Industry Developments:

Phase Change Materials

For engineers working in electronics thermal management, phase-change materials, or PCMs, are an effective type of thermal interface material (TIM). They're typically used between cooling solution and power generating electronics and devices and can provide thermal performance superior to dry TIM pads. But phase-change materials have much wider applications in and outside of electronics thermal management. These include cooling commercial goods and different applications used for cooling buildings.

Basic Characteristics

Most phase-change materials function via the change in enthalpy by heating a substance from solid to high viscosity liquid(HVL), known as the enthalpy of fusion. The enthalpy of fusion for this condition is a latent heat, because during the phase change the temperature remains constant. [1] Initially, a PCM's temperature rises as it absorbs heat, but when it reaches the temperature at which it changes phase (melting point) it absorbs large amounts of heat at a near constant temperature. The PCM continues to absorb heat without significantly increasing in temperature until all the material is transformed to liquid. When the ambient temperature falls, the PCM changes back to solid, releasing its stored latent heat. [2] This property enables PCMs to store or release large volumes of energy as a function of its surrounding temperature.

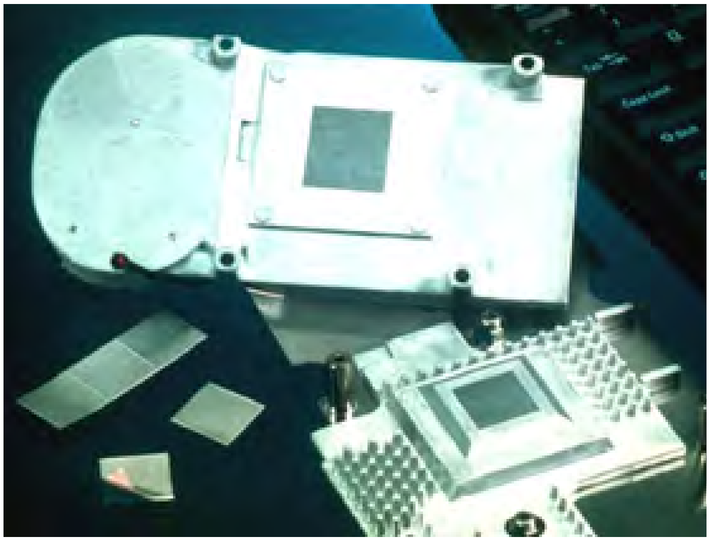

Figure 1. Phase Change Thermal Interface Materials [1]

When used as TIMs, phase-change materials completely fill interfacial air gaps and voids. They also displace entrapped air between power-dissipating electronic components. Upon reaching the required melt temperature, a TIM pad will fully change phase and attain minimum bond-line thickness (MBLT) – typically less than 0.0254 mm (0.001 inch), and maximum surface wetting. This results in practically minimal thermal contact resistance due to a very small thermal resistance path.

Phase-change TIMs became available commercially before the turn of the century, and today many choices are available. This includes their base resin material, additives, conductive fillers and features that make them easier to install and remove.

Recently, Intel researchers developed a PCM that is less likely to bleed out of interfaces when in HVL state. The Intel PCM incorporates organophilic clay. The clay particles improve the reliability and performance of TIM materials by slowing diffusion of oxygen and water through the thermal interface material. The resulting nanocomposite phase change material has improved high-acceleration stress test ("HAST") performance, and slows the release of volatile components for reduced pump-out, bleed-out, and dry-out of the thermal interface material. The clay particles also improve the thermo-oxidative stability of the TIM for improved bake and thermal cycling ("TC") performance. [4]

Figure 2. A PCM-Filled Core Inside a Mug Cools Freshly Brewed Coffee to an Ideal Temperature and Keeps it There by Releasing Heat [4]

Other PCM Applications

PureTemp, a technology developed by Entropy Solutions, turns natural oils into phase change materials capable of maintaining a specific temperature between -40 to 149°C (- 40 to 300°F) for hours. PureTemp technology involves purifying a variety of vegetable oils and then isolating different compounds within the blends. Each compound naturally melts or solidifies at a different specific temperature and can be used as the base material for an application, depending on the phase change point needed. [5]

There are many non-biologically based PCMs, but most are petroleum- or mineral-based, with varying levels of toxicity, or water-based, with more limited temperature ranges. PureTemp's materials are biodegradable and nontoxic. PureTemp materials also have a broader range of potential phase change temperatures and containment sizes: Its coffee mug, for example, has a rigid inner core of PCM that could fit in the palm of your hand, while blankets and clothing use the material in thin, flexible sheets or pockets of microcapsules.

The PureTemp mug's inner PCM core has a phase change point of 60°C(140°F), which is considered an ideal drinking temperature. Coffee is typically brewed, however, at about 88 to 93°C (190 to 200°F). When freshly brewed coffee is poured into the mug, the PCM [inside the core] melts, pulling energy in the form of heat from the coffee. It takes a minute or two to reach the optimal drinking temperature — and the PCM's phase change point. As the coffee cools below 60°C (140°F), the PCM starts to solidify again, releasing the stored heat back into the coffee and maintaining a desirable temperature.

Structural Thermal Management

bioPCM is a nano engineered phase-change material for integrating PCMs into building structures. Developed by Phase Change Energy Solutions, bioPCM absorbs and releases heat using PCMs that melt and solidify at room temperature[6]. Like PureTemp's coffee cup PCM, the phase change materials used by bioPCM are derived from bio-based materials, e.g. palm and soy oils, rather than from petroleum or salt hydrates. When the phase change materials are placed in a building, they absorb heat during the day and release heat into the building at night. bioPCM reduces temperature fluctuation within the building and thereby reduces HVAC demand.

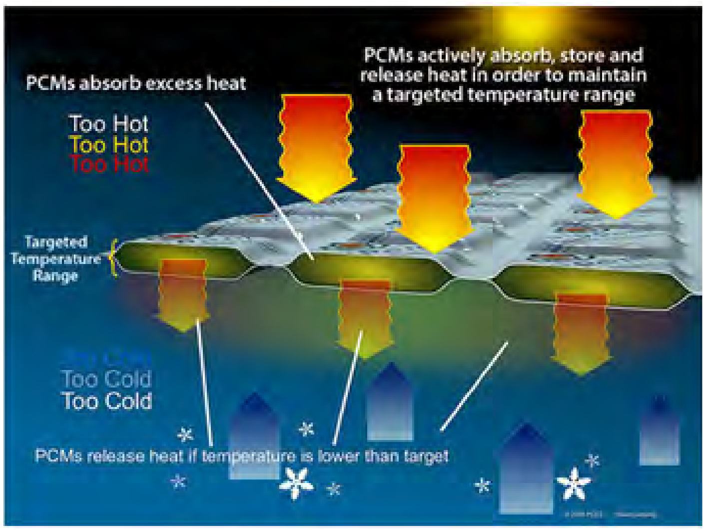

Figure 3. Diagram Showing how the BioPCM Material Absorbs and Releases Heat Using Bio-based PCMs [6]

One of the company's commercial building products, bioPCmats are designed to provide energy savings. When installed in ceiling and wall panels the bioPCmats work day and night to stabilize indoor temperatures. This passive approach to saving energy provides greater comfort for building occupants and more efficient HVAC system. In the exterior walls, each 419 mm(16.5 inch) wide bioPCmat is simply stapled to the studs over the standard insulation. In ceilings, bioPCmat is placed over the sheet rock in the attic before insulation is applied. The product can be easily trimmed around wall outlets and fixtures with scissors or a utility knife.

PCMs and Solar Storage

Along with keeping buildings cool, phase-change materials may soon store excess solar power until it is needed. One form of solar power, concentrated solar, uses sunlight to generate steam that is used to produce electricity. These concentrated solar power plants work well while the sun is shining, but they have a hard time delivering energy at night or when it's cloudy. Excess heat not needed for immediate electricity generation can be stored and used at a later time. [7]

Researchers from the German Aerospace Center recently tested what they say is the world's largest high-temperature PCM storage module in Carboneras, Spain. The insulated, steel-reinforced tower is 85.8 m (26 feet) tall and filled with 15 tons of salt.

Figure 4. The German Aerospace Center's Test PCM Facility in Spain [7]

To charge the module, superheated steam from an adjoining coal-fired power plant is piped through a network of finned tubes that heats the sodium nitrate salt to its melting point of 419°C (581°F). The liquid salt can then retain its stored thermal energy for up to 24 hours. To discharge the heat, operators essentially run the system in reverse, pumping water through the finned tubes to turn it back into steam, which goes on to spin the turbines that produce electricity.

Until now, solar thermal power plants have either gone without thermal storage or relied on molten salts that remain liquid throughout their charging and discharging cycles. By keeping the salts liquid, though, the system is not taking advantage of the efficiencies inherent in phase change. The reduced cost could help stored solar power compete with conventional gas and coal fired power plants for reliable base load power.

The International Energy Agency predicts that concentrated solar power will become cost competitive with conventional fossil fuel power as early as 2025 and, along with photovoltaic solar power, could provide up to 25% of global electricity production by 2050.

PCM Capsules

Micro-encapsulation allows PCMs to be produced in capsules ranging from less than one micron to several hundred microns in size. Microcapsules can be round or asymmetrical in shape. These formations allow PCMs to be added easily and economically into construction materials, such as concrete. The result of their presence is a reduction in structural temperature fluctuations, and reduced energy consumption for heating and cooling.

Figure 5. Micrometer-sized Beads of Micronal PCM from BSAF Added to Cement [8]

In micro-encapsulated PCMs, the phase change substance is typically a paraffin or fatty ester acid that absorbs and releases heat in order to maintain a defined temperature. Whether the PCM is in liquid or solid state the capsule remains solid. [9] A typical application is in gypsum wallboards. Micronal PCM, a product of BASF, can be added to transform a thermally insubstantial board into the equivalent of a thick wall made of concrete. Heat absorption during the day and release during the night is optimized because of the microencapsulated form of Micronal PCM paraffins, which supply a huge surface through which the heat can be exchanged. [8]

Encapsulating PCMs at the molecular level is a newer technology. Developed by DuPont, this technique allows a very high concentration of PCMs within a polymer compound. With molecular-encapsulation, the polymer molecules are designed to connect to the paraffin molecules, creating a homogeneous product. Molecular-encapsulation allows drilling and cutting through building materials without any PCMs leakage. [10]

Consequently, the phase change materials have found a broad spectrum of applications in the space electronics cooling to building materials to consumer products. The unique ability to store and release heat at certain daytime temperatures allows PCM to be used as a thermal management solution. Further advances in materials as well as nano-technology will further enhance its transport and storage capabilities.

References:

1. http://en.wikipedia.org/wiki/Enthalpy_of_fusion

2. http://en.wikipedia.org/wiki/Phase-change_material

3. Parker Chomerics, http://www.chomerics.com/products/thermal/phase-change/index.html

4. http://www.google.com/patents/EP1654759B1?cl=en

5. http://discovermagazine.com/2013/september/21-running-hot-and-cold-forever

6. http://www.phasechange.com

7. http://www.pbs.org/wgbh/nova/next/tech/melting-to-keep-cool/

8. http://www.micronal.de/portal/basf/ien/dt.jsp?setCursor=1_290868

9. Dubey, K. and Mishra, R., A Review on Properties of Phase Change Material for Solar Thermal Storage System, ICARI-2014.

10. http://www.edsl.myzen.co.uk/downloads/misc/DuPont%20ENERGAIN(r)%20PCM%20Guidebook_December%202010.pdf