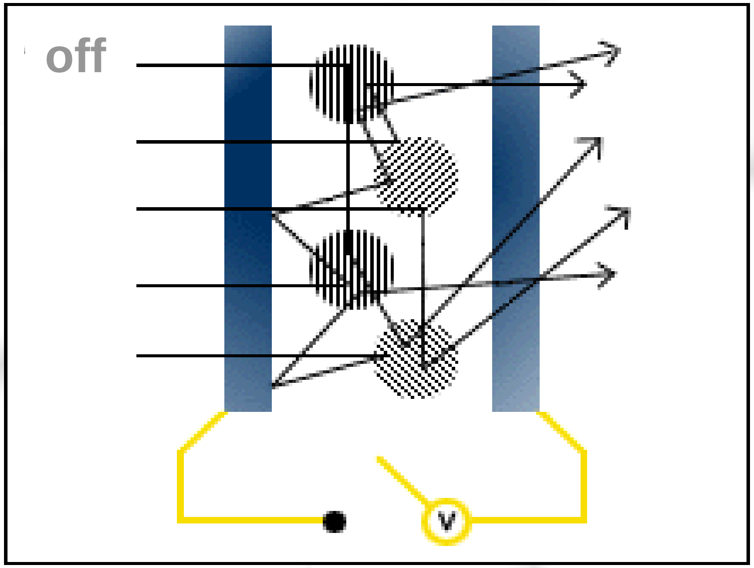


TCO are used as top electrode:

- Need of high transparency in the absorption region of the absorber
- Relatively good conductivity (to avoid ohmic drops)
- Good durability
- Cost…

Polarization: Liquid Crystal glazing

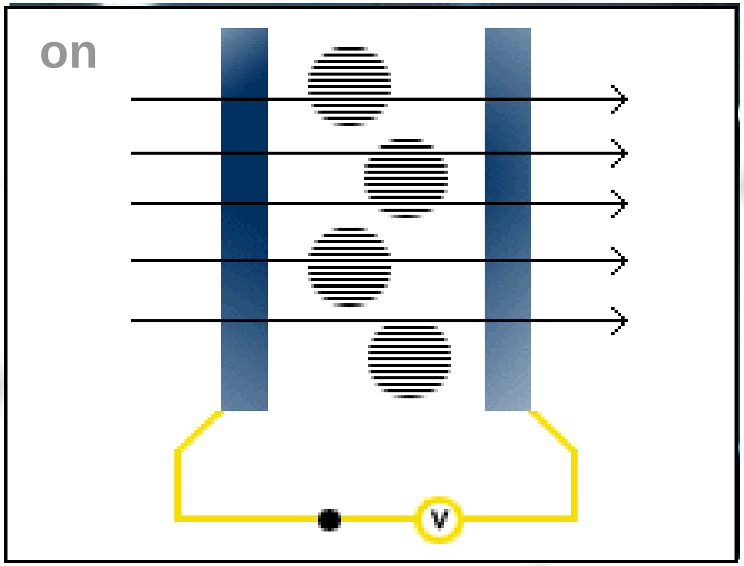
Privalite®



Diffusing...

Polarization: Liquid Crystal glazing

Privalite®



Not diffusing…

Electrodes needs:
- **moderate conductivity,**
- **highly transparent (no haze),**
- **chemically stable…**

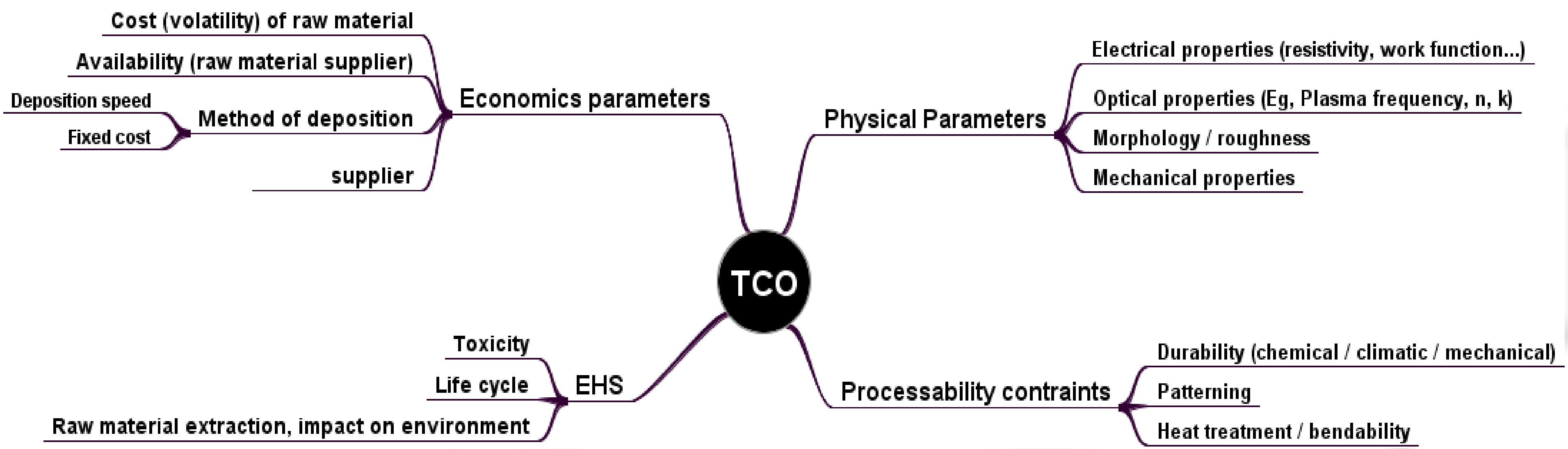
Summary

- Significant reduction of energy consumption for heating or cooling (thereby reducing the CO_2 production) by fubctionalizing glass surfaces with transparent conductive material, either TCC or TCOs

- TCOs (ex SnO_2:F) are used, especially when coating is not protected and emissivities required are not too low

- TCM systems can be design as electrodes and adapted to meet product specitications : durability / process / transformation…

Conclusion: Table of merit



➡ **No TCM is perfectly fitted for every application !**

Thank you