Sodium Silicate Composite Filled by Zinc Oxide as Low Resistance Thermal Grease

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Abstract. Thermal interface material (TIM) is a solution for handling the heat generated by electronic components such as the central processing unit (CPU). CPU thermal management is important to maintain the performance and endurance of the CPU itself. Thermal interface material of the type of thermal grease in the form of a composite is very suitable for use on the CPU. Sodium silicate as a matrix and zinc oxide as fillers has many advantages compared to silicon and metal as the raw material for making thermal grease for CPU which is widely used today. This research aims to produce thermal grease for CPU that has better quality than those on the market today, especially when viewed from the value of thermal resistance. Thermal grease is made by mixing nanosized zinc oxide fillers and sodium silicate matrix with filler concentrations of 14 wt%, 18 wt%, and 20 wt%. Thermal resistance is determined by the application-specific test method against time and compared with thermal grease on the market today. The results showed that thermal grease with sodium silicate matrix and 16 wt% zinc oxide filler had 0.0123 °C/W of thermal resistance which was lower than the market thermal grease.

1. Introduction

The development of electronic components is very rapid at this time, especially for CPU, but along with the increasingly sophisticated CPU, the heat generated by the CPU will also be even greater [1]. This poses a challenge to keep the CPU temperature cool, as cold CPU temperatures will impact on performance, durability and good CPU efficiency [2]. To keep the CPU at the allowed operating temperature, not only heat sink as the cooling unit is used, but also third material called TIM [3]. A TIM serves to improve the area of heat transfer between the CPU and the heat sink which is reduced due to the surface roughness of both [4,5].

Generally, TIM is a composite with polymer matrix and filler which has high thermal conductivity [6]. The ideal TIM not only has a high thermal conductivity, but must have a small thermal expansion coefficient, and low thermal resistance [7]. TIM can be categorized as thermal fluid, thermal grease, resilient thermal conductor, and solder [7]. From those various types of TIM, thermal grease is the most suitable for CPU cooling [8].

The most common material used for thermal grease matrix is silicon, besides that thermal grease can also be made from sodium silicate, polyethylene glycol (PEG), and paraffin wax as a matrix [7, 9, and 10]. Among those several matrices of thermal grease, sodium silicate thermal conductivity is the highest one; even its thermal conductivity is almost close to solder, which is about 20.8x10⁻⁴ W/cm².°C [7, 10, and 11]. Apart from high thermal conductivity, sodium silicate also has a low viscosity of 127
cps which is far lower than silicon with a viscosity of 8,800 cps [7]. This shows good wetting ability and the ability to accommodate more filler. This is an advantage because of the more filler, the higher thermal conductivity of thermal grease [9].

The fillers commonly used in the manufacture of thermal grease are ceramics and metals, but ceramics are more recommended because they are insulators and have lower thermal expansion coefficient [7-9, and 12]. Research conducted by Sim et al. in 2005 stated that ceramic filled TIM with zinc oxide had better thermal conductivity and thermal stability than alumina filled TIM. Today, the best thermal grease for CPU on the market is silicon matrix and metal filled thermal grease which is very expensive [13]. With all the advantages possess by sodium silicate and zinc oxide, these two materials are very potential to be used as raw materials for the manufacture of thermal grease for CPU.

The aim of this work is to study the true characteristics of sodium silicate and zinc oxide composites as thermal grease for CPU. This work, of course, will be able to provide important data for the development of thermal grease in the future so that later thermal grease will have really good quality and can meet consumer desires.

2. Method
Sodium silicate used in this study was technical grade and obtained from Science Company while zinc oxide was nanosized pro analysis grade and obtained from Prevest DentPro. Thermal grease preparation was done by mixing sodium silicate and zinc oxide in a beaker glass in a certain amount as shown in table 1. The mixture was stirred at a speed of 60 rpm for 5 minutes.

| Sample | Composition | Thermal Grease (g) | Zinc Oxide | Sodium Silicate |
|--------|-------------|--------------------|------------|----------------|
| Sample 1 | 16          | 84                 |
| Sample 2 | 18          | 82                 |
| Sample 3 | 20          | 80                 |

Generally, most studies did not use the actual equipment in carrying out testing [3,6,10,14, and 15] this is considered unable to provide a real picture of the quality of the TIM produced when applied to actual working conditions. It is very good if the resulting TIM is tested with actual equipment. Testing with application-specific test methods is very suitable for testing TIM that is intended for special applications [16], as in this study where thermal grease is intended specifically to be applied to the CPU. Thermal resistance is a parameter of the performance of thermal grease, so it is important to measure to determine the quality of thermal grease [9]. Thermal resistances are obtained using equation (1).

\[ R = \frac{T_1 - T_2}{q} \]  

Where R is the thermal resistance, q the heat flowing (watt), T₁ the surface temperature of the electronic component (°C), T₂ the surface temperature of the heat sink (°C) used during testing. To measure the thermal resistance of thermal grease, first the CPU thermal design power (TDP) value was needed, the CPU TDP value was calculated as q. Thermal grease was weighed as much as m (g) and applied to the CPU by flattening it to cover the entire surface of the CPU. The CPU was installed on the computer motherboard, the heat sink was mounted on the computer's CPU, the thermocouple and the computer was turned on, and then CPU stress was run. At the same time the T₁ temperature of the CPU surface and T₂ temperature of the CPU heat sink surface was recorded, and then thermal resistance of thermal grease was calculated using equation (1). The value of thermal resistance was measured by time and compared with market thermal grease (TGP) which was a silicon matrix and
metal filled thermal grease. To maintenance the same and matches the CPU TDP for each experiment the CPU was stressed so that the CPU was forced to always work 100% (full load).

3. Result and discussion
The following is figure 1 which shows the thermal resistance of composites with sodium silicate matrix and zinc oxide fillers as thermal grease compared to TGP as a function of time.

![Figure 1. Thermal resistance of thermal grease as a function of time.](image)

Figure 1 shows that at 1-120 minutes the thermal resistance of thermal grease based on sodium silicate and zinc oxide, sample 1-3, are lower than silicon and metal based thermal grease, TGP. This indicates that sodium silicate and zinc oxide based thermal grease has better performance than silicon and metal based thermal grease as the lower thermal resistance, the better thermal grease performance [9 and 17]. The use of sodium silicate matrix which has a higher thermal conductivity [7] has a large influence on thermal resistance of thermal grease. In any fill composition, sodium silicate and zinc oxide based thermal grease always outperform silicon and metal-based thermal greases. The ability to deliver high heat from sodium silicate causes the heat generated by the CPU to flow more smoothly into the heat sink so that it did not accumulate much on the CPU surface. Compared to TGP, sodium silicate matrix composites and zinc oxide fillers as thermal grease have much lower thermal resistance. Another thing that can be identified is that the mass filler fraction has a good influence on the thermal resistance value of thermal grease with sodium silicate matrix and zinc oxide filler. For the filler mass fraction range from 0.18 to 0.20, the more filler contained in thermal grease, the lower the thermal resistance. This can be caused that thermal grease containing more fillers gets the effect of pump-out and dry-out effects [12] that are smaller than thermal grease which contains less filler. A greater number of fillers will slow down the movement of the matrix so that not many matrices come out of the interface.

The thermal resistance of all thermal greases has a positive tendency over time. This is considered as bad condition as the thermal resistance of a TIM must be as low as possible [9]. Thermal greases which viscosity decreases as a result of temperature rise will get the effect of pump-out. Thermal grease will be forced to migrate from the interface and can cause contamination. Aside from the pump-out effect, another thermal effect is also called a dry-out. This effect generally occurs in high temperature operations. At high temperature operation, it is possible to separate the thermal grease matrix and filler. The separation and loss of matrices can result in the poor wetting ability of thermal grease so that it can increase its thermal resistance [8]. Thermal grease will experience a decrease in viscosity and increase in wetting ability if the temperature rises, which is an advantage because it can reduce thermal resistance [8]. Based on this, theoretically, it can be estimated that the longer the running time then the thermal resistance of thermal grease should also decrease or at least remain. Figure 1 shows the opposite, thermal resistance of thermal grease continues to increase over time. This can occur as the dry-out effect takes place simultaneously with the pump-out effect. Migration from
thermal grease out of the interface is also followed by separation of the matrix and thermal grease fillers. As a result, the number of matrices left on the interface is increasingly not enough to wet the interface surface or in other words the thermal grease wetting ability decreases. It can be seen that the TGP thermal resistance appears to be more stable when compared to 1-3. The increase in thermal resistance of TGP was only 9.17% of its initial value, namely the value at 1 minute of testing, while for the 1-3 footage, the increase was 111.60%, 87.805 and 34.06% respectively. Based on the previous explanation, it can be seen that the effect of pump-out and dry-out that occurred in the thermal grease made from sodium silicate and zinc oxide resulted in a significant increase in thermal resistance.

The migration that occurs in sodium silicate and zinc oxide based thermal grease is proven by figure 2.

![Figure 2](image)

**Figure 2.** Migration patterns on sodium silicate and zinc oxide based thermal greases due to temperature changes. (a) Thermal grease migration before testing. (b) Thermal grease migration after testing for 120 minutes.

From figure 2, it can be identified that thermal grease moves from the CPU surface to the edge of the CPU. The effect of pump-out and dry-out that occurs due to changes in CPU temperature greatly affects the thermal resistance value of sodium silicate and zinc oxide based thermal greases, while this effect does not appear to occur in silicon and metal based thermal greases. Following is the migration pattern on silicon and metal based thermal grease shown in figure 3.

![Figure 3](image)

**Figure 3.** Migration patterns on silicon and metals based thermal greases due to temperature changes. (a) Thermal grease migration before testing. (b) Thermal grease migration after testing for 120 minutes.

The pump-out and dry-out effect on the silicon and metal based thermal grease do not appear to occur at all. This situation can be due to the far greater viscosity of silicon than sodium silicate [7], so that with an increase in temperature, silicon-based thermal grease does not become dilute enough to flow out of the interface. This situation is also evidenced by figure 3 which shows very small migration of silicon-based thermal grease. Based on this condition, the stability of thermal resistance from TGP can be explained.

4. Conclusion

Based on the results of the research that has been carried out, it shows that sodium silicate matrix composites and zinc oxide fillers as thermal grease have lower thermal resistance than the market thermal grease which is silicon matrix and metal filled thermal grease. The best thermal resistance of the produced thermal grease was obtained from a mixture of 84 wt% sodium silicate and 16 wt% zinc oxide with a value of 0.0123°C/W, while thermal grease with a mixture of 80 wt% sodium silicate and
20 wt% zinc oxide had the best thermal resistance stability which almost equaled the stability of silicon and metal based thermal grease with only 34% change of its initial value.

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