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Phase Change Materials for Energy Efficient Housing Applications

MSE 395

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Overview

- Introduction and Background
  - Examples of phase change materials (PCMs)
- Solid-liquid-gas phase change materials
  - Characteristics
  - Classification and development
  - Applications and examples
- Thermochromic phase change materials
  - Optical properties
  - Applications and examples
- Conclusion

Introduction and background

- Any material goes through a phase change
  - Temperature (thermo-)
  - Electric charge (electro-)
  - Acidity, pH (halo-)
  - Pressure (piezo-)

- Two Classifications
  - Solid-liquid-gas phase change
  - Crystal structural phase change

Phase change causes changes in:

- Mechanical
- Magnetic
- Electrical
- **Thermo**
- **Optical**

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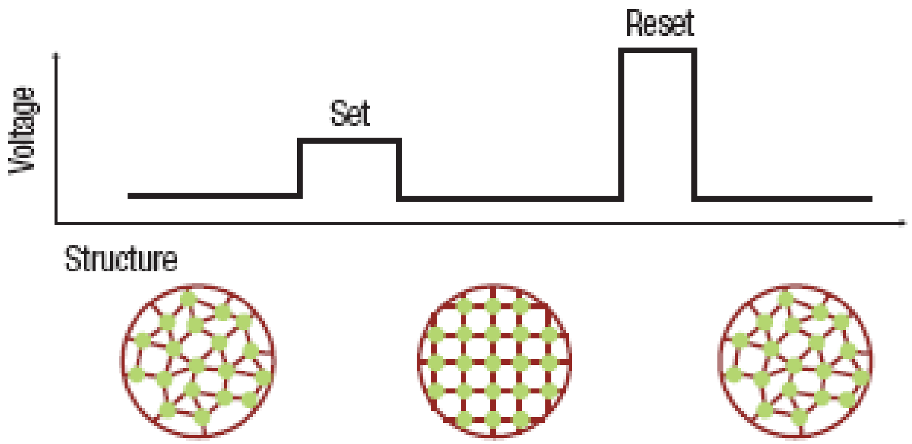
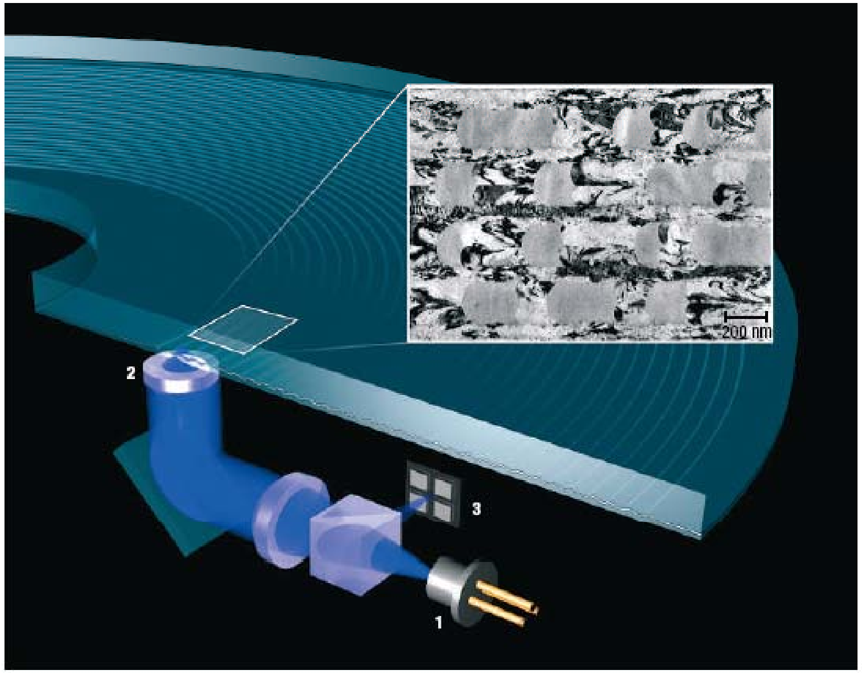
PCMs example – Rewritable DVDs

- Ge-Sb-Te (GST) chalcogenide alloy
  - Crystalline ←→ Amorphous phase change using laser
  - High intensity / short pulse : Amorphous
  - Low intensity / long pulse : Crystalline





Solid-liquid-gas PCM

- <u>**Solid-liquid**</u>, solid-solid, liquid-gas, solid-gas

- Latent heat storage (LHS)
  - Heat is absorbed → melt → liquid
  - Heat is released → solidify → solid
  - Heat of fusion (ΔH_{fusion})

- Different from sensible heat storage (SHS) !
  - Heat is stored by raising the temperature of material
  - Specific Heat capacity (C_p or C_v)

Solid-liquid-gas PCM - Characteristics

Selection criteria

Thermodynamic Properties	**(i) Melting temperature in desired temperature range** **(ii) High latent heat of fusion per unit volume** (iii) High specific heat, **high density** and thermal conductivity (iv) Small volume change on phase transformation (v) Congruent melting
Kinetic Properties	**(i) High nucleation rate to avoid super cooling** (ii) High rate of crystal growth to meet demand of heat recovery from the storage system
Chemical Properties	**(i) Complete reversible freeze/melt cycle** (ii) No degradation after a large number of freeze/melt cycle (iii) No corrosiveness to the construction materials (iv) Non-toxic, non-flammable and non-explosive material
Economic Properties	(i) Low cost (ii) Large-scale availabilities

Solid-liquid-gas PCM – Classification

- Large numbers of PCMs available -5 to 190 °C

Classification

Organic

- ✓ Thermally and chemically stable
- ✓ No super cooling, segregation
- × Low LHS / unit volume
- × Costly and flammable

Paraffin C_nH_{2n+2}

Fatty acids $CH_3(CH_2)_{2n}COOH$

Inorganic

- ✓ Highest LHS / unit volume
- ✓ Low cost, largely available
- × Large super cooling effects
- × Dehydration and instability

Salt hydrates M_nH_2O

Eutectics

- ✓ High LHS / unit volume
- ✓ Sharp melting point
- × Limited data is available
- × Strong odor

organic-organic

organic-inorganic

inorganic-inorganic

Solid-liquid-gas PCM – Examples

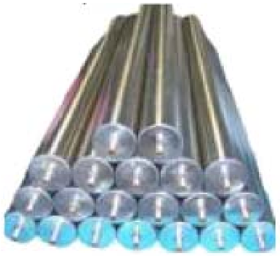
Materials	Melting point (°C)	Heat of fusion solid ←→ liquid (kJ / kg)	Specific Heat *solid / liquid* (kJ / kg °C)	Density *solid / liquid* (kg / m^3)
Water	0	333.6	2.05 / 4.18	999 / 1000
Lauric acid $CH_3(CH_2)_{10}COOH$	41 – 43	**211.6**	1.76 / 2.27	1007 / 862
$Mn(NO_3)_2\ 6H_2O$ + $MnCl_2\ 4H_2O$ (4 wt%)	15 – 25	125.9	2.34 / 2.78	**1795 / 1728**
Capric acid (65 mol%) + Lauric acid (35 mol%)	18 – 20	140.8	1.97 / 2.24	- / -

Commercial grade PCMs

E23 ™ - EPS Ltd	23	155.0	0.69 / -	1475 / -
RT27 ™ - Rubitherm	28	146.0	1.80 / 2.40	870 / 750

Solid-liquid-gas PCM – Applications 1

- Macro-encapsulation
  - Failed due to poor thermal conductivity
  - Tend to solidify at the edges
- Micro-encapsulation
  - Easily incorporated into construction materials
- Steel, polypropylene
- Usually embedded with high conductivity materials with high conductive structure



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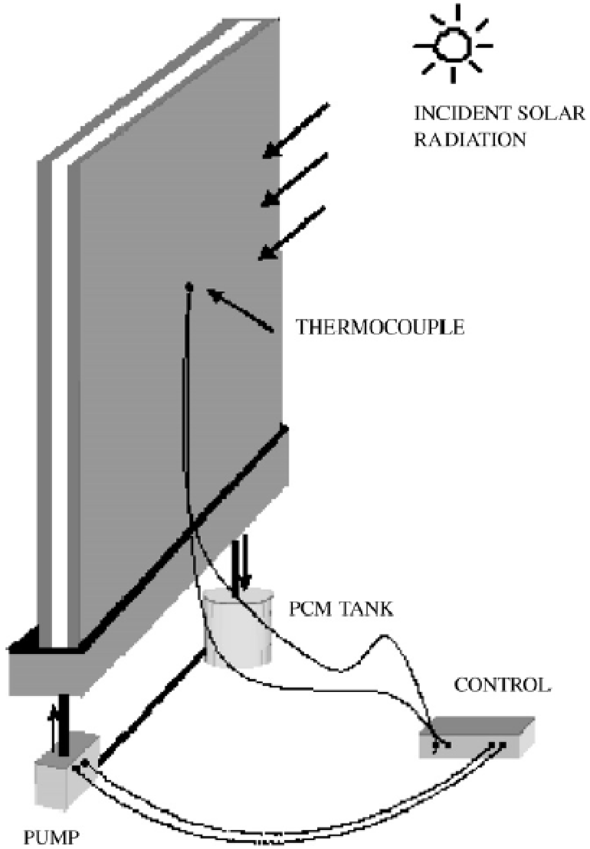
Solid-liquid-gas PCM – Applications 2

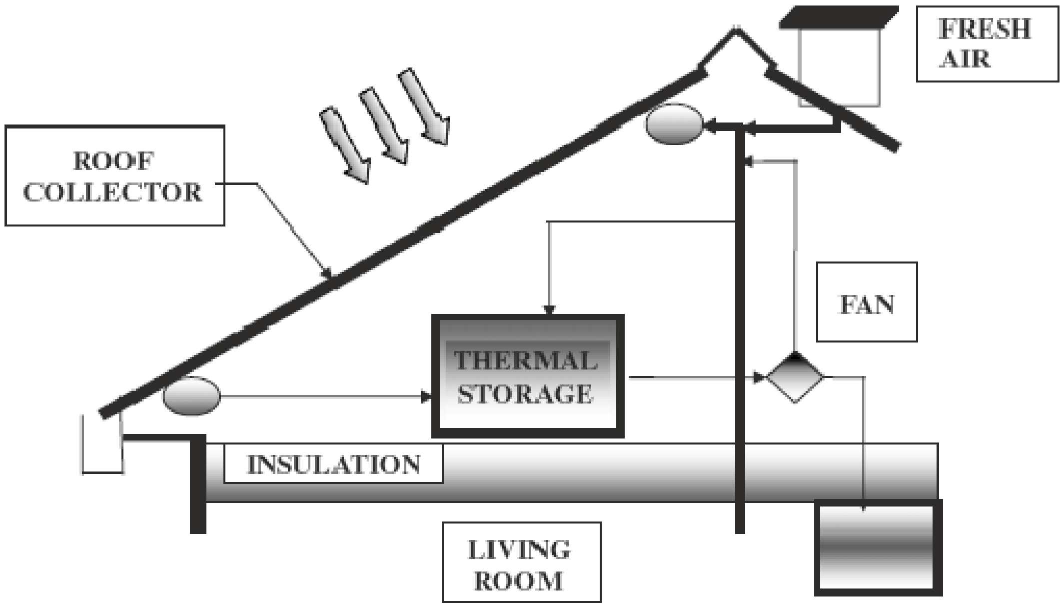
- Passive storage systems
  - Wallboards
  - Ceiling boards
  - Building blocks
  - Movable curtain (shutter)

- PCM wallboards
  - Lightweight 120m^2 house (Madison, WI)
  - Saves up to 15% annual energy (3GJ)
  - Optimal ~1 to 3 ^oC above RT



Solid-liquid-gas PCM – Applications 3

- Active storage systems
  - Floor heating and cooling
  - Air-based heating and cooling – Uni. South Australia in 1997



- Day time or High Temp.
  - Collect solar heat
  - Circulate indoor hot air to cool down
- Night time or Low Temp.
  - Vent and circulate to warm indoor air

Solid-liquid-gas PCM – Concerns

- Many manufacturers data not verified
  - Discrepancy with independent research
- No commonly accepted quantitative criteria
- Lack knowledge on other properties
  - Kinetics – mass and heat transport process
  - Chemical – storage and safety concerns

Thermochromic PCM

- Optical properties vary in response to temperature
  - Ex) Liquid crystals, Dyes, ZnO, PbO, VO_2

- Idea: "*intelligent*" thin film coating on windows
  - Darken (hot) state: Reflect IR radiation while transmitting visible
  - Transparent (cold) state: Allow IR for maximum solar heat gain
  - Increase thermo and visual comfort !

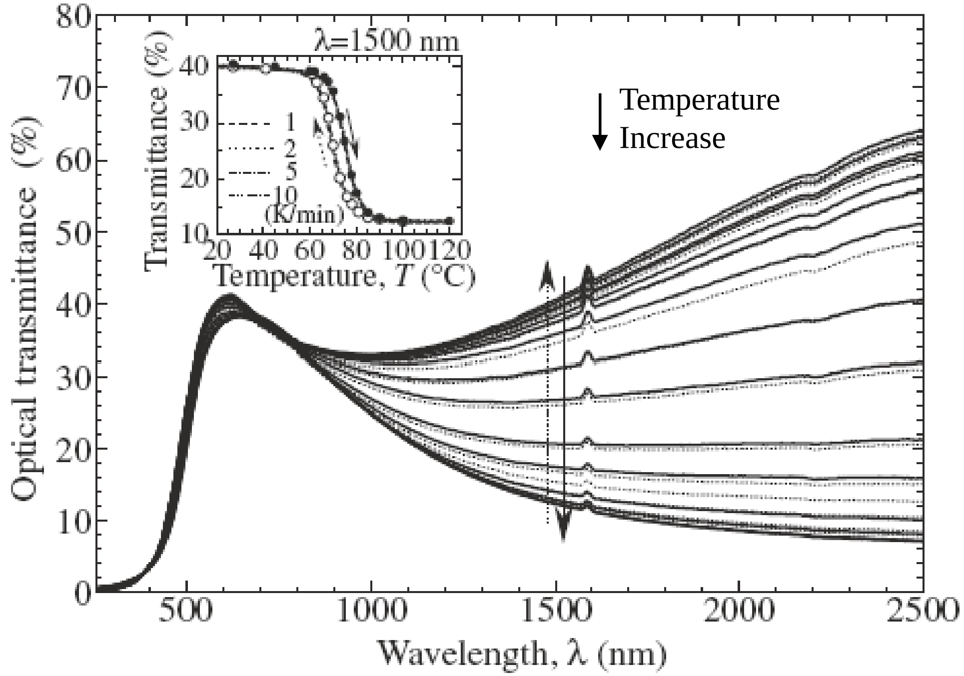
- VO_2 – phase transition closest to RT (68-70 ^oC)
  - Band gap ~0.7eV
  - Low temperature semiconducting phase
  - High temperature metallic phase

Thermochromic PCM – optical property 1

- Optical transmittance temperature dependency
  - IR transmittance – decrease from 40 to 0 % as T increase
  - Visible transmittance – relatively constant

- Reversible

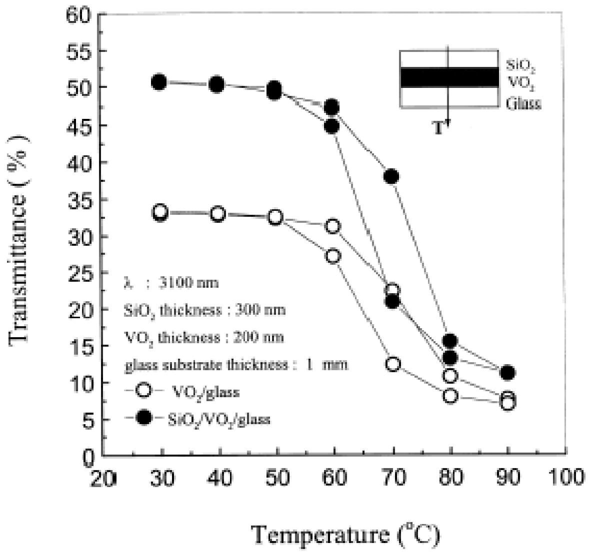
- Independent of ΔT rate

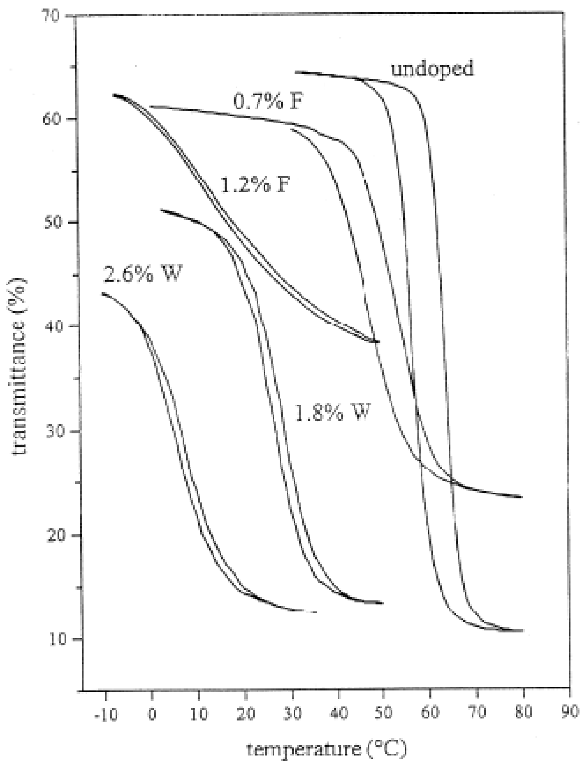


Thermochromic PCM – optical property 2

- W- F- doped VO_2 decreases transition temperature
  - Within human comfort range for practical applications

- Anti-reflection coating
  - Better thermochromic transition





Thermochromic PCM – Concerns

- Atmospheric pressure CVD produced thin film deteriorates easily
- Sol-gel produced thin film more robust, yet :
  - Delamination occurs in repeated thermal cycle
  - Oxidize easily to form other VO_x
  - High cost
- RT thin film is yellow, undesirable for commercial use

Conclusions

- PCMs are promising advanced materials for energy efficient housing applications

- Solid-liquid PCMs
  - Latent Heat storage units to maintain constant temperature
  - Detailed knowledge on properties to select optimum PCMs

- Thermochromic PCMs
  - Windows coating to provide thermo/visual comfort
  - Yellow buildings in the near future ?!

Questions and comments?