Heat energy transfer to space via graphene : Heat transfer analysis

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Abstract
The idea of transferring heat via graphene is analysed with respect to altitude in COMSOL Multiphysics and results have been documented in this paper.

Keywords
Graphene, Heat transfer, 2d analysis, COMSOL, Space.

Introduction
Graphene has been renowned as a wonder material and the author have tried to test this in heat transfer in solids(ht) module of COMSOL Multiphysics.

The properties used are:
i) Thermal conductivity : 3080-5150 W/mK [1] (for this analysis ~ 4000)

ii) Density : close to that of crystalline graphite ~ 2.267 g/cm^3

iii) Heat capacity : 0.643-2.10 J/g.K ~ 1.4 J/gK [2]

It should be kept in mind that the analysis depends on the properties chosen, and not the actual graphene sheets.

Design and analysis
Three designs have been made to test with convective heat flux of 5 W/m^2K in 2d with dimensions 1 x 1 mm, 1 x 10 mm and 1 x 100 mm.

i)

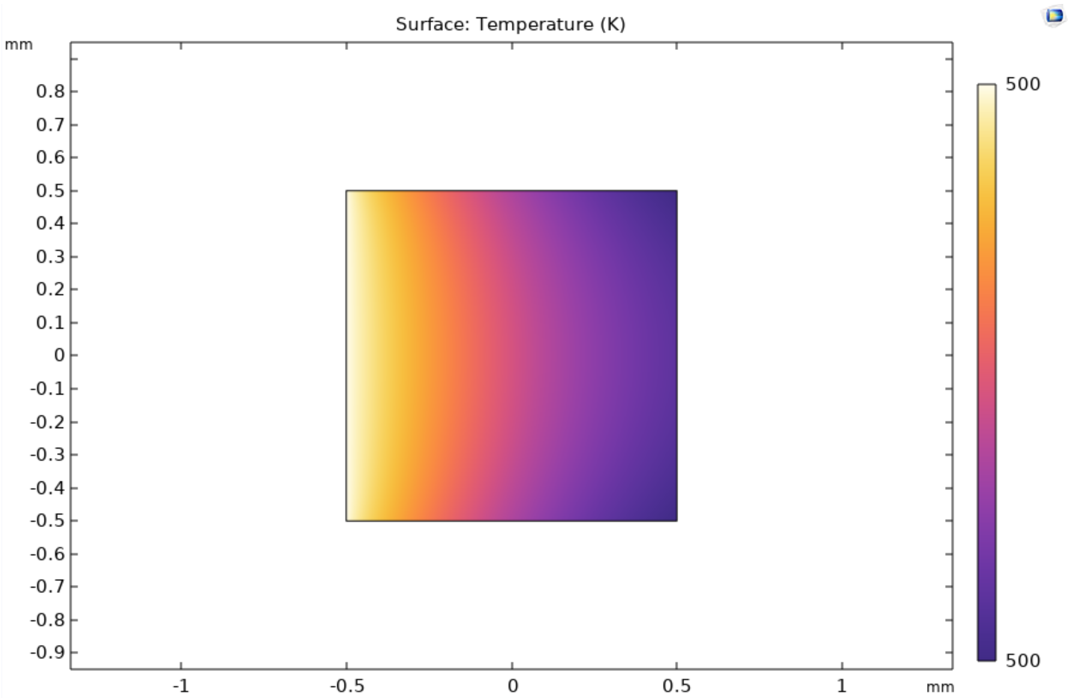


Figure 1

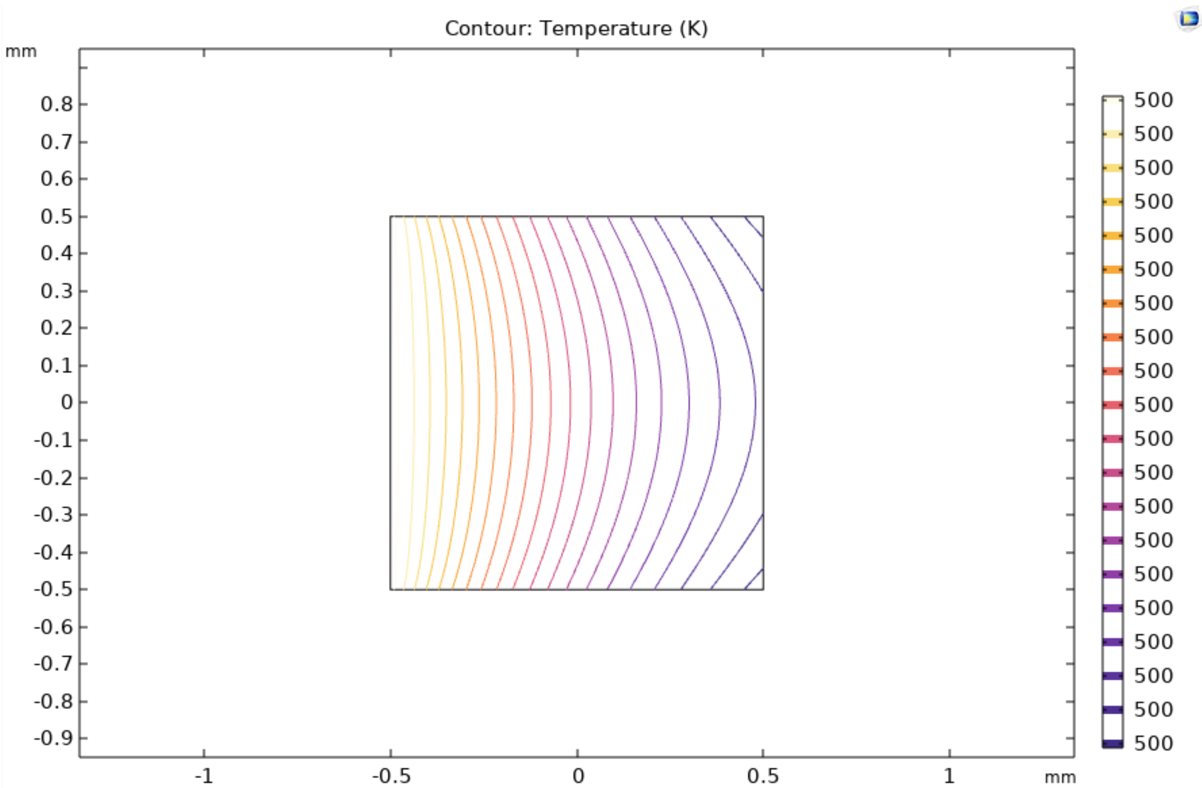


Figure 2

Figure 1 and 2 show the results for 1 x 1 mm graphene strip with left side given 500K temperature with convective heat flux as mentioned earlier.

ii)

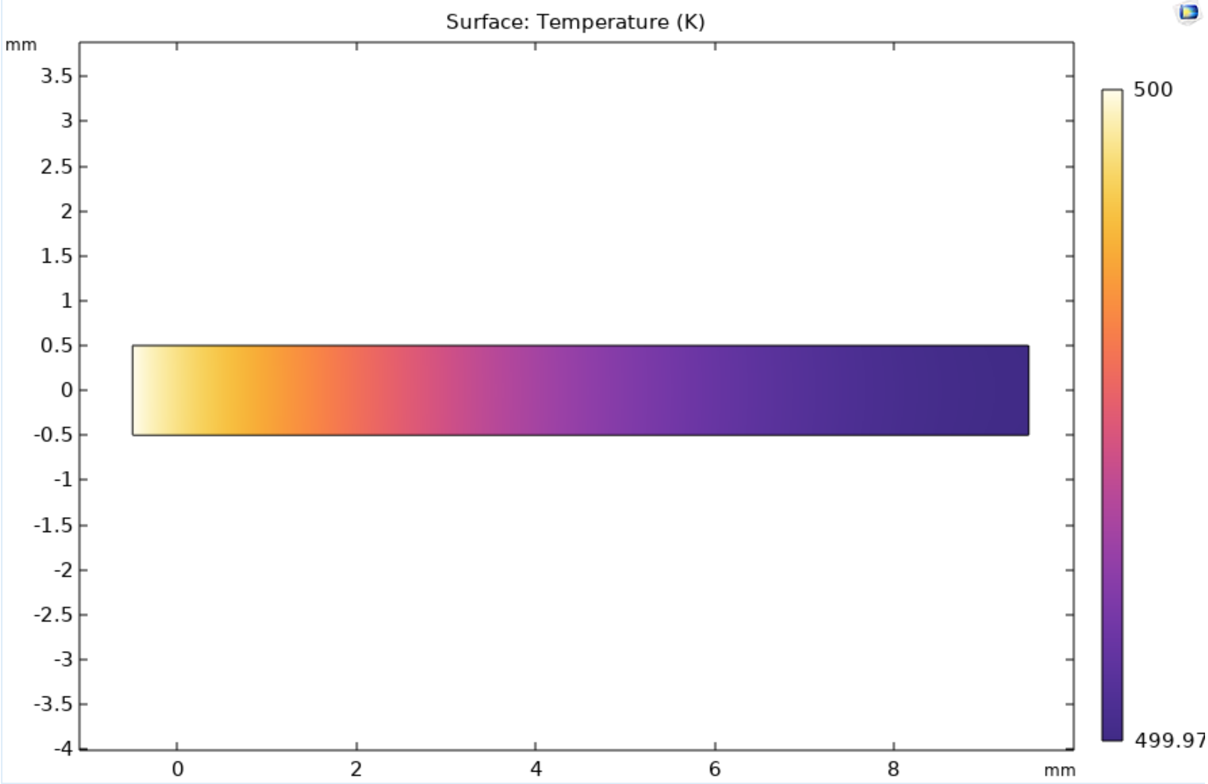


Figure 3

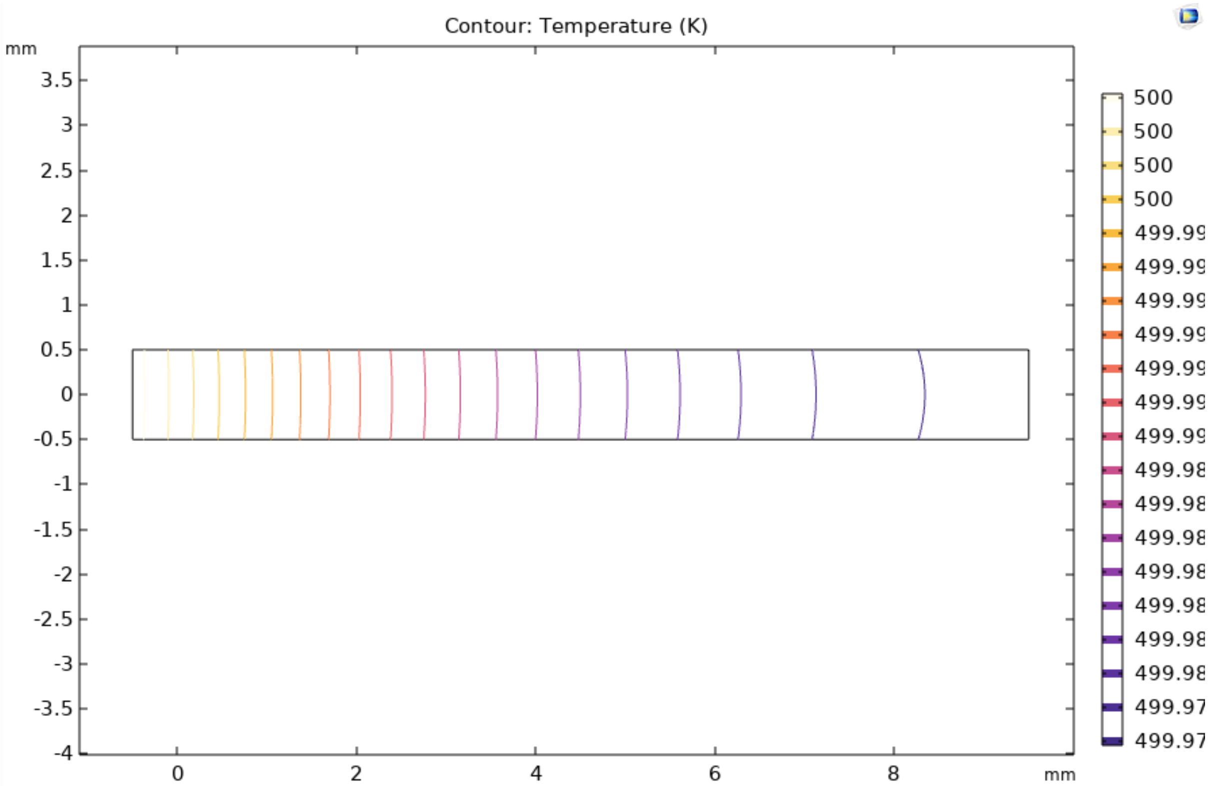


Figure 4

Figure 3 and 4 depicts analysis results with 1 x 10 mm strip and here the decline of temperature is evident unlike 1 x 1 mm.

iii)

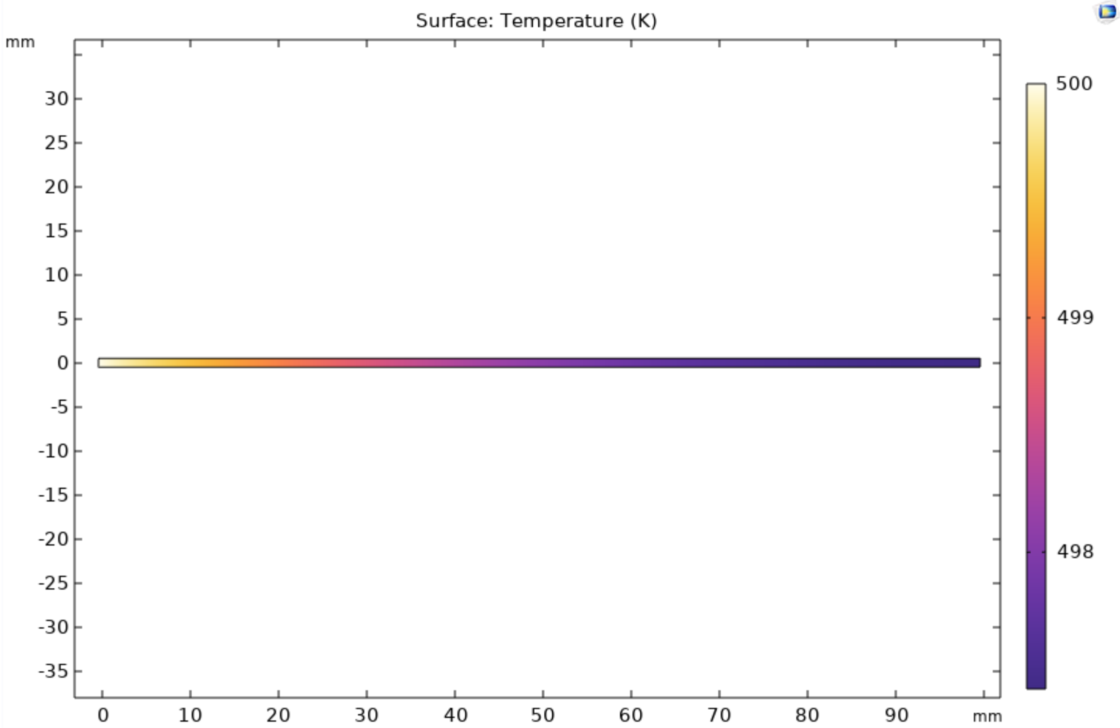


Figure 5

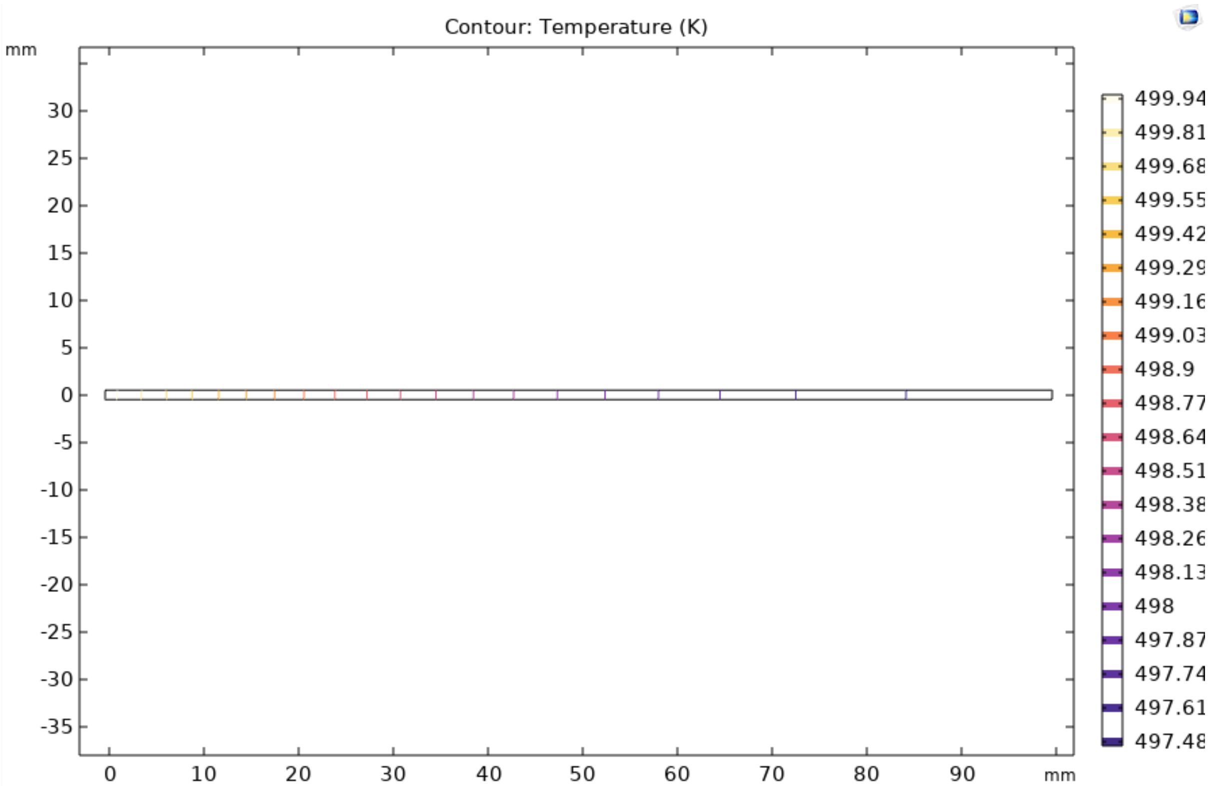


Figure 6

Figure 5 and 6 illustrates the results achieved with 1 x 100 mm dimensions and it is worth noting that the contour plots 20 lines within the 100 mm boundary so at the mark 100mm from temperature source <497.48 K temp is there, the plot shows 497.48 K at around 85mm.

The next part requires dimensions equivalent to the sorts of space elevators with dimensions of 1 x 500000000 mm (500km) but due to the limitations of the software and authors skills 1 x 1000 and 10000 mm have been achieved to be further plotted for a coarse estimation.

i) x 1000

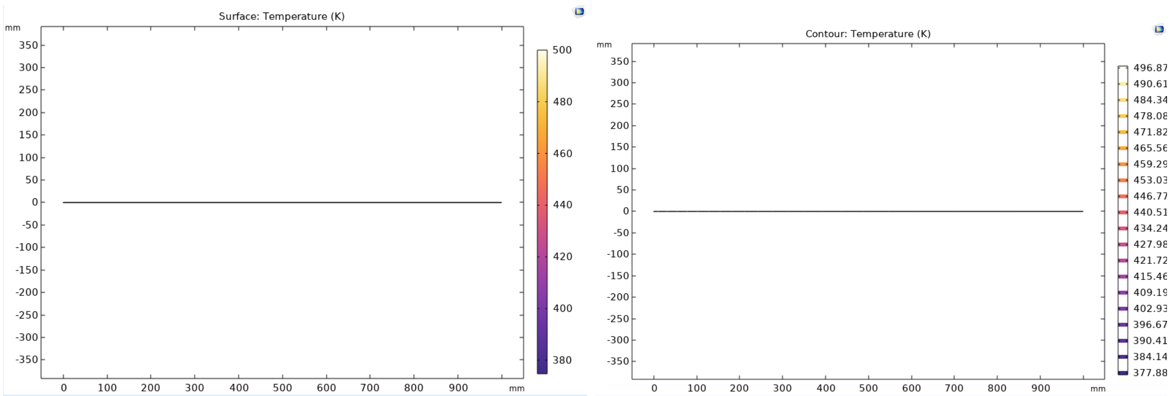


Figure 7 & 8

Figure 7 & 8 plots show a drop of about 133 K.

i) x 10000 mm

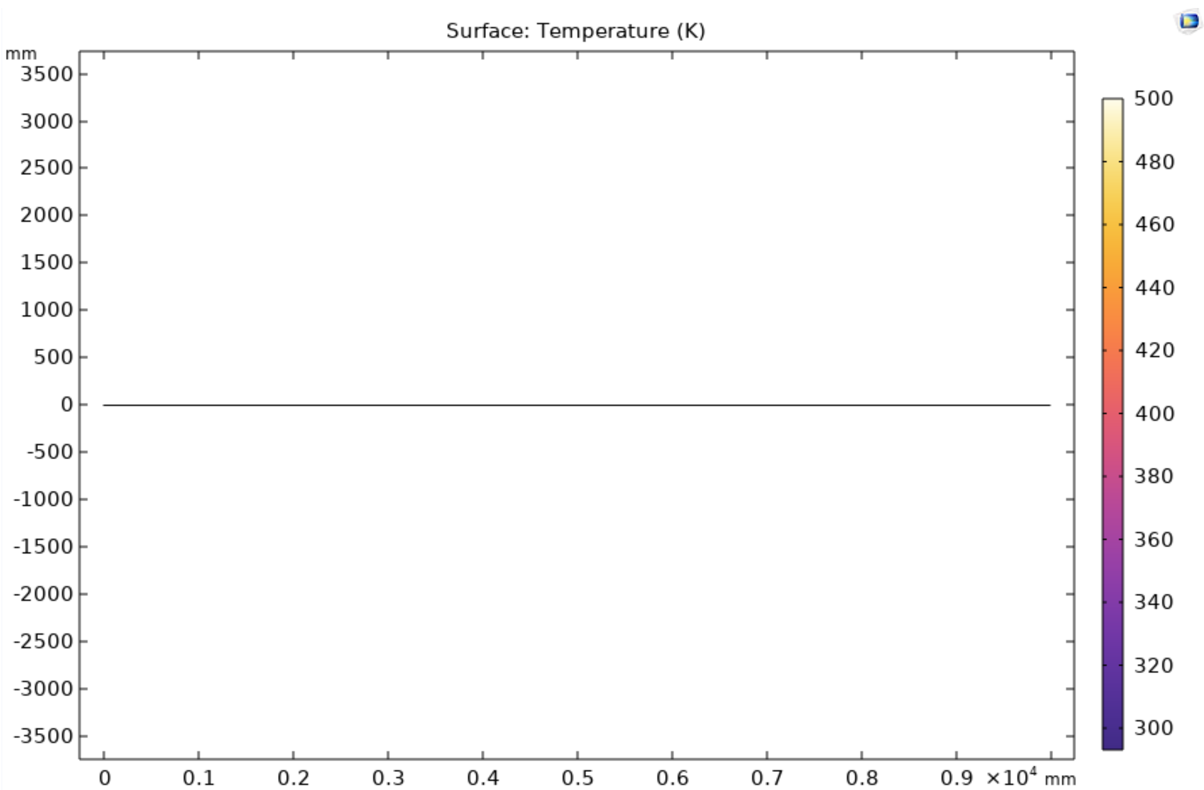


Figure 9

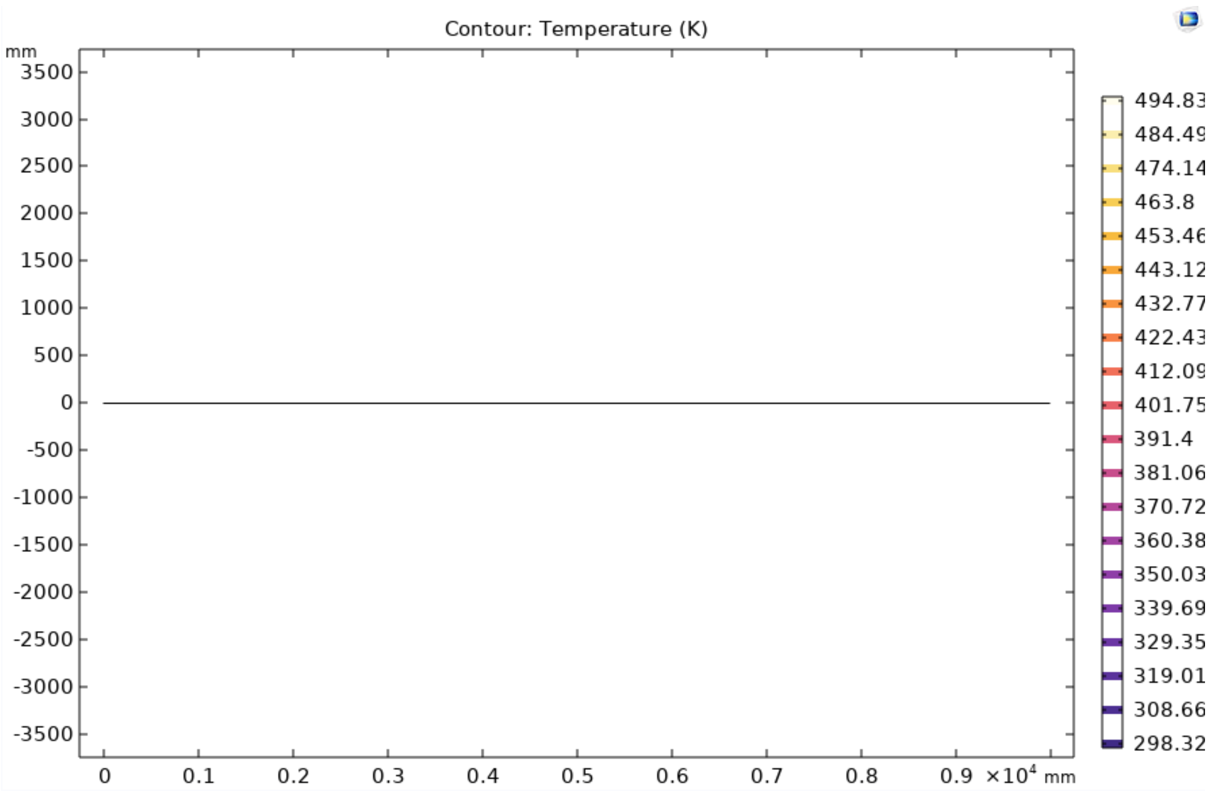


Figure 10

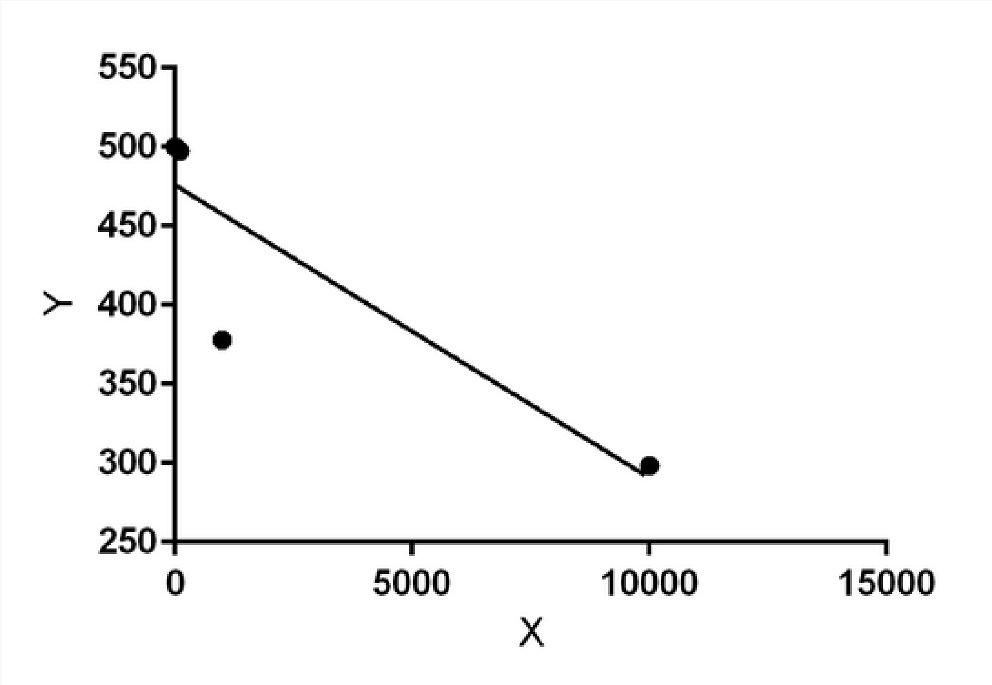
Here, figure 10 shows the drop of over 300k due to applied natural convection (convective heat flux of 5 W/m^2K) which suggests the lower part of the graphene cable, if made, must have insulation!

Conclusion

Mm	K
1	500
10	499.97
100	497.48
1000	377.88
10000	298.32

With above data at hand linear regression gives following output:

Linear Regression



Best-fit values	
Slope	-0.01853 ± 0.005947
Y-intercept	475.9 ± 26.73
X-intercept	25687
1/Slope	-53.98
95% Confidence Intervals	
Slope	-0.03745 to 0.0003963
Y-intercept	390.8 to 561.0
X-intercept	13498 to +infinity
Goodness of Fit	
R square	0.7639
Sy.x	51.95
Is slope significantly non-zero?	
F	9.705
DFn,DFd	1,3
P Value	0.0527
Deviation from horizontal?	Not Significant
Data	
Number of XY pairs	5
Equation	Y = -0.01853*X + 475.9

Figure 11 [3]

And nonlinear regression gives:

Regression type	Approximation formula	Coefficient of determination R^2
Polynomial regression of 2-th degree	Show source $y = \frac{58187}{5000000000} x^2 - \frac{684678279}{5000000000} x + \frac{5039293401893}{10000000000}$	0.997886868
Polynomial regression of 3-th degree	Show source $y = \frac{3}{250000000} x^3 - \frac{1202659}{10000000000} x^2 - \frac{138824271}{10000000000} x + \frac{5000646119731}{10000000000}$	0.961511751
Logarithmic regression	Show source $y = 539.82 - 22.8200035516 \cdot ln\left(x\right)$	0.805099708
Exponential regression	Show source $y = \frac{4791220936623}{10000000000} e^{\frac{-19871}{400000000} x}$	0.782912531
Linear regression	Show source $y = \frac{-92634399}{5000000000} x + \frac{1189751080729}{2500000000}$	0.763880573
Polynomial regression of 1-th degree	Show source $y = \frac{-92634399}{5000000000} x + \frac{4759004323899}{10000000000}$	0.763880573
Power regression	Show source $y = \frac{5538322380507}{10000000000} x^{\frac{-570165307}{10000000000}}$	0.734790496
Polynomial regression of 0-th degree	Show source $y = \frac{43473}{100}$	0
Polynomial regression of 4-th degree	Show source $y = \frac{1537}{10000000000} x^3 - \frac{2625417}{10000000000} x^2 - \frac{4776341}{10000000000} x + \frac{1250002012257}{2500000000}$	-475092.490184
Polynomial regression of 5-th degree	Show source $y = \frac{1}{10000000000} x^4 + \frac{49}{2500000000} x^3 - \frac{626219}{2500000000} x^2 - \frac{4705737}{10000000000} x + \frac{250000126501}{500000000}$	-28854476.4095

Figure 12 [4]

With coefficient of determination ~ 0.99 as shown below in figure 13.

Measurement points	
Number of points	5
Points you entered	(1, 500), (10, 499.97), (100, 497.48), (1000, 377.88), (10000, 298.32)
Approximation	
Regression type	Polynomial regression of 2-th degree
Function formula	Show source $y = \frac{58187}{5000000000} x^2 - \frac{684678279}{5000000000} x + \frac{5039293401893}{10000000000}$
Coefficient of determination R^2	0.997886868

Figure 13

Thus, heavy insulation at the lower end is a necessity which can be achieved with other wonder materials like sorbothane and/or aerogel.

References

[1] “Experimental review of graphene” Daniel R. Cooper, Benjamin D’Anjou, Nageswara Ghattamaneni, Benjamin Harack, Michael Hilke, Alexandre Horth, Norberto Majlis, Mathieu Massicotte, Leron Vandsburger, Eric Whiteway, and Victor Yu, McGill University, Montreal, Canada, H3A 2T8

[2] “Thermophysical properties of graphene-based nanofluids” KhaledElsaid

[3] https://www.graphpad.com/quickcalcs/linear1/

[4] https://calculla.com/regression_calculator