Beauty in Nature
-Nanostructure in Nature-

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Our society is supported by highly developed electronics mainly based on inorganic semiconductor technology in which ultrafine manufacturing techniques such as electron beam and lithography technologies are inevitable and many efforts have been executed to develop more fine technique reaching nanoscale. However, they are highly costly and it is not so clear whether these trends can extend further as it was so far. On this respect we should learn a lot from nature in which selfassemble method is utilized without highly developed costly device.

In nature there are many materials which are beautiful in color. Some of them are not the color of dyes but based on nanoscale periodic structure. For example the brilliant color of opals are based on the periodic structure of optical wave length order in silica. The beautiful colors of the inside of shells and some insects such as butterfly and jade insect are also based on the periodic structure of the order of several hundreds nanometer, which can be easily confirmed by both electron microscope observations and optical reflection spectrum measurements.

Beautiful color of feathers of peacock whose photograph is shown on the front cover of this book is also confirmed to be based on the periodic structure. Recently a photonic crystal which has three dimensional ordered structure with the periodicity of the order of optical wavelength has attracted much interest from both fundamental and practical view points. One can easily recognize that the beautiful material in nature are strongly related to the photonic crystals. Therefore we can learn a lot from the nature how to design and use the photonic crystal. Indeed we prepared the three-dimensional periodic structure of silica as the example of the photonic crystal by the sedimentation of silica SiO_2 spheres or polymer spheres of several hundreds nanometer in diameter by the sedimentation from the dispersed solution. That is we have prepared the synthetic opals as photonic crystals by the selfassembly method.

These synthetic opals has interconnected periodic array of voids. Therefore various materials such as liquids, liquid crystals, polymers, conducting polymers, photochromic dyes etc. can be infiltrated in the percolated voids. By infiltrating polymers in the opal and then removing silica by washing with HF, inverse opal was prepared by the template technique. This inverse opal has much larger voids than the original opal. The third material can be infiltrated in the voids of the inverse opal. By infiltrating the third material in the voids and then removing the inverse opal ,we prepared replica of the opal with any materials.

We have proposed tunable photonic crystal in which the photonic band gap (and stop band) can be reversibly controlled by fields or factors. For example we infiltrated liquid crystals in the opal or the inverse opal. The optical properties of these infiltrated opals and inverse opals can be tuned by temperature and also voltage. Conducting polymer infiltrated opals also exhibited tunability of optical properties by temperature and voltage. On the other hand polymer opals made by the sedimentation of polymer spheres or template method exhibited tunability by applied pressure.

The algae in water also shows nano-scale structure. Diatom is known to have nanoscale periodic structure. Indeed we have observed beautiful nanoscale structure in diatoms in sea and river. It should also be noted that the so called star sands made by foraminifer has also nanoscale structure. I would like to stress that the beautiful color based on the periodic structure is quite stable. Indeed I found that ammonite also exhibit beautiful color as shown on the front cover of this book and it originated in the periodic structure of nanometer order as shown in Fig.1. That is, the color based on the structure is so stable and even can be kept more than 100,000,000 years. During our electron microscope observation of the peacock we have accidentally found that the stem of the wing of the peacock are also composed of nano-scale honeycomb structure as shown in Fig.2. Therefore the peacock with large wings can move around and handle freely the large wings.

Many other interesting nanoscale structures in natural and biological materials such as bamboo etc are now under study.

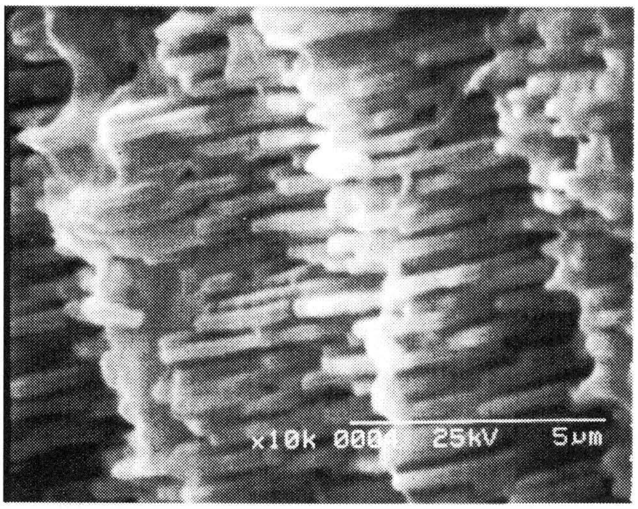

Fig.1. Scanning electron microscope figure of ammonite.

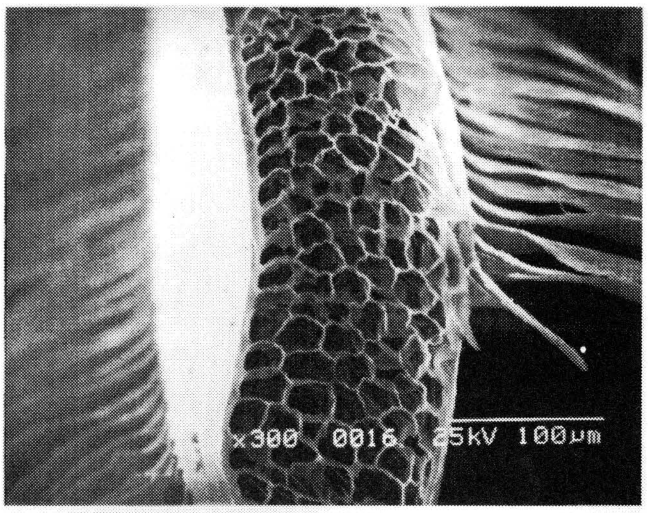

Fig.2. Scanning electron microscope figure of a stem of tail feather of a peacock.