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Graphene Based Thermal Conducting Paste and a Standalone Embedded System for Measurement of Thermal Conductivity

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Abstract : Graphene is an allotrope of carbon which is arranged in a honey-comb lattice structure. It is the basic building block of all other carbon allotropes such as graphite, charcoal, carbon nanotubes and fullerenes. Graphene has many miraculous properties. It is hypothesized to be 100 times stronger than steel and it is the only 2-dimensional substance in the world. The thickness of one layer of Graphene is so negligible i.e. it is just one carbon atom thick and so its single layer is considered to be 2-D. It is nearly transparent and conducts heat and electricity efficiently.

This paper is based on exploiting the following properties of graphene:

Graphene is the best known thermal conductor.

Graphene forms bonds with a huge number of materials at molecular level.

Graphene exhibits a variety of properties under the influence of different constraints.

Thermal grease (also called CPU grease, heat sink compound, heat sink paste, thermal compound, thermal gel, thermal interface material, thermal paste) is a kind of thermally conductive (but usually electrically insulating) compound, which is commonly used as an interface between heat sinks and heat sources (e.g., high power consuming semiconductor devices). The main purpose of thermal grease is to eliminate air gaps or spaces which turn the junction into a dielectric layer (which act as thermal insulator) from the interface area so as to maximize heat transfer. [1]

This Thermal paste/grease we created is comprised of TE-Graphene and ZnO2 (Zinc Oxide) mixed with the base matrix Silicone Grease where ZnO_2 is the binding agent. The extraordinary thermal conductivity of graphene makes this paste much more efficient than its counterparts which uses filler materials like diamond, silver, Boron Nitride etc.

To measure the thermal conductivity of the aforementioned material, we have designed a standalone embedded system to measure its thermal conductivity. This system's functionality is verified using the calculation and verification of the thermal conductivity of two standard materials viz. copper and aluminium.

Keywords: Graphene, Carbon allotrope, Thermal conductivity, Thermal Paste, Heat sink Compound, Embedded system.

I. INTRODUCTION

Thermal grease (also called CPU grease, heat paste, heat sink compound, heat sink paste, thermal compound, thermal gel, thermal interface material, thermal paste) is a kind of thermally conductive (but usually electrically insulating) compound, which is commonly used as an interface between heat sinks and heat sources. The main purpose of thermal grease is to eliminate air gaps or spaces which turn the junction into a dielectric layer (which act as thermal insulator) from the interface area so as to maximize heat transfer.

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To measure the thermal conductivity of the aforementioned material, we have designed a standalone embedded system to measure its thermal conductivity. This system's functionality is verified using the calculation and verification of the thermal conductivity of two standard materials viz. copper and aluminium.

This system we created is uses four K-type thermocouples as temperature sensor at four distinct points spaced at a distance of 2.5cm each. These temperature sensors note the values of temperature at four points viz. T1, T2, T3, T4 where T1, is the initial temperature. At the initial position, a MCH (Micro Ceramic Heater) is used to heat the test substance to the desired temperature and calculate the heat transfer through the course of the length of the test slide.

Now the data collected by the sensors are logged into the ATMega328 Microcontroller on board the system's circuitry. A 16x2 LCD digital display is now used to display the current values of the sensors with a refresh rate of 1 ms, and there is also a display of elapsed time (ET) in the LCD.

The system also uses a PL2303HX USB to TTL – UART converter IC to receive data from the Microcontroller and then forward the same to a Computer via USB interface.

The temperature values measured by the system were also exported into an Excel sheet and a dedicated GUI using Visual Basic was created for the purpose of calculating the Specific Heat(C) and the Thermal Conductivity(K) of the sample. The GUI was designed in such a way that the GUI automatically imports the temperature values into it. After entering the other parameters, it returns the respective values of Specific Heat (C) and Thermal Conductivity (K).

A. Graphene

Graphene is a very thin layer of pure carbon. It is a tightly packed, single layered sheet of carbon atoms that are bonded together in a hexagonal honeycomb lattice structure. Scientifically, it is an allotrope of carbon in the structure of a plane of sp2 hybridised bonded carbon atoms with a molecular bond length of 0.142 nanometres. When numerous layers of graphene are stacked on top of each other, graphite is formed which is a black, unrefined form of pure carbon with an inter-planar spacing of 0.335 nanometres.

is the thinnest compound known which has a viable structure without support of any other kind of atom at one atom thick, the lightest material known (with 1 square meter coming having around 0.77 milligrams). It is the strongest compound discovered (100-300 times stronger than steel and having a tensile stiffness of $0.15x10^9$ psi). It is the best conductor of heat at room temperature (having a thermal conductivity of approx. 5.29 × 10^3 W/mK) and also the best conductor of electricity known.

Bearing this in mind, it is surprising to know that carbon is the second most abundant mass within the human body and the fourth most abundant element in the universe (by mass), after hydrogen, helium and oxygen. So carbon is the chemical and physical basis for all known life on earth, and therefore graphene could well be an environment friendly and sustainable solution for an almost countless number of applications. The problem that prevented graphene from initially being available for developmental research and uses commercial uses was that the manufacture of industrial grade graphene was a very expensive and complex process (of chemical vapour disposition) that involved the use of toxic chemicals to grow graphene as a monolayer by exposing Platinum, Nickel or Titanium Carbide to ethylene or benzene at high temperatures.

Being able to create super capacitors out of graphene will possibly be the largest step in electronic engineering in a very long time. While the development of electronic components has been progressing at a very high rate over the last 20 years, power storage solutions such as batteries and capacitors have been the primary limiting factor due to size, power capacity and efficiency (most types of batteries are very inefficient, and capacitors are even less so). For example, with the development of currently available lithium-ion batteries, it is difficult to create a balance between energy density and power density; in this situation, it is essentially about compromising one for the other.

B. Thermal Properties Of Graphene

Before discussing the detailed properties of Nano carbon materials, it is essential to define the main quantities of heat conduction and outline the Nano scale size effects. Thermal conductivity is introduced through Fourier's law, $q = -K\Delta T$, where q is the heat flux, K is the thermal conductivity and ΔT is the temperature gradient. Here, K is considered to be a constant, dealing in small temperature (T) variations. he increasing power and reduced die size of CPUs used in computers increases a need for significantly improved thermal interface materials (TIM). The TIM is applied in between sink and source to reduce contact resistance at the junction between CPU and heat sink interface. This paper provides an in-depth assessment on 'thermal interface materials', and also creates a new breed of TIM using Graphene. The performance and problems of new commercial interface materials is discussed, as well as discussion of the pros and cons of different materials used.

The plan area of CPUs has been steadily decreasing but the power dissipation from computing devices has been ever increasing. Comparing the die sizes, we can see that the die size of the Pentium 2 was 25.4 mm square and the power dissipation was about 33 but the Pentium 4 die is 12.5 mm square and it dissipates up to 80 W. So, the aim of this Graphene based Thermal Paste is to transfer max amount of heat generated form the surface of the processor to the heat sink.

C. Methods To Reduce Contact Resistance

For solids of high thermal conductivity, the contact resistance may be reduced by the following two methods: (1) increasing the area of contact spots, accomplished by (a)increasing contact pressure which will 'flatten' the peaks of the micro roughness, and deflecting the mating surfaces to reduce any non-flatness, or (b) reducing the roughness of the surfaces before the interface is formed by grinding the surfaces to remove non-flatness and buffing the surface to reduce micro roughness; and (2) using a TIM of high thermal conductivity that can conform to the imperfect surface features of the mating surfaces. Load constraints on electronic components and circuit boards make it unfeasible to use high contact pressure and also manufacturing highly finished surfaces is not feasible due to cost constraints. Therefore, the practical and feasible alternative to overcome this problem is to use a TIM applied at a moderate contact pressure.

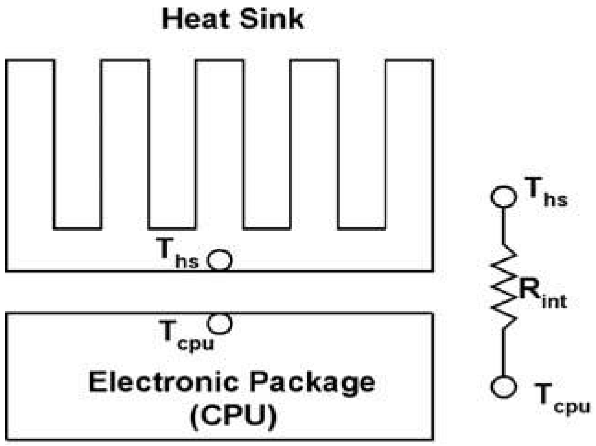
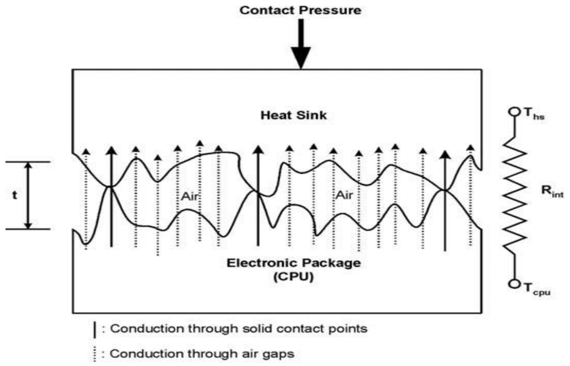


Fig 1: Heat Sink Junction



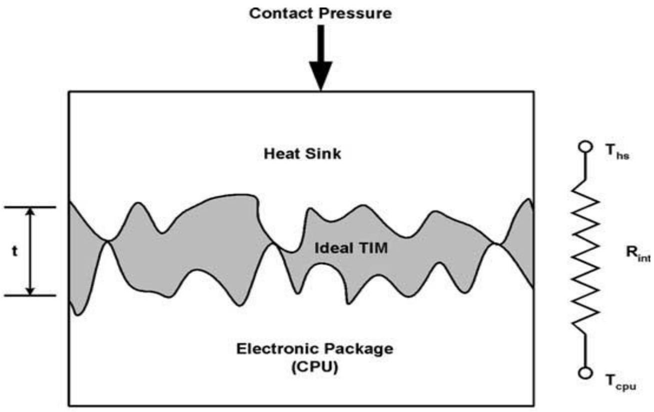


Fig3: heat sink interface with thermal grease

D. Standalone Thermal Analyser

A thermal analyser is a device that analyses the thermal conductivity of a material that is tested. It basically uses temperature sensors as probes to calculate the temperature at fixed points and then in turn calculates the amount of heat dessipitated from the initial point.

This system we created is uses four K-type thermocouples as temperature sensor at four distinct points spaced at a distance of 2.5cm each. These temperature sensors note the values of temperature at four points viz. T1, T2, T3, T4 where T1, is the initial temperature. At the initial position, a MCH (Micro Ceramic Heater) is used to heat the test substance to the desired temperature and calculate the heat transfer through the course of the length of the test slide.

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The system also uses a PL2303HX USB to TTL – UART converter IC to receive data from the Microcontroller and then forward the same to a Computer via USB interface. The temperature values measured by the system were also exported into an Excel sheet and a dedicated GUI using Visual Basic was created for the purpose of calculating the Specific Heat(C) and the Thermal Conductivity(K) of the sample. The GUI was designed in such a way that the GUI automatically imports the temperature values into it. After entering the other parameters, it returns the respective values of Specific Heat (C) and Thermal Conductivity (K).

The Atmel 8-bit AVR RISC-based microcontroller combines 32 kB ISP flash memory with read-while-write capabilities, 1 kB EEPROM, 2 kB SRAM, 23 general purpose I/O lines.The operating voltage is between 1.8-5.5 volts and it achieves throughput of approximately 1 MIPS per MHz.

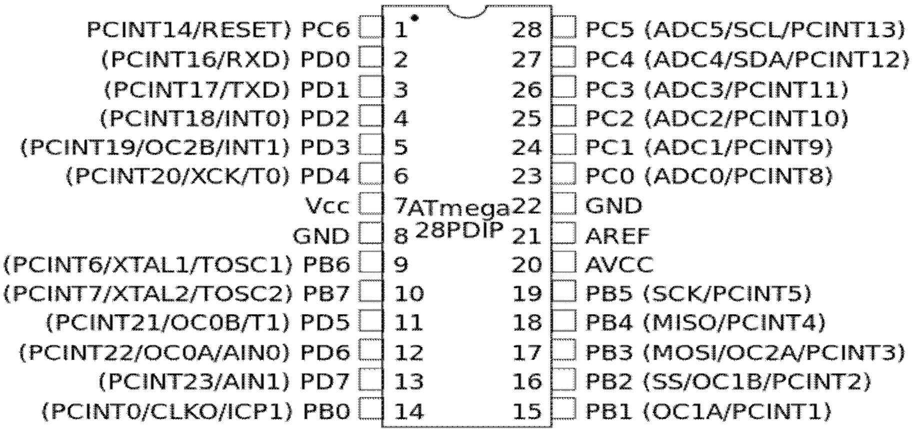


Fig 4: ATMega 328 Pin out Diagram

E. K-Type Thermocouple

A thermocouple is an electrical device consisting of two different conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent potential difference due to thermoelectric effect, and this voltage can be calculated and calibrated to measure temperature. Thermocouples are a widely used variety of temperature sensor.

Commercially, thermocouples are inexpensive and come with standard connectors. They can measure a wide range of temperatures. Unlike most other methods of temperature measurement, thermocouples are self-powered and they require no external form of power.

Fig 5: K-type Thermocouple

F. 16x2 LCD Display

LCD (Liquid Crystal Display) screen is an electronic display device. A 16x2 LCD display is a basic module commonly used in various devices and circuits. These LCD displays are preferred over seven segment displays and other multi segment LEDs as the reasons being: LCDs are economical; very easily programmable. Also they have no limitation of displaying special and even custom characters. A 16x2 LCD means it can display 16 characters in each row and there are 2 such row.

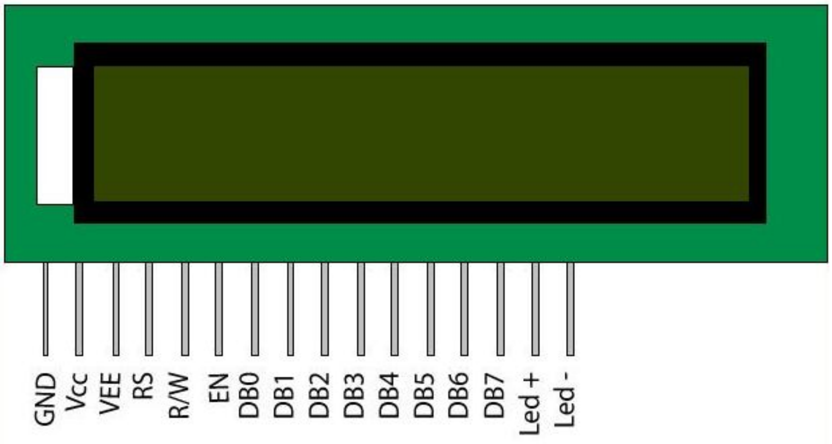


Fig 6: 16 x 2 LCD Display

Pin No	Function	Name
1	Ground (0V)	Ground
2	Supply voltage; 5V (4.7V – 5.3V)	Vcc
3	Contrast adjustment; through a variable resistor	V_{EE}
4	Selects command register when low; and data register when high	Register Select
5	Low-Write/ High-Read	Read/write
6	Sends data to data pins when a high to low pulse is given	Enable
7	8-bit data pins	DB0
8		DB1
9		DB2
10		DB3
11		DB4
12		DB5
13		DB6
14		DB7
15	Backlight V_{CC} (5V)	Led+
16	Backlight Ground (0V)	Led-

MAXIM IC MAX6675 Cold Junction Compensated K-Type Thermocouple to Digital Converter. This is an 8-pin SOIC attaches directly to any K-Type Thermocouple and it is interfaced using a SPI read-only interface. It works best with 8-pin SOIC to DIP adapters. It is a zero drift IC.

Pins

VCC - input voltage (+3.0 to +5.5 V) SCK bCS

T- negative thermocouple terminal (typically yellow for K-type)

T+ positive thermocouple terminal (typically red for K-type)

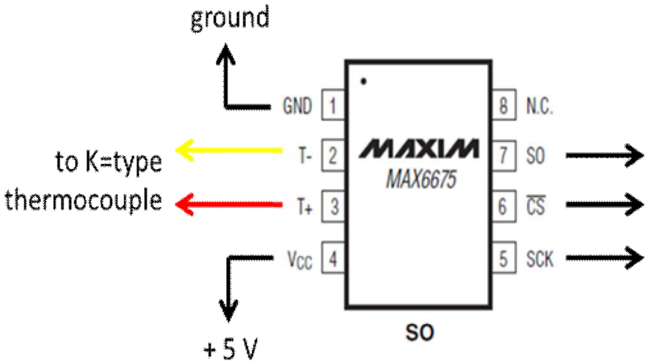


Fig 7: MAX6675 IC

G. Complete System

The assembly of the components made the complete system a standalone embedded system to measure thermal conductivity. Below are few images of the system that will illustrate the system.

Fig 8: complete setup of the thermal analyser

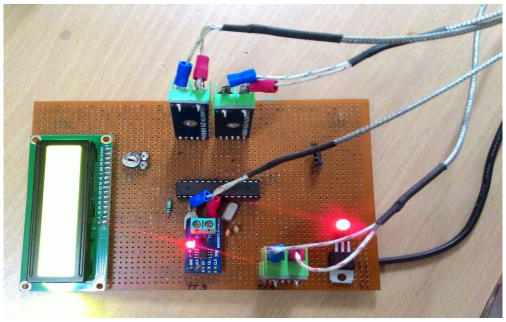


Fig 9: complete circuitry of the thermal analyser

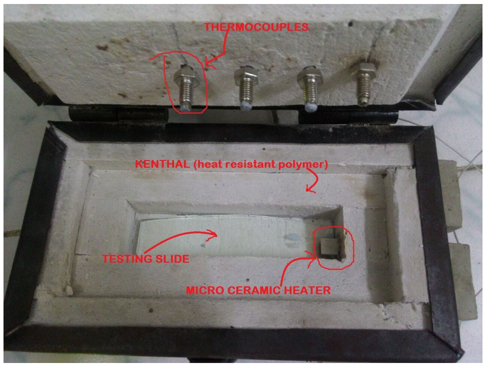


Fig 10: Description of the internal chamber

H. Results And Calculations

1) Calculation Of Specific Heat Of Te-Graphene: mw (mass of water) = 0.055gm
cw (specific heat of water) = 4186
Tw = 29 · C
m_x (mass of TE-Graphene) =0.000055 kg
T_x (initial temperature) = 29°C
T_f (Thermal equilibrium temp) = 31° C
C_x = ? $C_x = (m_w \times c_w \times (T2-T1)) \;/\; (m_x \times (T2-T1))$
C_x= 0.046 Kcal/Kg°C

I. Standardization Test Of The Device Using A Standard Material I.E Copper (Cu)

Thermal conductivity calculation of copper
T1 = 231
T2 = 114
t = 1 min
Therefore, T1-T2= 117°C
Again,
T1= 207
T2 = 113
t = 2 min
therefore, T1-T2= 94°C
Again,
T1=185
T2 = 106
t = 3 min
therefore, T1-T2= 79°C
Now, $(T1-T2)_{\text{average}}$ = 96°C
Now,
Q= m c (del T)
= 0.1063
Now,
K= (Q x d) / (A x del T x t)
now, the actual thermal conductivity of copper is 385 W/Mk and the obtained thermal conductivity is 392 W/Mk.
So, we can see that the the thermal conductivity calculation of the stanadard material has an error of ± 0.96 %
Hence, after the standardization test, we can confirm that the results output by the standalone embedded system is acceptable.
Thermal conductivity calculation of different batches of the experimental thermal grease having different proportions of filler material Thermal paste containing 10% ZnO_2 and 3 % TE-Graphene
T1 = 269
T2 = 201
t = 1 min
Therefore, T1-T2= 68°C
Again,
1= 205
T2 = 189
t = 2 min
therefore, T1-T2= 16°C
Again,
T1=180
T2 = 167
x d) / (A x del T x t)

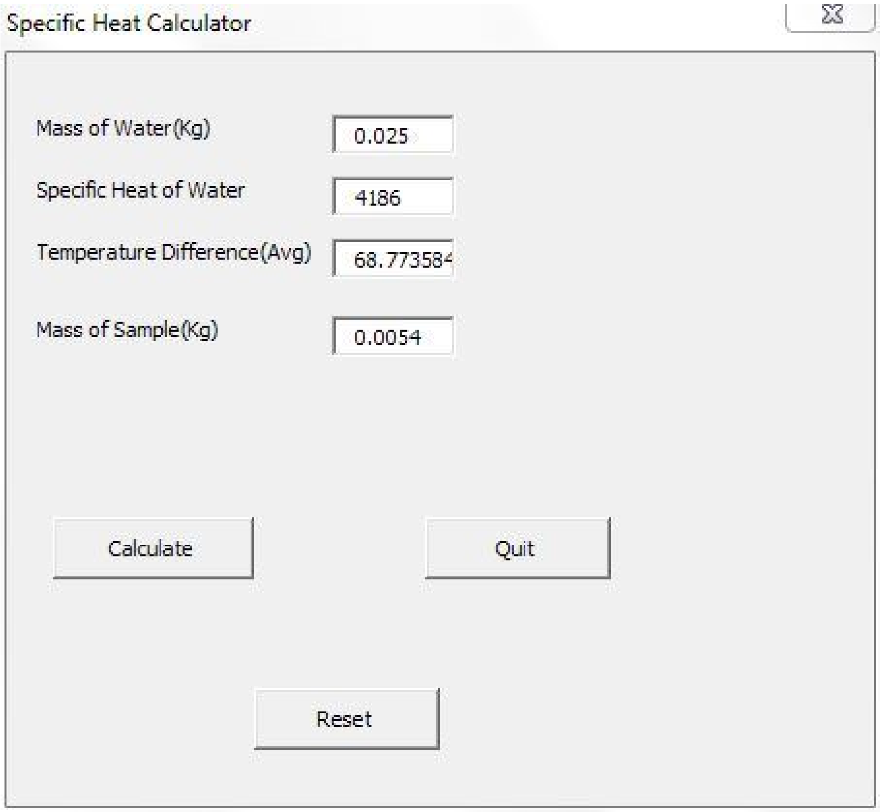
= 101.25 W/Mk
Thermal
T1 = 270T2 = 220t = 1 minTherefore, T1-T2= 50^{o}C
Again, T1= 201
T2 = 192t = 2 mintherefore, T1-T2 = 9^{o}C Again,T1=180T2 = 172
t = 3 mintherefore, T1-T2= 8^{o}C
Now,$(T1-T2)_{average}$ = 22.33^{o}C
Now, Q= m c (del T) = 0.324 JCx = 0.197 Kcal/Kg^{o}C
Now, K= (Q x d) / (A x del T x t = 134.34 W/Mk
Thermal paste containing 40 % ZnO_2 and 22 % TE-Graphene T1 = 270
T2 = 243t = 1 minTherefore, T1-T2= 27^{o}CAgain,
T1= 204T2 = 198t = 2 mintherefore, T1-T2= 6^{o}CAgain,T1=180T2 = 175t = 3 min
therefore, T1-T2 = 5^{o}CNow,$(T1-T2)_{average}$ =12.66 ^{o}C
Now, Q= m c (del T) = 0.324 JCx = 0.197 Kcal/Kg^{o}C Now,
K= (Q x d) / (A x del T x t) = 263.96 W/Mk

Thermal paste purchased from market named – Silvo heat sink compound The aforementioned thermal compound is tested in the similar fashion in our standalone Thermal analyser and our proprietary GUI developed by us calculated its thermal conductivity to be 67.143 W/Mk.

Thermalpaste purchased from market named – IDL heat sink compound

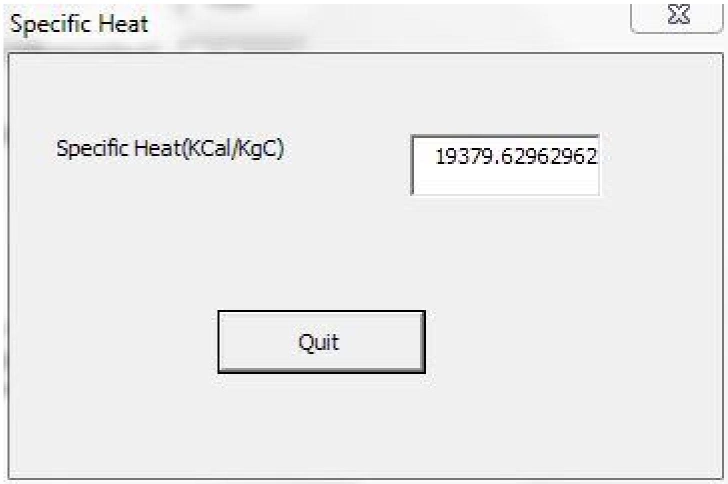
The aforementioned thermal compound is tested in the similar fashion in our standalone Thermal analyser and our proprietary GUI developed by us calculated its thermal conductivity to be 122.24 W/Mk.

To calculate the different values such as thermal conductivity, specific heat, heat transfer a proprietary GUI was developed. The screenshots of the said GUI are as follows:


Specific Heat Calculator

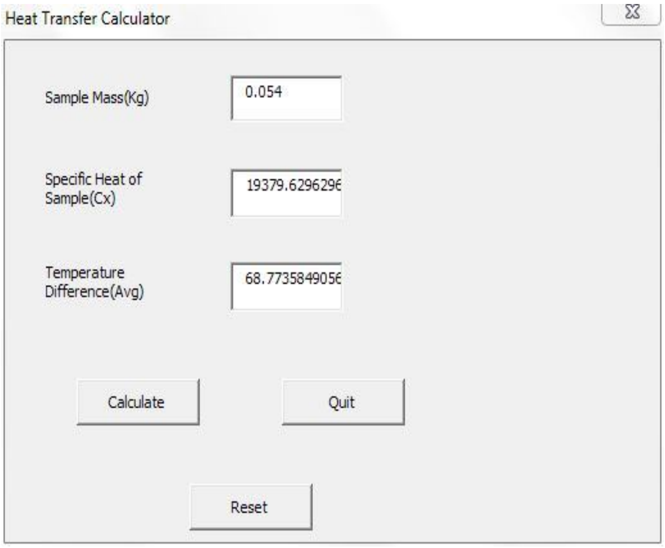
Mass of Water(Kg)	0.025
Specific Heat of Water	4186
Temperature Difference(Avg)	68.773584
Mass of Sample(Kg)	0.0054

Fig 11: GUI for calculating the Specific Heat



Specific Heat(KCal/KgC) 19379.62962962

Fig 12: GUI for displaying the Specific Heat result

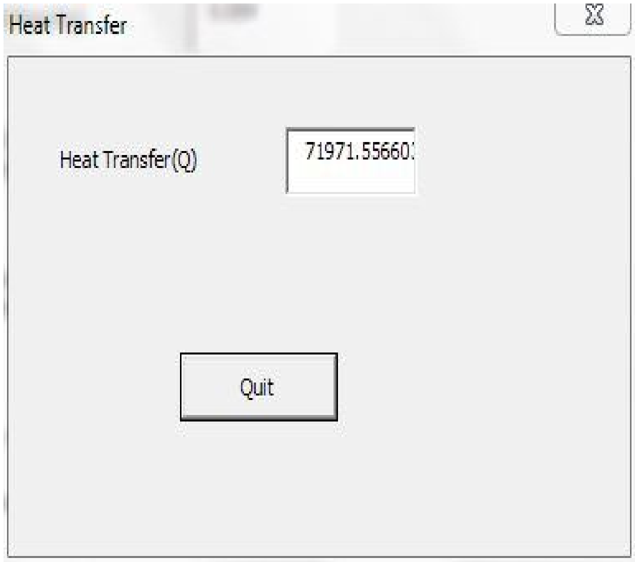


Sample Mass(Kg) 0.054

Specific Heat of Sample(Cx) 19379.6296296

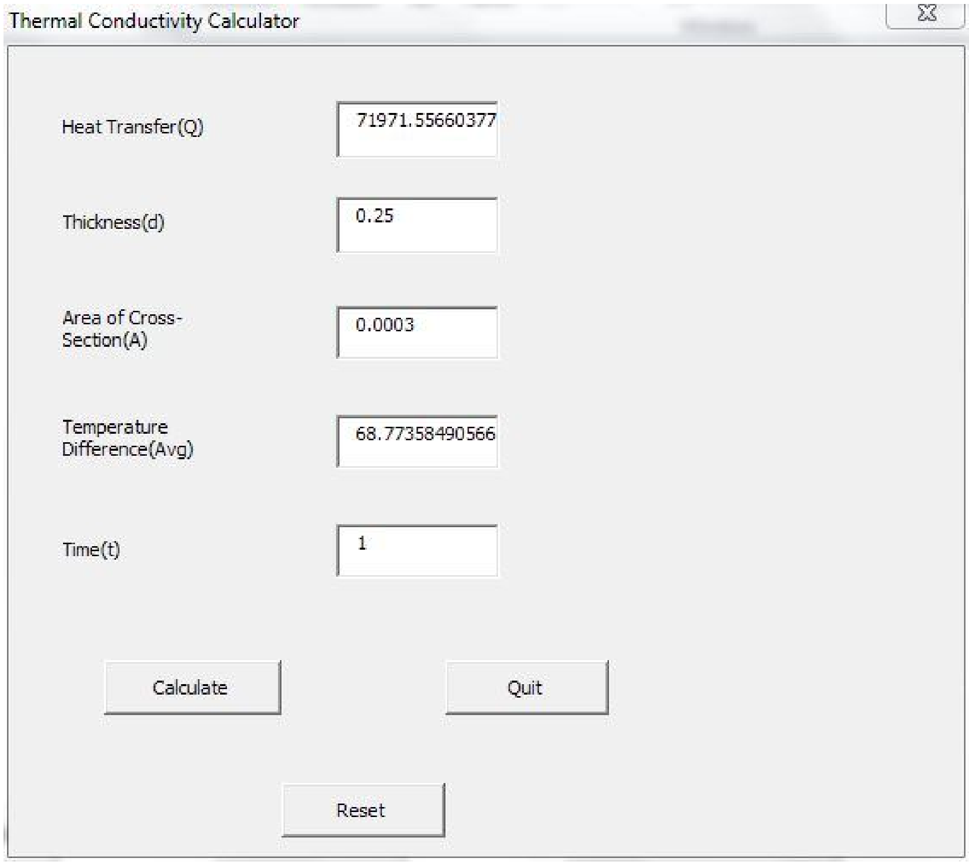
Temperature Difference(Avg) 68.7735849056

Fig 13: GUI for calculating Heat Transfer



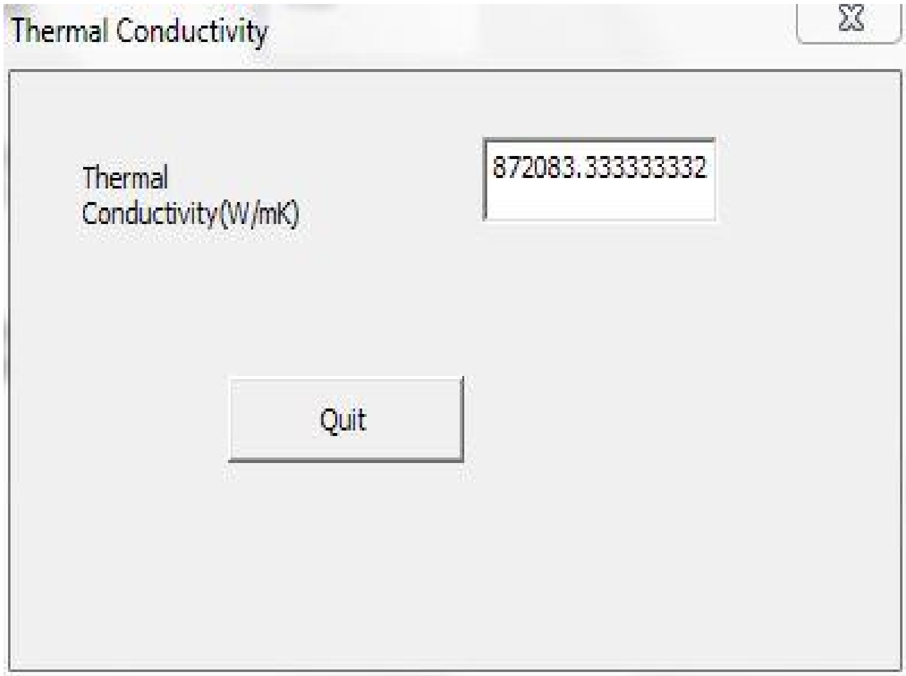
Heat Transfer(Q) 71971.55660

Fig 14: GUI for displaying the Heat Transfer result



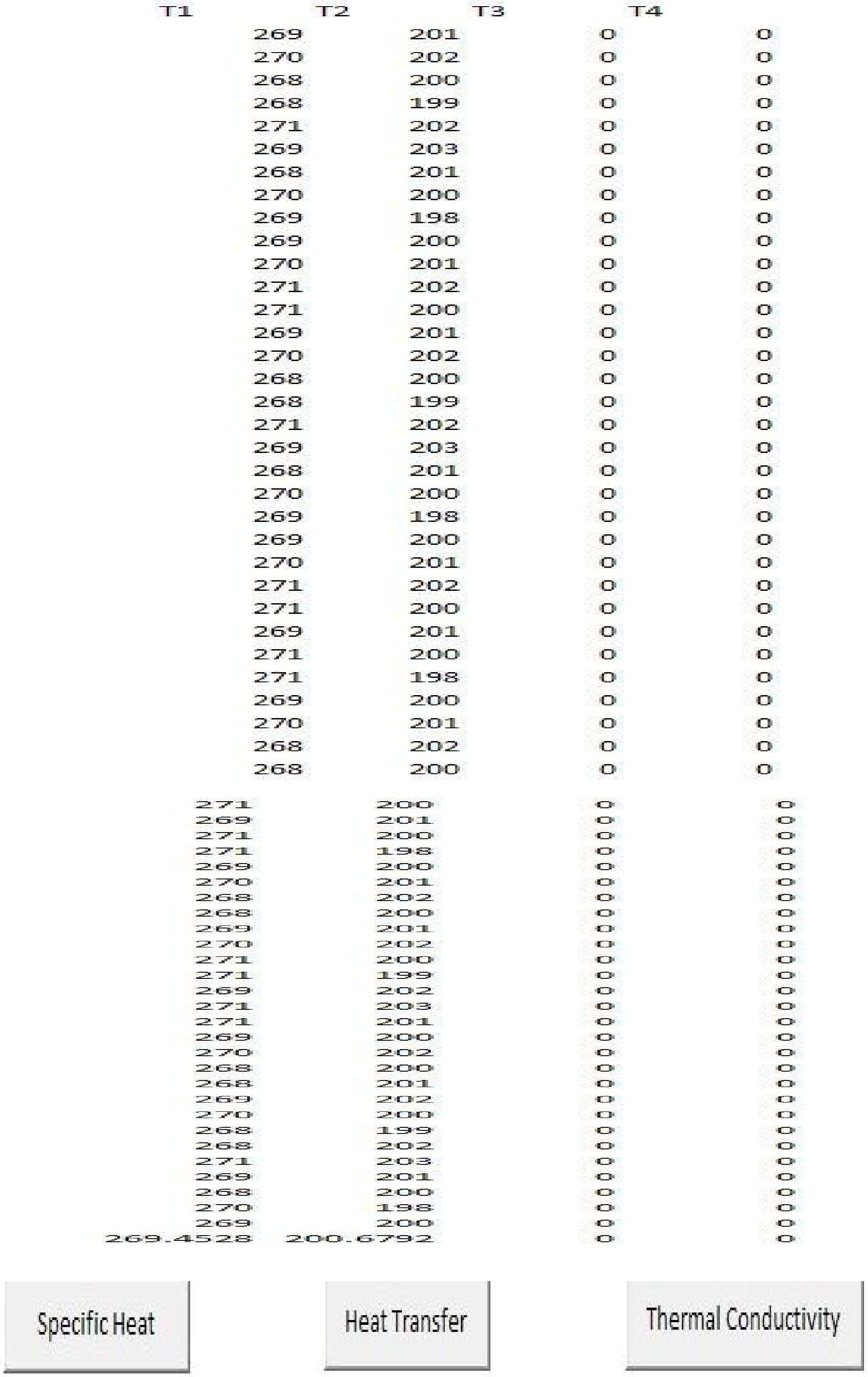
Heat Transfer(Q) 71971.55660377
Thickness(d) 0.25
Area of Cross-Section(A) 0.0003
Temperature Difference(Avg) 68.77358490566
Time(t) 1

Fig 15: GUI for calculating the Thermal Conductivity



Thermal Conductivity(W/mK) 872083.333333332

Fig 16: GUI for displaying the Thermal Conductivity result



T1	T2	T3	T4
269	201	0	0
270	202	0	0
268	200	0	0
268	199	0	0
271	202	0	0
269	203	0	0
268	201	0	0
270	200	0	0
269	198	0	0
269	200	0	0
270	201	0	0
271	202	0	0
271	200	0	0
269	201	0	0
270	202	0	0
268	200	0	0
268	199	0	0
271	202	0	0
269	203	0	0
268	201	0	0
270	200	0	0
269	198	0	0
269	200	0	0
270	201	0	0
271	202	0	0
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268	200	0	0
268	201	0	0
269	202	0	0
270	200	0	0
268	199	0	0
268	202	0	0
271	203	0	0
269	201	0	0
268	200	0	0
270	198	0	0
269	200	0	0
269.4528	200.6792	0	0

Table 1: Temperature readouts from the system

The following are the graphs for different values of the different tested thermal compounds:

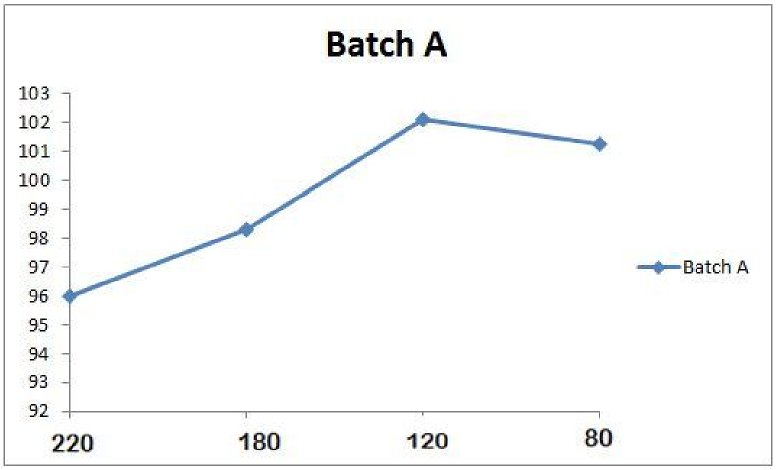

Fig 17: Graph for Batch

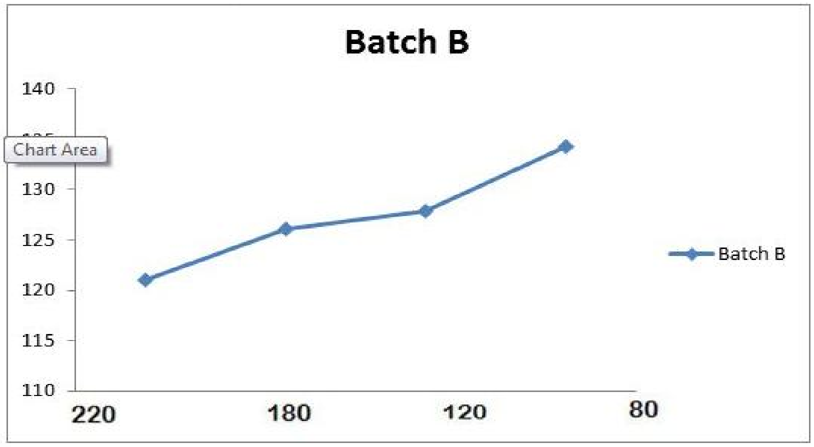

Fig18: Graph for Batch B

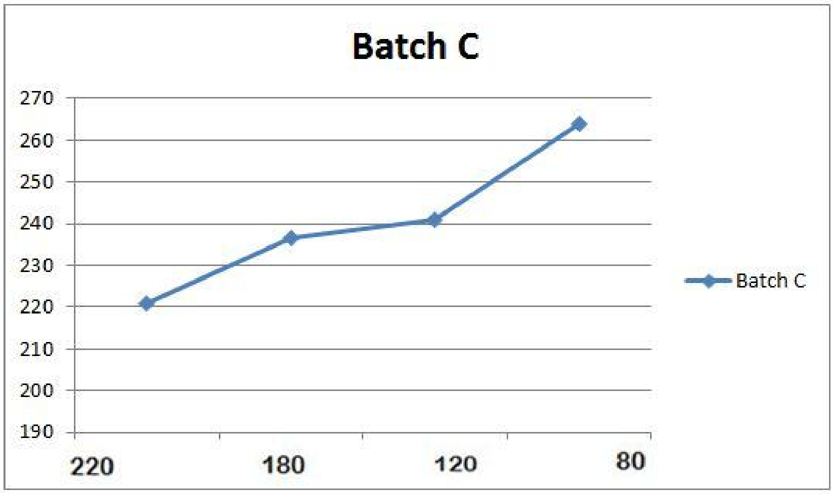

Fig19: Graph for Batch C

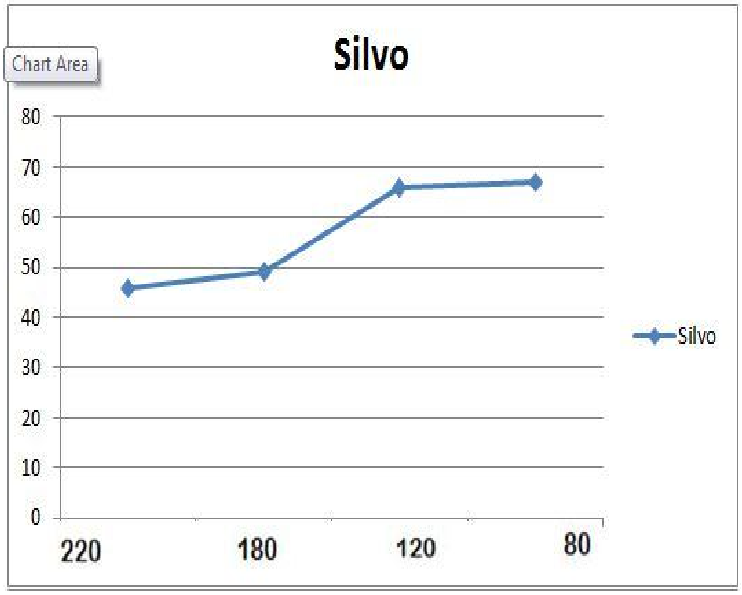

Fig 20: Graph for Silvo

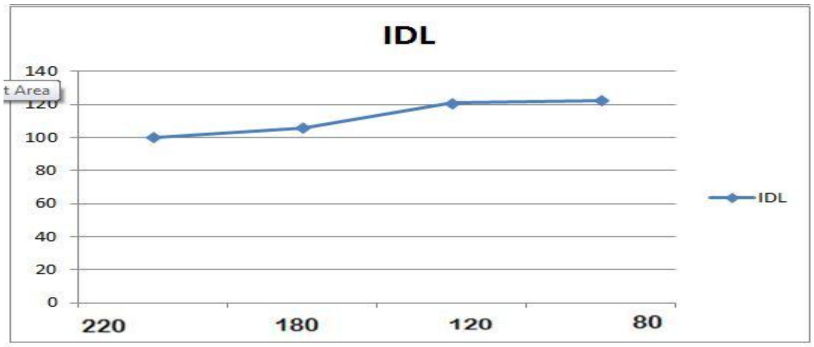

Fig 21: Graph for IDL

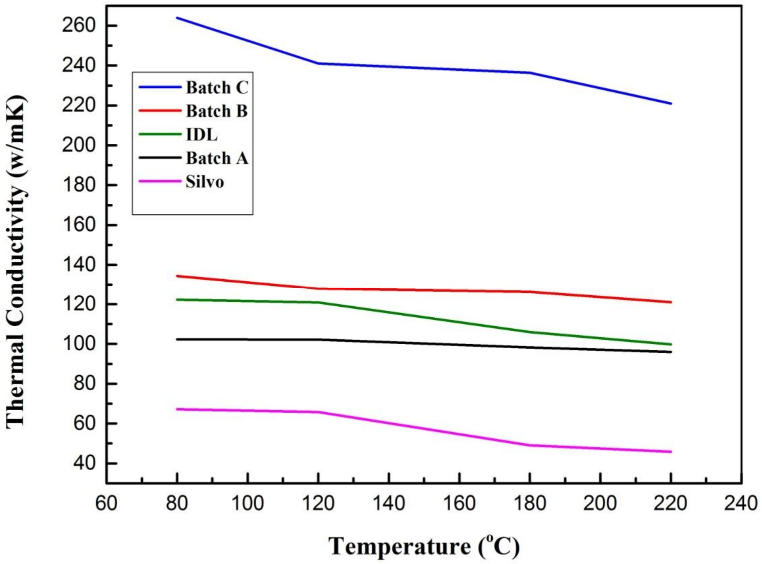

Fig 22: Graph for comparative thermal conductivities

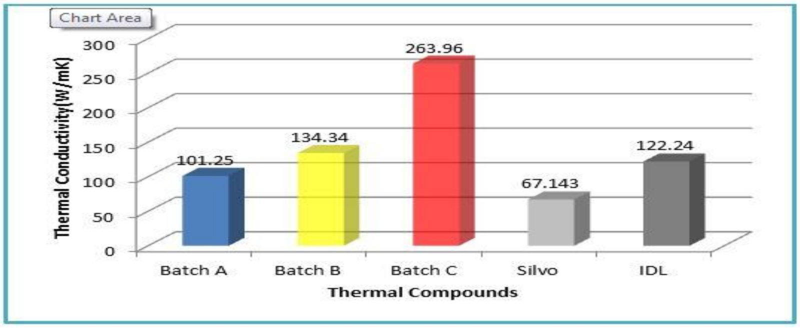

Fig 23: Bar graph of all the tested materials

II. CONCLUSION

As it is evident from the above graphs, we can see that the thermal conductivity of all thermal compounds increases with rise in temperature. Moreover we can see that among all the thermal greases we tested, it is found that Batch C has the best thermal conductivity. And hence we can conclude that Graphene is a feasible as well as better thermal compound. The future scope of this thermal compound is that by different iterations, we can see that there are endless possibilities of creating thermal compound having much higher thermal conductivity. And also the standalone thermal analyser can be used to analyse solids, liquids and gases.

III. ACKNOWLEDGEMENT

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