"Materials and Production" field

Achievement : Creation of unconventional inorganic materials with novel electronic functions based on nano-structure engineering

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Summary

Discovery of new materials is a major driving force that transforms industry and our society. Dr. Hideo Hosono endeavored to create new functional materials in areas where others had not yet achieved success. For example, it was said that "transparent oxides" like glass are unsuitable as electrofunctional material because of their electrical nonconductivity, but Dr. Hosono studied their nano-structure and developed the "transparent amorphous oxide semiconductor." Today, it is extensively used in technologies such as liquid crystal displays (LCDs) and organic light-emitting diode (OLED) displays, contributing enormously towards our society.

Furthermore, he has developed a series of unconventional inorganic materials with electronic functions. In the field of superconductivity research, he focused on iron compounds, which nobody had been paying attention to, and achieved high superconducting transition temperature. He also developed "electrically conductive cement" by modifying the nano-structure of what had been considered an archetypal insulator material.

Focusing on the behavior of electrons, and striving for the development of materials that meet the needs of society

"I want to pursue the kind of materials development that could solve issues faced by our society", felt Dr. Hideo Hosono, who was deeply impressed by reading "Discovery of Nylon" by Minoru Imoto (published by Tokyo Kagaku Dojin) during his years at a technology college. Dr. Hosono went on to major in chemistry at Tokyo Metropolitan University, and in 1982, began his research career as a research associate at Nagoya Institute of Technology.

His research themes at the time were the elucidation of the optical properties and the microstructure of high purity silica glass (silicon dioxide), and the creation of ceramics from glass. He later took up the challenge of "creating a range of materials with electronic functions solely from oxides, such as glass."

The color and electrical characteristics of inorganic materials are determined by the behavior of their electrons. Oxides such as glass are transparent or white because their electrons have what experts call the "wide-bandgap" property. They were also thought to lack electronically active functions, since oxides are generally insulators.

However, with discoveries such as superconducting material made with copper oxides in 1986, huge potential in materials research was starting to emerge. Dr. Hosono too was seeing great potential in transparent oxides. Around this time, he announced his experiment results and demonstrated that when the nano-structure of oxides, which normally only turn white in color, is modified, they exhibit light-induced coloration.

The key to Dr. Hosono's research was the electron. In a later interview for a professional journal, he said, "My focus has solely been on the property of electrons in solids. It may lead to semiconductors, superconductors or catalysts, but it ultimately comes down to the ingenious utilization of electrons in solids."

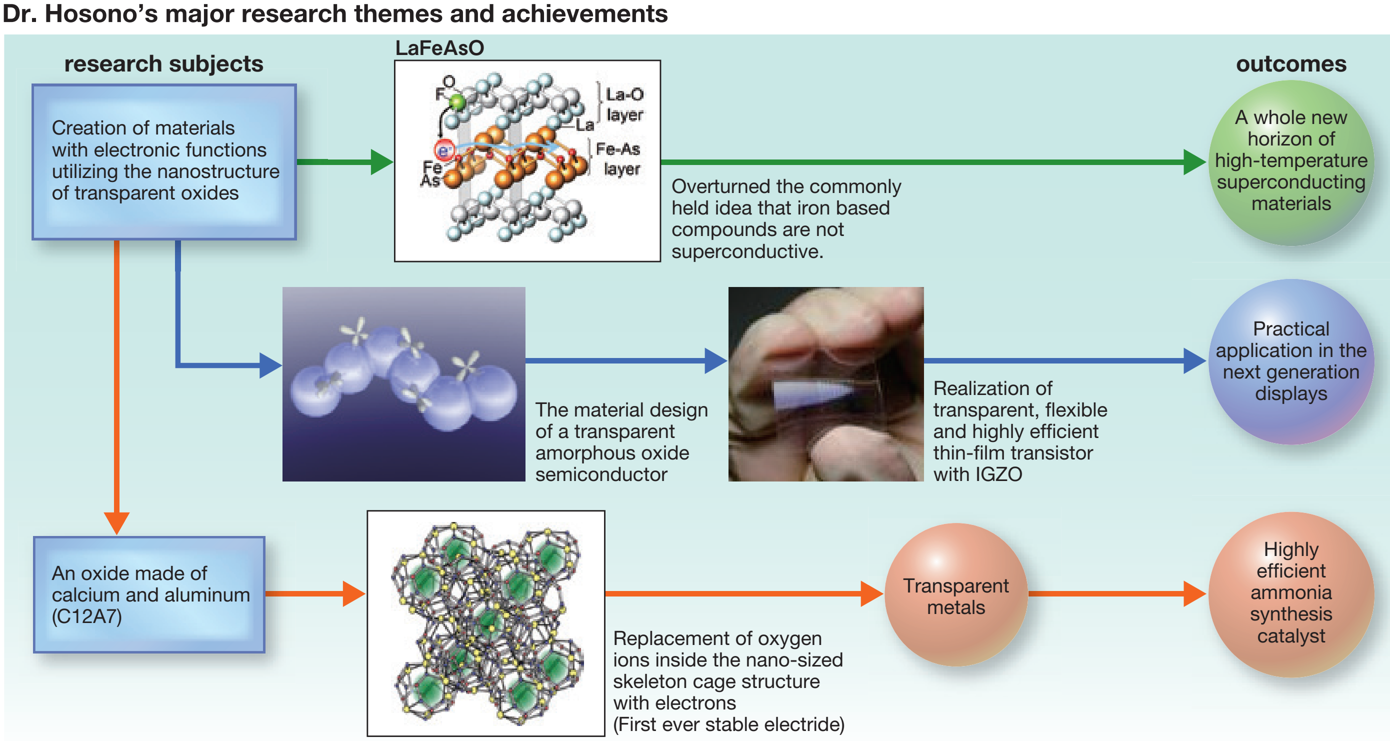
Creating materials with superior electronic properties from common elements

In 1993, Dr. Hosono assumed the post of associate professor at the Research Laboratory of Engineering Materials (present day Materials and Structures Laboratory), Tokyo Institute of Technology. Here, his underlying research theme was the "creation of electrofunctional materials with transparent oxides such as glass".

At the time, it was commonly believed that "transparent oxides" were unsuitable as electrofunctional materials because of their electrical nonconductivity. Dr. Hosono, however, intentionally chose glass, a "transparent oxide," as the subject of his research, in part because of his aspiration to "challenge unexplored frontiers," but also in response to the large societal need for such materials.

For example, transistors used in LCDs and solar cell development require semiconductors with not only superior electronic properties but also to allow light to pass through. At the time, indium oxide containing a small amount of tin was known to meet this requirement. Indium, however, is a scarce rare-metal that is very expensive, as well difficult

Dr. Hosono's major research themes and achievements



to secure in sufficient quantities.

Dr. Hosono's strategy was to create materials that could meet the needs of society from commonly available materials by modifying the nano-structure of transparent oxides. In 1994, he began the research and development of transparent conductive materials. By studying the oxides' nano-structure and the behavior of the electrons within, he revealed that "in transparent conductive oxides, there is a spatial spread of the metal ion orbitals that carry electron conduction."

Using this as a design guideline, he undertook the development of numerous oxide semiconductors. In 1997, Dr. Hosono, together with his mentor Dr. Hiroshi Kawazoe, successfully developed the world's first "p-type transparent oxide semiconductor." This research was later applied to the creation of the world's first p-channel oxide thin-film transistor.

Before long, Dr. Hosono's work drew attention both within and outside Japan. Subsequently, Japan's research grant program "ERATO (Exploratory Research for Advanced Technology/ Strategic Basic Research Program)" selected Dr. Hosono's proposal of "transparent electro-active materials project." Prompted by this project, he successfully went on to achieve his goals one by one. Among the wide range of themes Dr. Hosono undertook, "transparent amorphous oxide semiconductors (TAOS) with high electron mobility" is an example of practical technology that has since been adopted worldwide.

Set off by Dr. Hosono's research, TAOS became one of the major fields of semiconductor research. In particular, Dr. Hosono developed the world's first In-Ga-Zn-O thin film transistor (IGZO-TFT), which saw practical application as an energy-efficient device, due to its high electron mobility despite lacking the highly ordered atomic arrangement seen in crystal, and its high transparency. Today, it is beginning to replace amorphous silicon semiconductors in LCDs on devices such as PC monitors and tablet PCs. Most recently, it is also starting to be implemented in large-sized OLED televisions.

The challenge of electrically conductive cement and iron-based superconductors

Beside the development of transparent oxide semiconductors and luminescent materials, Dr. Hosono had another theme he wanted to pursue, namely, "the research on the electronic functions of a calcium aluminate C12A7", an ingredient of cement. Cement is made up of several compounds, all of which are typical insulators. Dr. Hosono noticed that C12A7 was made up of nano-sized cage structures. He then replaced the oxide ions held gently inside the "cages" with electrons and created a new material called the electride, which has excellent electrical conductivity like a metal, as well as superconductivity at low temperatures.

The discovery of electrides completely transformed the image of cement as a new material with great potential. Other unique properties of electrides, including greater electron emission ability and chemical stability, opened up the possibility of their application as catalysts for various chemical reactions.

From there on, Dr. Hosono demonstrated that ammonia synthesis, which had theretofore required high temperature and high pressure, could efficiently be achieved under ambient pressure using the electride as a catalyst. From fertilizer to gunpowder, ammonia is a chemical substance of universal applications that is used to create numerous indispensable materials for mankind. Therefore, its potential in contributing towards the building of a sustainable society is seen with great anticipation.

Through the modification of the nano-structure, Dr. Hosono created electrically conductive cement. In other words, he "turned cement into metal." These challenges towards the characteristics of materials led to broadening his research area still further. One of his researches that astonished the world was the discovery of iron-based high temperature superconductors.

Until then, iron, a typical magnetic element, was thought to be unfavorable for superconductivity. However, by forming a layered crystal structure through the reaction of iron with phosphorus and arsenic, Dr. Hosono achieved control over electrons, and in 2006, discovered that an iron-based compound (LaFePO) is superconductive. In 2008, he drew attention from around the world with the announcement of LaFeAsO, which has a superconducting transition temperature of 26 K.

Dr. Hosono's research has pioneered a new frontier in the exploration of superconducting materials by discovering iron-based superconductors in addition to the already known copper-based superconductors. Because iron-based superconductors have a high critical magnetic field and exhibit small anisotropic properties, applied research is under way to explore their potential for practical use in materials, such as for superconducting magnets.

It is greatly anticipated that Dr. Hideo Hosono's successful research, which focuses on the behavior of electrons in substances from an original perspective, will continue to give rise to materials that will transform our society.