MATEC Web of Conferences **18**, 03009 (2014)
DOI: 10.1051/matecconf/20141803009

Novel solid – solid phase change material based on polyethylene glycol and cellulose used for temperature stabilisation

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Abstract. Thermal management is one of crucial issues in the development of modern electronic devices. In the recent years interest in phase change materials (PCMs) as alternative cooling possibility has increased significantly. Preliminary results concerning the research into possibility of the use of solid-solid phase change materials (S-S PCMs) for stabilisation temperature of electronic devices has been presented in the paper. Novel solid-solid phase change material based on polyethylene glycol and cellulose has been synthesized. Attempt to improve its thermal conductivity has been taken. Material has been synthesized for the purpose of stabilisation of temperature of electronic devices.

1 Introduction

Thermal management is an continuously evolving topic. There is much interest in thermal stabilisation of electronic devices due to the fact that devices like cell phones, laptop computers and similar appliances have become commonly used. Many research studies are focused on improvement of thermal management also because of the fact that the size of electronic equipment become smaller while the power dissipation for the same equipment became higher.

One of the methods for thermal stabilisation is application of phase change materials. Due to their properties they have possibilities to accumulate heat and remove this heat from the system. Examples of phase change materials applications are presented below [1]:

1) Buildings applications, e.g.: thermal comfort, building conditioning, moving redundant heat from the period of availability to the period in which waste heat could be used
2) Medicine applications, e.g.: transport of organs, blood, vaccines, medicines
3) Thermal energy storage
4) Waste heat recovery
5) Solar power plants
6) Cooling and thermal protection of food
7) Electronics devices thermal management: electronic equipment cooling
8) Thermal system in the spacecraft

The idea of using phase change materials for stabilisation of electronic devices temperature relates to the great potential of PCMs. There is a wide range of PCMs types with various range of transition temperature and heat of fusion. Phase change materials are characterised by ability to heat accumulation. The accumulation occurs at specified temperature range, characteristic for the particular material. During the phase transition heat is absorbed and stored by PCM and released during the reverse transition. It enables removing large amount of heat from components subjected to damage caused by high temperature.

Fundamental way of PCMs classification is to group them by the type of transition[2]. Classification has been shown in the Fig. 1

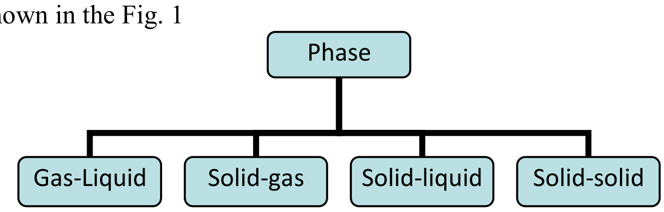

Figure 1. Phase change materials classification by the type of transformation

The most commonly used phase change materials are substances with solid-liquid transition. They are frequently used due to large selection and relatively high heat of fusion. Interest in another group of PCMs – solid-solid (S-S) PCMs has recently increased. It is related to the several advantages of those materials. First of all when solid-solid phase change materials are used there is no leakage or gas generation in any of transition stage. It provides the opportunity to avoid equipment failure or occurrence of corrosion. Second advantage is no volume change during the transition or very small change. It

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gives the possibility to use them in small size systems and applications where space is limited.

Unfortunately S-S PCMs are usually characterized by relatively low heat of fusion compared to the solid-liquid PCMs. Additionally, there is a problem related to all kinds of PCMs – low thermal conductivity. These makes it necessary to carriy out the researches on new phase change materials development.

Interest in phase change materials due to thermal management of electronic devices became bigger last years. There are number of works conducted in this area. Several interesting examples have been presented below.

Kandasamy et al. [3] have presented results of experimental and numerical investigations of phase change material (PCM)-based heat sink in transient thermal management of plastic quad flat package (QFP) electronic devices. They have compared two cases: heat sink with and without PCMs using and shown when it is reasonable to use PCMs for electronic cooling.

Qu et al. [4] have presented and compered three kinds of systems designed for electronic devices cooling: (a)hybrid heat sink with parallel fins sintered onto its top and copper metal foam–paraffin composite saturated in its hollow basement, (b) hollow basement saturated with pure paraffin, (c) solid copper basement.

Weng et al. [5] have been experimentally investigated thermal performances of system containing a heat pipe and container with phase change material. Their insights and observations concerning among others impact of the applications of different types and various amounts of PCMs they have concluded in the paper.

S.C. Fok et al. [6] have presented results of experimental study of use PCM placed inside heat sinks with and without internal fins in the portable electronic devices. They have compared and present results associated with the change of parameters like: use of PCMs, number of fins, power level.

Department of Thermal and Fluid Flow Machines (KCiMP) at Faculty of Energy and Fuels at AGH University of Science and Technology works on solid-solid phase change materials dedicated for stabilisations of electronic devices temperature.

2 Phase change materials

2.1. PCM for thermal management

Prepared material modified by appendix of graphite will be tested in the matter of possibility of thermal stabilization of electronic devices application. Material has been selected due to corresponding phase transition temperature. Possibility of use of prepared material will be tested on the testing rig in conditions of computer processor work. Every computer processor (CPU) has specific maximum temperature of safe work. Usually this temperature is known as critical temperature. It is advisable to keep CPU temperature on the range around 20^{o}C below critical temperature. Examples of critical temperature for computer processors are presented in table 1.

Table 1. Examples of critical temperature for computer processor[7]

CPU type	Critical temperature
Intel Core 2 Extreme (Kentsfield QX6800)	54,8
AMD Phenom X4	61
Pentium D (Smithfield 805, 820)	63
Intel Core i7 (Sandy-Bridge)	72,6
AMD Mobile Sempron	95

It is predicted that phase change materials with transition temperature 40-50 °C will be able to reduced possibility of overheating of CPU.

Power consumption diagram for processor is presented on figure 2 [8]. Specification was determined with the use of following nomenclature. Maximum power(P_{max}) is a maximum input power during normal working conditions. Designed thermal power(P_{tdp}) is a maximum power kept in conditions of real work in the real ambient thermal conditions. Active power(P_{active}) is a thermal design of power in the average time. Idle power is a power consumption in standby mode where the use of the clock is zero or small. For example, during a switch to the sleep mode in the measured nominal worst case.

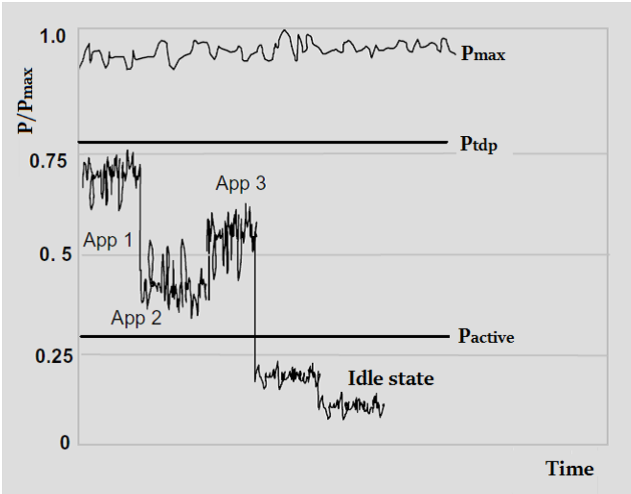

Figure 2. Example of CPU power consumption characteristics[8]

It is necessary to determine during the designing, the maximum power that processor is able to get. It is a power which should not be reached by processor, because it can cause permanent damage in its parameters. It is important from the perspective of the temperature stabilisation, because processor is able to achieve large power in short time. In that kind of situation significantly more heat is generated, so more heat have to be dissipated to prevent overheating. The assumption of 75% power consumption causes that the strongest CPU load will not negatively affect its efficiency. Examples of energy consumption is shown in Figure 5. As shown in the graph power consumed by the processor at the time of work is not uniform and changing depending on the load by programs. The relationship of power consumption dependence on time is an example of thermal changes taking place on the computer processor[8].

It is anticipated that the properties of tested material will allow its use for stabilization of operating temperature of electronic devices. This possibility is associated with periodic requirements of heat dissipation. A computer processor does not have the demand for cooling at a constant level. It make phase change materials work possible in cases in which they do not have to dissipate heat from computer processor continuously. It is also important that on the CPU surface there are formed areas of higher and lower heat concentrations. It is visualised by temperatures gradients on the figure 3. It gives possibilities to use smaller amount of phase change materials what is important when size and weight of electronic devices are required smaller and smaller.

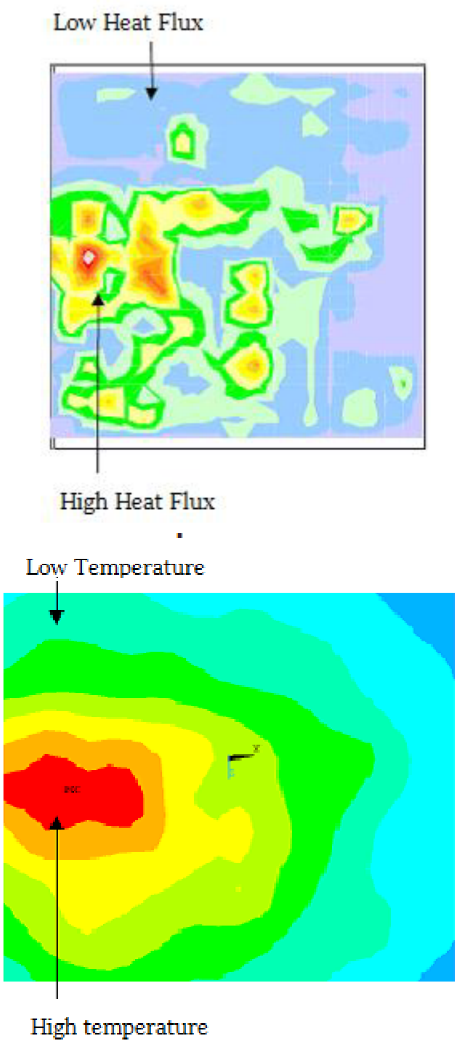

Figure 3. Example of heat distribution on the processor [8]

2.1. Solid-solid phase change materials

Group of solid-solid phase change materials based on polyethylene glycol (PEG) and cellulose has been synthesised. Polyethylene glycol with different molecular weights: PEG 2000, PEG 4000, PEG 8000 and PEG 12000 has been used. Materials differ also in the PEG percentage of the final materials. Detailed information about synthesized materials are presented in table 2.

Table 2. Synthesized solid – solid phase change materials based on polyethylene glycol and cellulose

Material	PEG type	PEG percentage, %
PEG_2000_50	PEG 2000	50
PEG_2000_65		65
PEG_2000_75		75
PEG_2000_80		80
PEG_4000_50	PEG 4000	50
PEG_4000_65		65
PEG_4000_75		75
PEG_4000_80		80
PEG_8000_50	PEG 8000	50
PEG_8000_65		65
PEG_8000_75		75
PEG_8000_80		80
PEG_12000_50	12 000	50
PEG_12000_65		65
PEG_12000_75		75
PEG_12000_80		80

Synthesized materials have been investigated and their properties have been compared in order to select the most appropriate material for stabilisation of electronic devices temperature. Phase transition temperature and value of latent heat absorbed during the transition have been characterised by differential scanning calorimetry and results are presented on figures 4 and 5. It has been observed that both properties depends on kind of polyethylene glycol used for synthesis.

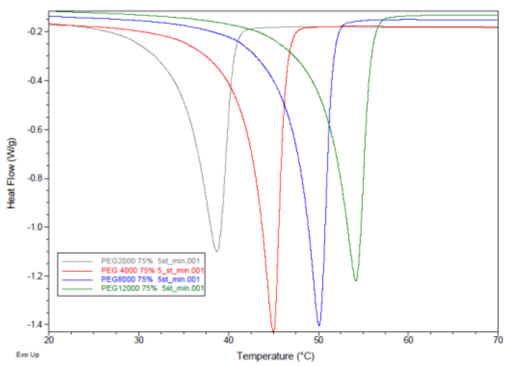

Figure 4. DSC curves for materials synthesized with the use of various kinds of PEG

Figure 4 presents DSC curves for materials synthesized with use of the same amount of PEG 2000 (grey curve), PEG 4000 (red), PEG 8000 (blue) and PEG 12000 (green).

DSC results gave information that phase change temperature changes when type of PEG is different. It can be presented as the following relationship:

$$T_{PEG2000} < T_{PEG4000} < T_{PEG8000} < T_{PEG12000} \quad (1)$$

The same relationship can be referenced for the enthalpy:

$$H_{PEG2000} < H_{PEG4000} < H_{PEG8000} < H_{PEG12000} \quad (2)$$

Latent heat and transition temperature increase for materials containing PEG of higher molecular weight.

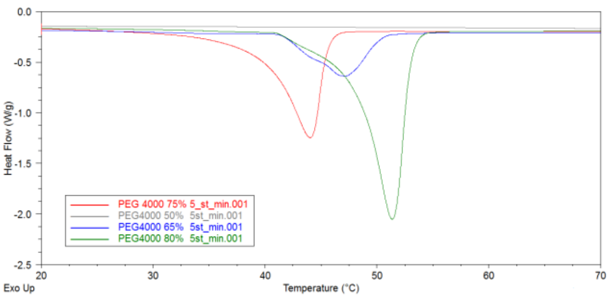

Figure 5. DSC curves for materials with different PEG ratio

Figure 5 presents DSC curves for materials containing various content of PEG 4000: 50% (gray curve), 65% (blue), 75% (red), 80% (green). It has been observed that heat of fusion is increasing while content of PEG is increasing. Transition temperature changes as well.

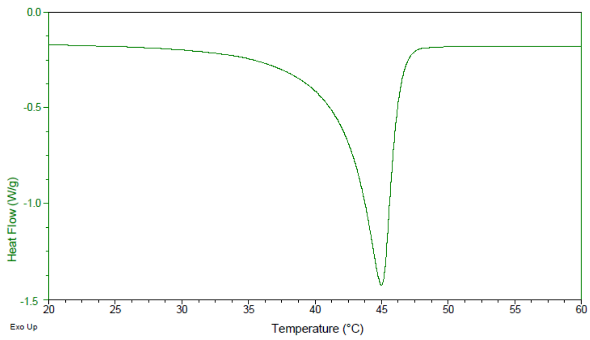

Figure 6. DSC curve for PEG_4000_75

For further research one material has been selected: PEG_4000_75. Transition temperature of this material has been presented in table 2 and DSC curves on the figure 6.

Table 3. PEG_4000_75 material properties

Phase change temperature °C		**Heat of fusion J/g**
Onset	41,0	61,4
Endset	48,5	
Peak	44,5	

3 Conclusion

Temperature stabilisation and heat dissipation during the period of operation of electronic devices is important and necessary for proper work. It is important to increase current solutions and develop new in this field. One of the possibilities which can be used is application of phase change materials, especially solid-solid phase change materials. Group of S-S PCMs are particularly important because of their great advantage. During the transition of S-S PCMs there is no gas or liquid generation, so possibility of leakage is unlikely. It reduces probability of devices damage or occurrence of corrosion. There is number of works carried out to increase possibility of use phase change materials for electronic devices cooling. Group of novel solid-solid phase change materials based on polyethylene glycol and cellulose has been synthesized and one of them has been chosen for further work and testing for the possibility of electronics temperature stabilisation. Preliminary results of tests on the synthesized materials confirmed the possibility of its use for this application.

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