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A TRIAL OF GOAL SETTING FOR SELF-ORGANIZATION IN MATERIALS RESEARCH

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This paper tentatively defines goals for self-organization in materials research. The "self-organizing process (self-organization)", in which "desired materials and devices are prepared through the self-assembly of their components or through the formation of specific patterns in dynamic state where energy and substances dissipate," has attracted people's attention. Because the process is expected to be realized the preparation of nanostructures in a resource-saving and energy-saving manner. The goals for self-organization in material research include the following three: (A) Precision synthesis of molecular clusters, (B) Establishment of patterning and self-aligning technologies, and (C) Preparation of materials and devices through self-organization. In addition, this presentation is examining how to promote a measure required for achievement of the goals described above, and the project of self-organization in material research.

Key words: goals, self-assembly, patterning, self-aligning, self-organization

1. INTRODUCTION

In general, miniaturization of devices provides the advantages of "speeding up," "low power consumption" and "higher integration." Therefore, research of materials on the scale of nanometers has attracted people's attention. The approach for dealing with such nanometer scale materials can be roughly divided into two categories: One is the "top-down" approach, which carves out a surface as in the case of miniaturization of semiconductors; the other is the "bottom-up" approach, which builds up atoms or molecules into nanometer scale structures (nanostructures).

Until recently, nanotechnology has been targeted at semiconductor devices and mainly developed by the "top-down" approach. But researchers in various fields point out that preparation for nanostructures through the top-down approach will face greater difficulties in the near future, i.e., in a few to a few tens of years (these are difficulties associated with technological limitations, physical limitations and economical limitations). The bottom-up approach has gained the spotlight as a complement or alternative approach to the top-down approach on that account. Also in bottom-up approach, the "self-organizing process (self-organization) attracts attention by the reason that the self-organization is expected to be realized the preparation of nanostructures in a resource-saving and energy-saving manner. [1]

Therefore this paper covers the self-organization and tentatively defines goals of its research, and presents the proposal of collaborative research with clear objectives.

2. DEFINITION OF SELF-ORGANIZATION

There has been no clear definition about self-organization. In this paper, we discuss the self-organization by defining it as the "process utilized in the preparation of materials or devices, in which components of materials or devices assemble by themselves to form specific structures (self-assembly), or the process in which components spontaneously form specific patterns (dissipative structures) through energy and matter diffusion."[1, 2]

We give one example of self-assembly here. The formation of a globular structure called micelle, which occurs when soap molecules, having both the hydrophilic group with higher affinity for water and the hydrophobic group with lower affinity for water, are in water with the hydrophilic unit being on the surface and the hydrophobic unit being sequestered inside.

On the other hand, we quote "wind patterns on the sand" as one example of dissipative structures. Patterns of the sand on the surface of land exposed to external forces such as wind without being subjected to artificial processes.

3. GOALS OF SELF-ORGANIZATION IN MATERIALS RESEARCH

We have reported state-of-the-art of self-organization in materials research. [1] Here we have discussed the goals and issues to achieve goals of self-organization in materials research at the present stage with Dr. Tomohiko Yamaguchi, a chief researcher at the Nanotechnology Research Institute, National Institute of Advanced Industrial Science and Technology (AIST); and Professor Masatsugu Shimomura, a leader at the Dissipative Hierarchy Structures Laboratory of the Spatio-Temporal Function Materials Research Group, Frontier Research System, Institute of Physical and Chemical Research (RIKEN) and director of the Nanotechnology Research Center, Research Institute for Electronic Science, Hokkaido University. We present the conclusion of our discussion as the following three:

Goal A: Precision synthesis of molecular clusters

Goal A sets out to establish technologies that enable the precision synthesis of clusters of atoms or molecules (which can be sometimes components of systems), especially the clusters of molecules and nanostructures that are difficult to prepare when using conventional chemical synthesis methods, by utilizing the functions of atoms or molecules themselves (in a resource-saving and energy-saving manner) as well as to induce innovative functions in materials synthesized in such a manner.

For achieving Goal A, intermolecular interaction plays an important role in the self-assembly process. Therefore success in realizing self-organization through self-assembly depends on molecular designs.

Goal B: Establishment of patterning and self-aligning technologies

Goal B sets out to establish, irrespective of the physical states (gaseous, liquid and solid state) or scales (nano-, micro-, milli-, centi-meter and more) of the components of targeted systems, preparation processes through which useful patterns in the targeted systems can be formed in large quantity at one time by utilizing the functions of components of the systems themselves (in a resource-saving and energy-saving manner). And the preparation of desired structures by self-alignment of components at intended positions with high precision.

For achieving Goal B, researchers need to take into account not only molecular designs but also the environment around the molecules (external systems). In designing the external systems, researchers should establish methods for quantitatively evaluating the flows of energy and entropy through the relevant molecules and associated external systems, then discover principles in the designing of appropriate external systems that permit the desired patterning and periodicity of the relevant molecules, and develop technologies that allow the application of those principles to the relevant molecules and external systems.

Goal C: Preparation of materials and devices through self-organization

Goal C sets out to realize smart materials which exercise their functions in response to changes in ambient conditions such as temperature and exposure to light and molecular devices by creating hierarchical structures in two or more scales by means of, for example, combining the technologies mentioned as Goal A and Goal B and inducing functions characteristic to each hierarchy.

For achieving Goal C, it is important to prepare desired materials and devices through formation of dissipative structures by utilizing structure and parts (components) prepared through the self-assembly mechanism. Moreover it is also important to prepare desired materials and devices by inducing self-organization of the components prepared through the self-assembly mechanism."

As stated, in order to prepare various nanostructures, it is highly significant to develop not only conventional nanopreparation techniques but also techniques utilizing the self-organization.

Furthermore, if the self-organization becomes applicable to the preparation of materials and devices, which are now created by other processes, it may greatly contribute to resource-saving and energy-saving and, further, to environmental protection. In this context, progress of self-organization in materials research is expected by researchers not only in the filed of nanotechnology but also from a wide variety of research fields. I propose in the following paragraphs two issues to facilitate progress of self-organization in materials research.

4. CONCLUSION

So far in this paper, we have described our views regarding the goals and issues to achieve such goals. We propose in the following paragraphs two issues to facilitate progress of self-organization in materials research.

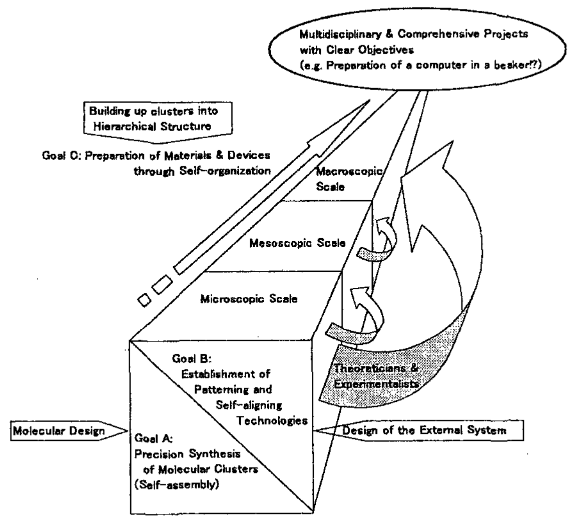

Figure1 Progress of Self-organization in Materials Research [2]

(1) Collaboration between Theoreticians and Experimentalists targeting the establishment of technologies for molecular designing, etc. [1, 2]

With regard to the clarification of principles of self-organization, participation of theoreticians in various fields is necessary because dominating laws of systems are scale-dependent. The same situation holds true for experimentalists.

One of the specific measures enables collaboration between theoreticians and experimentalists is to secure human resources to serve as an interface between such theoreticians and experimentalists. Here, the people to serve as an interface should have the peculiar aptitude for such works. It is not necessarily easy to secure human resources having such special aptitude. One possible practical measure to secure such human resources may be, when organizing a project of research through the approaches proposed in the following sections, the specification of functions to be served by people as an interface and to assign the role as an interface to researchers participating in the relevant research project.

(2) Promotion of Multidisciplinary and Comprehensive Research with Clear Objectives [1, 2]

With a view to realizing the application of the self-organization to techniques for the mass production of materials, devices, etc., researchers must attain Goal C (Preparation of materials and devices through the self-organization). In order to develop technologies for preparing complex three-dimensional structures by hierarchically building-up atomic or molecular clusters, cooperation from researchers in a wide variety of fields including mathematics, physics, chemistry, biology, material engineering, mechanical engineering and ...etc. is required in addition to collaboration between theoreticians and experimentalists discussed in the above. Moreover, with an eye toward practical application of technologies developed, it is imperative for researchers and engineers in the industrial community to participate in such research activities.

As of now, however, concepts regarding the self-organization vary in accordance with the research field, and the sense of mission in research activities is not always shared among researchers. One possible means of tapping into the collective wisdom of researchers in various fields or organizations to promote research on self-organization may be the implementation of a "multidisciplinary and comprehensive research project with clear objectives."

As the first step to implement such a project, researchers need to set forth such an objective that gives a concrete image to everyone and for which increase in technological levels is essential, as "preparation of a computer in a beaker," and gather experts whose involvement is necessary for the achievement of the objective as well as researchers in a wide variety of fields who are interested in achieving the objective.

As the second step, researchers need to specify issues to achieve the objective. Specifically speaking, issues to be handled to achieve the above objective may, as an example, include the development and preparation of ① structures that are analogous to transistors, ② structures analogous to circuitry, and ③ structures analogous to a central processing unit (CPU) (architecture).

Moreover, in promoting such a research project, it may be necessary to clarify the roles and responsibilities to be taken by research groups and researchers intending to address these issues.

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