Advanced-functional Metal and Ceramics on Polymorphism

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Advanced-functional metal and ceramics should be progressed and created on the basis of characteristic length such as the Fermi wave length, the mean free path, the coherent length etc. These lengths have themselves for each material. In this paper, needs diversification, reconsideration of conductivity, carbon polymorphisms, nano-structure in superconductivity will be reviewed and forecasted.

Keywords : needs diversification, conductivity, polymorphism, carbon nano-tube, diamond, superconductor, nano-technology, nano-structures, self-organization

1. What is the Source of Needs Diversification ?

We have had an answer for the question. In the field of metal and ceramics, the source of needs diversification is to find some advanced functions and to create some new functions in the current materials or matters on polymorphism.

In most information technology (IT) industries and power technology (PT) industries, the following progress cycle is always running with an appropriate clockwise cycle time. Nowadays the cycle time is steeply shortened by three or five years as contrast with ten or thirty years in the last century. Moreover, in order to achieve the purpose most researchers in both industries should be played with a new term, nano-technology, day after day.

In the electric and electronic materials, fundamental functions of electrical conductivity, thermal conductivity and mechanical properties should be advanced and created by means of the conventional top-down approach and/or the new coming bottom-up approach. These two approaches are generally defined as the nano-technology. Both of them will be reviewed and forecasted here.

2. Reconsideration of Electrical Conductivity

Now we are obliged to understand six conductivities in the same matter on the basis of the nano-technology as shown in Table

Fig. 1. Progress cycle for metal and ceramics

1. To transfer the macro-technology to the nano-technology means to understand some conductivity change three-dimensional behaviors to lower-dimensional ones in advanced electric and electronic materials

In the table, there are two assumptions by Prof. Tsuneya Andoh that three sizes of a rectangular body system are L_x , L_y and L_z , and a relationship among these sizes is in $L_x < L_y < L_z$. As typical Fermi wave lengths, λ_F , we know $\lambda_F \approx 0.1\text{nm}$ for copper and silver, and $\lambda_F \approx 40\text{nm}$ for GaAs/AlGaAs heterostructure.

On the otherhand, in the actual conductor another characteristic length, mean free path Λ of free electrons is important. The mean free path predominates the electrical conductivity with a significant inverse temperature dependency. As typical mean free paths of the metals, we know $\Lambda = 10\text{nm}-100\text{nm}$ at the room temperature, and $\Lambda = 0.1\text{mm}-1\text{mm}$ at low temperatures. Furthermore, when a size of the matter is smaller than the mean free path Λ , conduction electrons of the matter are ballistic, and free from any disturbances without the conductor ends.

In addition to the electrical conductivity, we are interested to improve the strength of the high-conductivity bulk metals. Pure aluminum such 5N or 6N has disadvantage of low mechanical strength of less than few MPa at the room temperature, as contrast with excellent characteristics of high-RRR of 1,000 to 20,000, low specific gravity, and high degree of transparency to particles. Two contrary properties have been performed by using Al-0.1-2wt%Ni alloy, in which Ni has very low solubility in aluminum and the grain refining effect, and almost Ni additives become precipitates in the grainboundary region. As a result of precipitation and grain refinement, this Al-Ni alloy achieved high mechanical strength of

Table 1. Dimensional conductivity change in the same material

Dimensionality	Relative length to λ_F	Actual shape
3D	$\lambda_F \ll L_x < L_y < L_z$	Bulk
Semi-2D	$\lambda_F \approx L_x \ll L_y < L_z$	Thin film
2D	$L_x < \lambda_F \ll L_y < L_z$	MOS-FET, Heterostructure
Semi-1D	$L_x < L_y \approx \lambda_F \ll L_z$	Quantum wire, Nano-wire
1D	$L_x < L_y < \lambda_F \ll L_z$	—
ZeroD	$L_x < L_y < L_z \approx \lambda_F$	Quantum dot, Artificial atom

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Fig. 2. Carbon polymorphisms as the electric and electronic materials

79-120MPa (room temperature) and 117-167MPa (4.2K) with high-RRR of 490-170, being preferable to the high-conductivity copper. This is a typical example of self-organization due to solidification change in the pure metal in order to achieve an advanced-function for the same matter.

3. New Coming Carbon Polymorphisms

Two carbon polymorphisms, carbon nanotube superconductor and diamond superconductor, have come latest year (2003-2004).

Fig.2 shows carbon polymorphisms as the electric and electronic materials. In addition, we can review that there were the bamboo charcoal filament by Thomas Edison in 1879, the carbon fiber resistor (1960 years), the carbon brush of graphite, the fullerene superconductor in 1985, and the carbon nanotube in 1991.

The carbon nanotube (CNT) exhibits not only unique atomic arrangements with three different chiral indexes but also interesting physical properties such as the ability to be either metallic or semiconductive, one-dimensional electrical behavior, quantum conductance, and ballistic transport characteristics, allowing a huge electrical current density, in the range of 10^9 A/cm^2 , that is two or three orders of conventional wiring metals. In order to realize CNT electronic devices, we make effort to develop many technology such as a material-growth, an ohmic contact, passivation, doping. Moreover, a successful discovery of proximity-induced superconductivity in multi-walled CNTs in 2003 will lead us to develop new electronic devices.

Furthermore, diamond semiconductor and diamond superconductor will also lead to new high-frequency and high-power electronic devices, while diamond has been an electrical insulator well known. Especially, the discovery of diamond superconductor in 2004 suggests that doping different valence elements to an electrical insulator or a semiconductor, such as silicon or germanium, is able to create many other polymorphisms.

4. Nano-structure in Superconductors

In superconductor and superconducting devices both the

Fig. 3. A history of nano-technology in superconductivity

nano-structure and the nano-technology are indispensable on behalf of organization of the superconductivity, because that coherent length, ξ of the essential characteristic length in the superconductivity is equivalent size to the nano-structure. The coherent length, ξ is in the range 0.3nm to 10nm.

Fig.3 shows a history of nano-technology in superconductivity. Since 1960 years, we have made much effort to realize an ideal superconductors and its device. First, they tried superconducting filament size to reduce in order to withstand from the intrinsic magnetic instability by means of the top-down approach. Second, they enhanced the critical current density of superconductors to introduce pinning sites with an appropriate size of around 2ξ also by the top-down approach.

On the other hand, on behalf of the broadband communications over 100Gbps or the wave shape measurement, the single flux quantum, SFQ circuits using the low-temperature and high-temperature superconductor have been developed by means of the bottom-up approach, if anything. This nano-technology will be systematized future electronic devices.

In summary, we should do our best in developing advanced materials to realize new polymorphisms on behalf of the electronic and electric materials on the basis of nano-technologies.

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