THERMODYNAMICS AND NANOTECHNOLOGY FOR 5G COMMUNICATION TECHNOLOGY AND ENERGY HARVESTING

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5G communication technology has been skyrocketing, and has changed everything in our daily lives, and its applications in various fields are also promising. However, the thermal conductivity/dissipation problems of highly integrated electronic devices and electrical equipment are becoming more and more prominent, and thermodynamics offers a solution, and fractal meta-surfaces provides an extremely efficient approach to transfer the generated waste heat, which can be used for thermal energy harvesting, and a fractal thermodynamic model is developed for thermal management.
Keywords: Natural fiber(wool fiber, polar bear hair), nanofiber, nanofilm, nanofluid, nanoparticle, fractal boundary layer, fractal metamaterial, fractal metasurface

1. Introduction

We have entered an unprecedented era with 5G communications technology[1], the trend towards 6G is now on the horizon[2], and the 7G era[3] is also approaching rapidly. It has changed everything in our daily lives. According to the 2023 China Internet Development Report, by June 2023, the total number of mobile base stations in China reached 11.29 million, of which 2.937 million 5G base stations were built and opened, where energy consumption has become a Gordian knot[4]. Communication equipment often generates high temperature alarms[5], and many cooling technologies[6] and thermal energy harvesting technologies[7,8] have become hot spots in the communication field, this paper offers a promising thermodynamic solution to the emerging problem.

2. Thermal conductivity and thermal efficiency

Thermal management has become a critical issue for high power density equipment and devices[9,10] The high temperature due to high power dissipation and poor thermal conductivity will not only greatly affect the reliable operation of equipment and devices in 5G base stations, but also significantly increase the cost of controlling the temperature of the stations.

Materials scientists have been searching for new materials with high thermal conductivity and thermal efficiency for 5G base stations[11,12,13], among which nanomaterials are extremely promising, and bubble electrospinning[14-18] is one of the best candidates for mass fabrication of various functional nanomaterials, it has the ability to fabricate a single nanofiber with two or more interfaces[18]. This breakthrough in fiber technology has opened a new window for designing internal interfaces in a single nanofiber to embody various attractive functionalities for broad applications in 5G systems[19]. Another promising technology for 5G-inspired materials is 3D printing, which can produce various microdevices with special shapes and properties[20,21,22].

Advanced nanomaterials with excellent thermal conductivity can quickly transfer the waste heat proposed by the equipment and devices in 5G base stations to their surroundings, the thermal efficiency can not only improve the reliability and efficiency of the equipment and devices, but also simply the thermal management.

3. Waste heat and thermal energy harvesting

The equipment and devices in 5G base stations produce a large amount of waste heat[23], and energy harvesting is a key technology that provides a viable solution to the challenge at hand[24], and nanofluids can greatly enhance their efficiency and heat transfer capabilities[25-27].

Interconnections in a micro/nano-scale integrated device leave no room for traditional heat transfer, such as that of air conditioning and heating equipment for the home, only nanofluids can be used. Nanofluids can form a nanoscale boundary layer with metal nanoparticles, which is also called fractal boundary layer[28] and can be modelled by the fractional thermal model[28,29].

Figure 1 shows a schematic diagram for temperature control in a 5G base station[30], much waste heat is proposed by the electrical components, and can be used by thermal energy harvesting devices. To achieve high thermal efficiency, the nanoscale boundary layer shown in Fig.1 is a nano/micro film embedded with metal nanoparticles, which can greatly enhance the heat transfer from the electrical component to its surroundings.

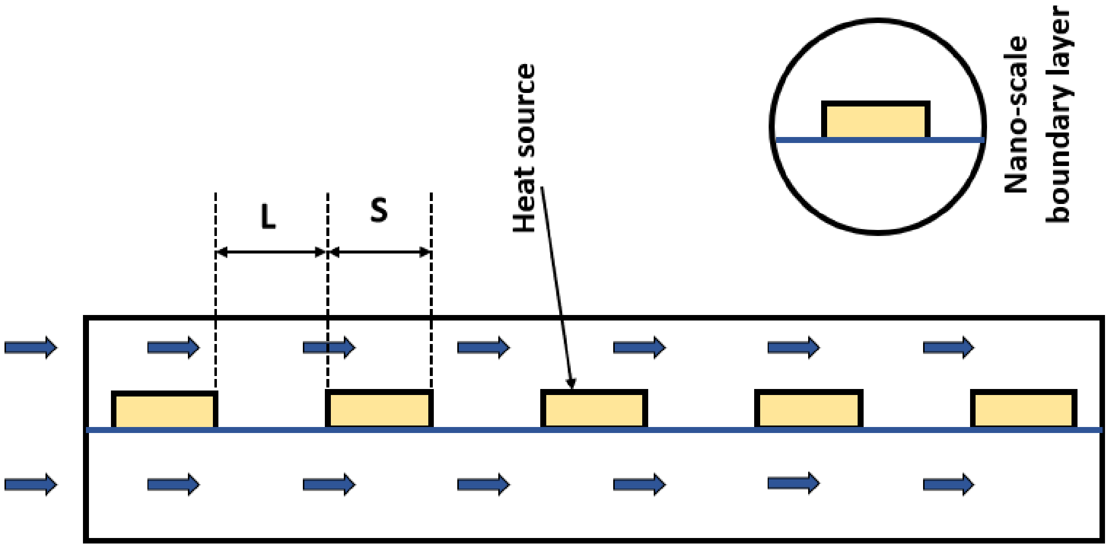

Figure 1 Micro-channel flow with multiple e electronic components as heat sources. The nano-scale boundary layer can be a fractal meta-surafce containing metal nanoparticles with good thermal conductivity.

4. Nature-inspired nanomaterials

Some natural fibers, such as wool fibers[31] and polar animal hairs[32], have unique thermal properties, and nature-inspired nanomaterials with hierarchical structure are also promising, which are called as fractal metamaterials or meta-fractal[33,34], fractal metasurface[35], and the fractal dimensions are the main key for applications[36,37,38]. A thin film with hierarchical metamaterial structure can be used to improve waste heat transfer and also for thermal energy harvesting.

5. Fractal thermodynamics

The one-dimensional heat equation for Fig.1 can be written as

$$\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}(k\frac{\partial T}{\partial x})+Q(x) \tag{1}$$

where T is temperature, k is the thermal conductivity coefficient, Q is the heat source. Eq.(1) is simple, but it can not model the effect of the electric components' size and distribution on the heat transfer, and a three-dimensional model has to be considered:

$$\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}(k_x\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(k_y\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(k_z\frac{\partial T}{\partial z})+Q(x,y,z) \tag{2}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x} \tag{3}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y} \tag{4}$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z} \tag{5}$$

where k_x, k_y and k_z are, respectively, thermal conductivity coefficients in *x-, y-* and *z*-directions, *u,v* and *w* -air velocity components in *x-, y-* and *z*-directions, p-pressure, ρ -density.

The system is complex, furthermore, the zig-zag boundary makes the numerical simulation even more complex. To solve the above problems, the fractal thermodynamical model[39] is simple and reliable.

Consider the fluid problem in a fractal space, and we have establish a one-dimensional fractal-fractional model

$$\frac{\partial^\alpha T}{\partial t^\alpha} = \frac{\partial^\alpha}{\partial x^\alpha}(k\frac{\partial^\alpha T}{\partial x^\alpha}) + Q(x) \tag{6}$$

where the two-scale fractal derivative is defined as[39]

$$\frac{\partial^\alpha T}{\partial x^\alpha}(x_0) = \Gamma(1+\alpha)\lim_{x-x_0\to L}\frac{T(x,t)-T(x_0,t)}{(x-x_0)^\alpha} \tag{7}$$

$$\frac{\partial^\alpha T}{\partial t^\alpha}(t_0) = \Gamma(1+\alpha)\lim_{t-t_0\to \Delta t}\frac{T(x,t)-T(x,t_0)}{(t-t_0)^\alpha} \tag{8}$$

where *L* is the distance between two adjacent electric components, and assume *L<S, S*-the width of the components as illustrated in Fig.1, Γ -gamma function, Δt - the time for the air moving through the adjacent distance, it can be calculated as

$$\Delta t = t - t_0 = \frac{L}{u} \tag{9}$$

where *u* is the nanofluid's velocity. The fractional order can be calculated as

$$\alpha = \frac{V-V_0}{V} \tag{10}$$

where *V* is the total volume of the inner tube, V_0 is the volume occupied by the electric components.

We give an explanation of the simplified Eq.(6). According the definition of the fractal derivative, we have

$$\frac{\partial^\alpha T}{\partial x^\alpha}(x_0) = \Gamma(1+\alpha)(x-x_0)^{1-\alpha}\lim_{x-x_0\to L}\frac{T(x,t)-T(x_0,t)}{(x-x_0)} \approx \Gamma(1+\alpha)L^{1-\alpha}\frac{\partial T}{\partial x} \tag{11}$$

$$\frac{\partial^\alpha T}{\partial t^\alpha}(t_0) = \Gamma(1+\alpha)(t-t_0)^{1-\alpha}\lim_{t-t_0\to \Delta t}\frac{T(x,t)-T(x,t_0)}{(t-t_0)} \approx \Gamma(1+\alpha)(\Delta t)^{1-\alpha}\frac{\partial T}{\partial t} \tag{12}$$

So Eq.(6) can be written as

$$\Gamma(1+\alpha)(\frac{L}{u})^{1-\alpha}\frac{\partial T}{\partial t} = \Gamma(1+\alpha)L^{1-\alpha}\frac{\partial}{\partial x}(k\Gamma(1+\alpha)L^{1-\alpha}\frac{\partial T}{\partial x}) + Q(x) \tag{13}$$

Finally, we obtain the following model

$$\frac{\partial T}{\partial t} = \Gamma(1+\alpha)(uL)^{1-\alpha}\frac{\partial}{\partial x}(k\frac{\partial T}{\partial x}) + \frac{Q(x)}{\Gamma(1+\alpha)} \tag{14}$$

It is obvious from Eq.(14) that one-dimensional fractal-fractional model involves nanofluid's velocity (u) and electric components' distribution (L), and electric components' volume (α), so Eq.(14) is much more reasonable than Eq.(1). The nanofluid's velocity can be calculated by Bernoulli equation

$$\frac{1}{2}u^2 + \frac{p}{\rho} = B \tag{15}$$

where *B* is the Bernoulli constant, p-pressure, ρ -density.

The fractal thermodynamical model is much attractive for engineering applications, for examples, fractal Schrodinger equation[40], fractal Camassa-Holm and Degasperis-Procesi models[41], and fractal variational principles[42].

6. Conclusions

We can now look forward with optimism that fractal thermodynamics opens a whole new window for 5G communication technology and its higher generations (6G or 7G), nanofibers with metal nanoparticles prove to be a good medium for electronic components to dissipate the wasted heat to their surroundings. This issue invites professors from Zhongyuan University of Technology, Zhengzhou, China to address the prominent problem arising in 5G base stations, and Yancheng Polytechnic College, China to address another hot topic on nanoscale fluid mechanics and nanomaterials.

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