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SCIENCE AND TECHNOLOGY

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13 FEBRUARY 1987

JAPAN REPORT
SCIENCE AND TECHNOLOGY

CONTENTS

/7310

INTERDISCIPLINARY RESEARCH DISCUSSED AT FORUM

Tokyo PUROMETEUSU in Japanese May 86 pp 78-83

[Article by Takayuki Tanno, Planning Section, Planning Department, Science and Technology Agency]

[Text] 1. History, Background, and Forum Objectives

Forums on scientific technology have been held once a year since 1981 in compliance with the framework which the strategy committee with the prime minister as the chairman set up, and with the Science and Technology Agency taking care of planning and steering (refer to Table 1).

Last year, both academic and industrial scientists (61 including 8 from abroad) gathered in Hakone for the forum which was held from 20-22 December. These scientists were leaders in their respective fields of information, electronics, substance and material, as well as life science. In the forum, two major objectives were set forth and are as follows:

1) By providing opportunities for scientists from different fields to contact each other and let the participating scientists:

(1) expand their intellectual basis;

(2) develop new perspectives in their research field by getting to know research trends in different fields;

(3) discover underlying common problems and get insight into collaborative research, etc., thus positively triggering researcher's intellectual driving force, and contributing to the promotion of R&D.

2) Through discussion, participating scientists understand basic concepts toward the direction of R&D in interdisciplinary research fields concerning human functions.

2. Theme for Discussion

The discussions were conducted by setting up the following five individual themes under the general theme "exploring breakthroughs in new developments of scientific technology on the basis of understanding biosystems, in terms

Table 1. Past Schedule of Science and Technology Forum

Forum No 1--

Date: 11-13 February 1982

Site: Fujinoya Hotel, Miyanoshita, Hakone

Participants: 57 scientists from fields of information, electronic substance, and gene technology

Themes discussed:

1. Sessions for the specified field division (specified theme was not set up)
2. Sessions for the exchange division between different fields
   - o To promote research
   - o Processing large-scale information
   - o Development of the material and method
   - o Cooperation among different fields with respect to national projects

Forum No 2--

Date: 10-12 February 1983

Site: Oiso, Prince Hotel

Participants: 68 scientists (including 9 from abroad) from fields of information, electronic substance, and biological science

Themes discussed:

1. Sessions for the specified field division
   - o Future image of information and exchange electronics technology
   - o Method exploring high performance material
   - o Life science and gene technology

2. Sessions for discussion of exchange between different fields
   - o Morphogenesis of organisms, intellectual behavior, and information processing
   - o Ultra new material and its development
   - o Material problems in life science

Forum No 3--

Date: 9-11 February 1984

Site: Oiso, Prince Hotel

Participants: 66 scientists (including 8 from abroad) from fields of information, electronics substances, material, and biological science

[continued]

[continuation of Table 1]

Themes discussed:

1. Sessions for the specified field division
   - o New technological development on information exchange, transmission, and comprehension
   - o Developmental method for new functional material
   - o New elucidation measures for high dimensional life phenomena

2. Session for the exchange division between different fields
   - o Robot and artificial intelligence
   - o Censor and new material
   - o Processing of information in biosystem and the processing technology
   - o Bio-tip, molecular-tip, and technology tip
   - o Medical science, biological research, and information
   - o Electronics technique

Forum No 4--

Date: 31 January-2 February 1985

Site: Hotel Yokohama, Yokohama

Participants: 57 scientists (including 7 from abroad) relating to following themes

Themes discussed:

1. Integrated theme
   - o Science and technology--challenge to human functions

2. Individual theme
   - o Man-machine interface
   - o Artificial intelligence
   - o Substitution to mechanism in biosystem
   - o Artificial sensing
   - o Ultimate element design

Forum No 5--

Date: 20-22 November 1985

Site: Fujiya Hotel, Miyanoshita, Hakone

Participants: 61 scientists (including 8 from abroad) concerning following individual themes

1. Integrated theme
   - o New development of science and technology through understanding biosystem--exploring breakthrough by mutual exploitation among different fields

[continued]

[continuation of Table 1]

2. Individual themes
   - o Reaction biosystem, molecular recognition, and biofunctional material
   - o Artificial substitution of organ function and new material
   - o Sensing organ and super sensor
   - o Recognition function and information processing
   - o Artificial limbs and robotics

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of mutual exploitation of different disciplinary fields." Sessions were divided for individual themes.

1) Biosystem reactions, molecular recognition, and biofunctional materials
2) Artificial substitution of bio-organ functions and new materials
3) Sensing organ and super-sensor
4) Recognition function and information processing
5) Artificial limbs and robotics

Discussions over 3 days turned out to be very active and full of enthusiasm and exaltation with the participation of internationally outstanding scientists enhancing the trend.

Heterogeneity in sectors among medical science, biology, technology, and pure science were overcome. Exchange between different fields was achieved, resulting in a triggering of an intellectual driving force. A large number of proposals for the direction of research in each sector were presented and their future images were visualized.

3. Issues for Discussion in Each Division and the Results

Issues for discussion in each division and the discussion content will be described as follows:

1) Division of reaction in biosystem, molecular recognition, and biofunctional material

(1) Objectives of the discussion

To discuss research analysis of molecular mechanism recognition and information processing in biosystems by means of technology such as recombinant DNA technique, designing methods and developmental strategy of biomodel compounds, artificial enzymes or artificial vaccines, and to explore the means of collaboration between both fields. To further discuss the method of analysis and technological development on the reaction system consisting of a number of unit reactions.

(2) Discussion content

a. It became possible to predict secondary structures of amino acids to a considerable degree from their amino acid sequence as a primary research of the molecular recognition and information processing mechanisms in biosystem reactions. It was reported that on the basis of results, the enhancement of the biosystem reaction activities had already been realized by means of protein technology approach. But the more detailed relation between function and secondary structure of proteins is not yet clear. This problem is just beginning to be recognized as a concrete research objective and it was emphasized that the acceleration in this field of research was paramount to the development of biomimetics. It was further pointed out that the current knowledge about the protein itself was still too meager to design useful artificial enzymes and, therefore, the intensification of the protein research was desired.

b. Next, recent results concerning the cancer research field were reported. As to the transformation of cells, it was reported that many oncogenes have already been identified and the mechanism of canceration became fairly clear to some extent in certain individual cases. The canceration of cells, however, appears to be a complicated process made up of a number of unit processes, therefore, the necessity to study the functions of cells more thoroughly was emphasized.

c. The present status of high molecular membrane research intending to stimulate characteristics of biological phenomena (regulatory function) using models was reported. Also, it was reported that regulatory function characteristics of the biosystem including membrane composition and permeability were achieved by different approaches from those of the biosystem such as phase transition and heat. It was pointed out that to develop a function mimicking the molecular sequence regulation within the membrane which operates in the biosystem was mandatory in order to improve the regulatory function of the artificial membrane. If an artificial membrane can be built up and a functional molecule derived from the biosystem, it will be used industrially as a new membrane. In so doing, it was pointed out that on the basis of research success of the functioning process as a result of interaction of an agent with a membrane, a more efficient system can be constructed by designing artificial membranes and enzymes.

d. Dynamics of photochemical reactions were reported, representing a system research composed of a number of unit reactions. In that, it was pointed out that experimental and computational analysis of a continuous series of reactions in the multiconstituent system were helpful for the layout of functional elements in the biosynthesis and elucidation of the regulatory mechanism of the reaction.

e. With these discussions in mind, the following three points were concluded to be important in the future direction of research in the pertinent fields:

—The understanding of the highly dimensional structure of protein is becoming more sophisticated and the future effect to elucidate protein structures will bring the realization of the actual protein design.

--The selectivity and orbital-steering properties of the substrates in biosystem enzymatic reactions are extremely attractive and how to mimic them is a challenging problem for researchers. While a breakthrough is being explored in terms of biomimetics for multifunctional elements in lieu of conventional unifunctional elements, the strategy, that is which function of the biosystem is to be followed and mimicked, is important.

--From the point of view of biomimetics, things are not necessarily confined to limited biosystem conditions (e.g., the biosystem functions in mild conditions such as at ambient temperature, under normal pressure and in water) but rather one should industrially elicit and exploit biosystem functions from entirely new material and ideas beginning with the function of the biosystem itself.

2) Division for Artificial Organ Substitution

(1) Intentions of the discussion

To discuss problems in artificial organs currently in use and what improvements will bring it to the ideal. Further, to discuss what kind of new materials are being developed and how they could be involved in the artificial organ solution, and to discuss what kind of possible artificial organ will be aimed for in the future.

(2) Discussion ideas

a. A lot of opinions emerged concerning the problems in artificial organs and concrete measures were proposed in pursuit of perfection with respect to artificial blood vessels, the heart, and the kidney. In artificial blood vessels and the heart, common problems concerning hematocompatibility and histocompatibility were investigated. Improvement durability was discussed as an important factor in the artificial heart. Concerning the artificial kidney, how to improve function and aim at decreasing the size as well as increasing selectivity were discussed.

b. Possibilities about future artificial organs were discussed. Actually, in answer to the current problem of decreasing the high mortality in artificial liver cases, research was conducted toward the hybridization of hepatic cells and artificial materials. It was pointed out that the toxic substances must be removed as well as the induction of substances that are necessary for the regeneration of the hepatic function.

c. Also for artificial erythrocytes, a very promising possibility was shown and concrete measures for eliminating adverse effects were discussed.

d. Artificial cells in a broad sense including those of white blood cells and red blood cells became discussion subjects and particularly valuable proposals were presented about:

--the successful longevity by chemical approach;

--possibility of "superfunctionalization" of artificial cells by complex natural enzyme system;

--successful utilization of artificial carriers, artificial channels, and artificial enzymes;

--successful creation of artificial cells that recognize each other. The necessity to introduce biomimetic concepts in this field was emphasized.

e. In order to have a breakthrough in research throughout this field, it was pointed out that:

--research directed toward understanding polyfunctionality and multienzyme systems including the biomimetic approach or protein technology was important;

--taking advantage of the research results in the above, the pursuit of highly functionalized artificial cells compatible with natural cells in the biosystem is important. Artificial cells coexistent with man in a broad sense including artificial white blood and red blood cells that will be developed by this research was recognized to play an important role in supporting the future of human beings.

3) Session of the Super-sensor Division

(1) Objective of the discussion

Wide application of artificial vision to diverse fields such as medical care, physicochemical measurements and robotics. In this session, researchers of artificial electronic vision or those of materials for biofunctions and sensors as well as biochemists studying biosystem vision organs, got together to discuss visions from respective viewpoints and to explore measures for the development of the targeted artificial vision.

(2) Discussion results

a. The following four results from the research were reported to obtain clues for the measures to learn from vision functions in the biosystem and realize it as an artificial super-sensor.

--The reaction mechanism in the retina was introduced. According to the report, it became clear that in the retina there are two kinds of dipolar cells, viz ON type and OFF type which are connected to nerve cells at different positions with both sending positive and negative images. Also it was reported that the dynamic range of vision is 10^{12} with the rods of the optic cell accounting for 10^3, the cones 10^3, and the retina network the rest. Thus, very high sensitivity was demonstrated.

--The experiments on brain function of face recognition and so forth using monkeys were introduced. According to that, it was confirmed that there were different cells, respectively, reacting to the front of the face, the side of the face, or movement of the face.

--Research on the biosystem mechanism that converts light into an electrical signal was introduced. In that research, the mechanism of the generation of electrical potential inside the optic cells together with signal after the light hit the optic substance was discussed.

--Further research on plasticity of the vision center was introduced. The plasticity of the synapse (hands that connect cells) was suspected from an experiment using a cat and was actually demonstrated in the slice of the brain. It was reported that in the vision center, about 20 percent of the cells that exist in the columnar structure of the visual area plays the role of teacher and lets the rest of the cells (pupils) learn the selectivity of reactions.

b. With the above proposed problems in mind, functional differences between the natural vision system and the existing artificial ones were investigated. The results indicated that while measures were taken in artificial vision to try to catch up with natural vision with respect to dynamic range, noise, and plasticity, they were still considerably premature compared with the biosystem. At present, stereoscopic, central, and peripheral vision is far from being accessible through artificial vision. It was confirmed that effort should be directed toward this point by learning from natural vision.

c. To develop super-sensor, three research themes, dynamic range, noise, and plasticity should be investigated in further detail. Also, it was agreed that the function of the stereoscopic, central, and peripheral biosystem vision for which only elementary study has just started, should be investigated energetically.

d. Throughout session discussions, biosystem vision was marvelous, particularly when viewed as a system, needless to say as an individual process. It was agreed that further effort should be directed toward the development of devices simulating biosystem functions. It was pointed out that participating scientists should keep the point discussed in this session in mind, go back to their respective laboratories, and tackle the problems in further research. In addition, the necessity of organizing interdisciplinary association to continue discussion further was pointed out.

4) Session of Recognition Function Division

(1) Objectives of the discussion

Research to develop technologically intellectual functioning of the biosystem such as sophisticated recognition patterns, learning, conjecture, association, and memory is expected to open up new application fields that are different from those of the conventional computer. The session tries to grasp the status quo of this field of research, project future perspectives, extract biofunctions to be technologically developed and investigate the research strategy coping with problem development. How the exchange between physiology and technology should be and the perspective of the ultimate element through discussion from diverse viewpoints such as cerebroneural physiological functions and their fine structures, modeling recognition function of the biosystem, access to artificial intelligence by means of computers and ultimate element, i.e., molecular elements were discussed.

(2) Results of the discussion

a. The following problems were proposed concerning the state of research and its future direction.

--Information processing in the cerebroneural system by cell physiological approach.

--Brain processes involved in recognition of faces, body movements, and actions.

--Mechanisms of photoelectric conversion.

--Physiological approach to perception and recognition.

--Model of the recognition process and information processing system.

--Research technology.

--Future trends of current elements and the development of new devices.

b. On the basis of these, discussions were developed about the strategy for ongoing research. Generally speaking, discussions from the viewpoint of learning from the biosystem to approach computers that are easier to use was predominant. Discussions were earnestly conducted particularly regarding the differences between computers and the brain, what is meant by an easier-to-use computer and data processing machines that will arrive after parallel processing computers.

c. Consequently, the conclusion was drawn that deeper understanding of the brain will lead to computers that are as easy to use as the human brain. It was pointed out that as for the concrete measures, it was most important for specialists from each field to bring the most up-to-date findings, repeat research meetings many times, and pin down the direction of the research and that arranging research, therefore, was important to begin with.

d. Aiming at future information-processing-machines including high grade functions such as conjecture, concept recognition, and thought, a strategy integrating research in physiology, psychology, computer, and molecular elements were considered important. It was proposed that such a machine should no longer be called a computer but should be called a conceptor.

e. The following four items are listed to be discussed at the next opportunity:

--The process in which the brain is built up.
--Details of the plasticity of the brain.
--Hierarchy of neural power cells.
--Through study of the conjecture function.

5) Session of the artificial limbs and robotics division

(1) Objectives of the mechanism, on the basis of which life manipulates hands, legs, and bodies, not only in terms of bodily characteristics but also in terms of biomechanical findings, to exercise physiology and neurophysiology and to pursue the possibility of a letting machine (robot) having these abilities. To discuss material or sensors that artificially substitute limbs, etc., and try to get a perspective for the R&D of these technology elements. Further based on these discussions, to show the way to robots with intelligence and robots for the welfare and tools of rehabilitation aid.

(2) Summary of the discussion results

a. A man moves freely of his own will and manipulates hands skillfully and communicates with words. On the basis of the consensus that it is very important to elucidate these mechanisms, develop these functions in terms of machines or robots, and let them work with dangerous or harsh work instead of man and replace man's function which was unfortunately lost by accident, specialists from diverse fields got together in one room and discussions were conducted.

b. Discussions were conducted to understand the elementary process to get guidance for technological design of robots starting from a discussion of how far the mechanism of motion or movement is understood in the research of human beings or animals. Also active discussions were conducted on robot sensors, actuators, power sources, and structure materials for robots.

c. Regarding "the better coexistence of human beings and the machine," further discussion was conducted concerning compensation by scientific technology of human function and the abilities that were unfortunately lost from the standpoint of robotics, technology, brain physiology, medical science of rehabilitation and material.

d. As a result, it became clear that in respective fields, original research was already going on independently and the forthcoming collaborative research would be able to make the following three items move ahead, which were otherwise thought to be impossible to do until now.

--First is research to develop an artificial hand, a dexterous copy of the human hand capable of intellectual movement through integrating scientific technology.

--The second is research to resuscitate numb hands or legs caused by defects in the cerebrum and diencephalon, by electrically stimulating the cerebrum and diencephalon, making use of an achievement in movement physiology whereby walking was induced at the level of brain stem and spinal cord.

--The third is research on the mobility aid to help human movement and mobility such as the development of intellectual movable robots to meet the requirement of an advanced age society.

e. These new research fields being opened up are proposed to be called "bionobotics." Discussions were not sufficient and there remained problems to be discussed further. It was concluded that setting up the meeting in which researchers from different fields such as those gathered in the forum can continue discussions, would be effective.

4. On Closing the Description of the Forum

As described above, the most up-to-date information on types of research being conducted around the theme taken up throughout the discussions was brought up by the participating researchers. Further, a number of suggestions on the direction of research as well as how to tackle it including concrete proposals were presented and the fifth forum on science and technology turned out to be a fruitful one. This is reflected in the results of the questionnaire by participants from both within the country and abroad. In them, many researchers emphasized that "we wish to have a forum held continuously," "we wish to receive effective continued support for the advancement in diverse research fields," and "we wish to have more researchers participate in the forum." In addition, the participants from abroad expressed an opinion that their country did not have such a system in which both industrial and academic researchers got together in one room to have discussions and they would make efforts to arrange such a forum in their countries. Thus, the forum was also highly appreciated from the international point of view. Taking opinions or ideas from possibly more people into consideration, the Science and Technology Agency will continue to exert its efforts to improve and develop the forum further and to make it a more fruitful one.

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DEVELOPMENT OF BIOCHIPS, MOLECULAR DEVICES DISCUSSED

Tokyo BIO INDUSTRY in Japanese May 86 pp 48-54

[Text] Bioelements must be designed considering their diverse responses and fusing functions with conventional engineering, such as wiring, assembly processes and calculation methods, along with lower functions such as on/off switching. At present, various flux-conversion functions, for instance, between voltage and electron flux, molecular flux and electron flux, molecular flux and electric field, luminous flux and molecular flux, molecular flux and molecular flux, have been discovered. One future task is to adjust these discoveries to the industry. At the same time, studies to establish the conversion system between the self-wiring principle and the self-organization system are also required.

1. Introduction

It is widely predicted that electronics will further develop and an electronic society, or an electronic culture will flourish in the 21st century. Although the diversity of applied products in the next decade cannot be predicted, their fundamental principles can be foreseen. There are many functions expected, but they will not be feasible for a considerable period.

The foreseeable, fundamental principles are as follows:

1) Ultramicro elements.

2) Elements with various responsive functions.

3) Quick action and response.

4) Highly conductive, or ultraconductive materials particularly at room temperature.

5) Ultrafunctions...materials having properties of being equivalent to the brain mechanism.

6) The conversion technology among various fluxes...free conversion among fluxes, such as fluxes of photons, electrons, or molecules, communication flux, and energy flux.

7. The self-organization technology...the principles for building molecular substances, the assembly plant for small materials sized under submicrons, the construction of manufacturing plants.

In order to achieve these future technologies, a large-scale technological innovation must be made in the industry, where molecules will replace solids and microparticles such as ceramics and semiconductors which were used before 1985 as major materials. However divided, the functions of solids, particles, and crystals depend on those of molecules and atoms. The particular properties of a molecule itself cannot be fully used in them and therefore, from an industrial point of view, ceramics and semiconductors are far from ideal materials.

The purpose of this report is to refer to the maximum functions of molecules and how they can be applied in a practical sense. Biochips and molecular elements are selected for the materials of discussion as they are the representatives of functional molecules in biochemistry and biomimetics.

2. What Can Be Done With Biochips?

Among biologically functional molecules, only a few are used for biochips and it is dangerous to predict their future development from what is known so far. Except for those particular proteins which are now being discussed, the possibility exists that various functional proteins, sugars, nucleic acids, and complex lipids having respective physical properties can be applied to new, ultrafunctional elements. This report discusses functional proteins which have been studied or will be studied in the near future.

The flux conversion technology with functional proteins now a topic is to use cytochrome C's switching function as a biochip, when electrons are given. This is the lowest level biochip, and will not lead to technical innovation. However, it is the focus of attention, because it is practically applicable and comprehensible to people at large.

Among the characteristics of functional proteins including the on/off switching function, those which will lead to innovative technology as materials for microelectronics or communications engineering are those with the basic physical properties of proteins leading to (a) flux conversion technology, and (b) self-organization technology.

As for the conversion technology between fluxes, the physical and chemical properties of functional proteins known so far will have a relationship with future innovative technology as shown below.

1. Conversion from luminous flux to electron flux: Rhodopsin.

2. Electron (voltage, current) and electron flux: cytochrome, cytochrome c_3 is particularly important.

3. Molecular flux to electron flux: sensors, receptors.

4. Molecular flux to electric flux: ATPase, respiratory system.

5. Luminous flux to molecular flux: photosynthetic system.

6. Molecular flux to luminous flux: bioluminescence.

7. Molecular flux to molecular flux: receptors.

Some of these properties are discussed in detail, but all of them cannot be covered because of the limited length of this report.

Cytochromes are electron-transfer elements widely seen in living bodies. They are stable proteins of cubic form, easy to treat, and applicable to engineering use. The electron-transfer, where electrons are transferred from proteins of high potential to those of lower potential, occurs due to the valence conversion in iron ions from 2+ to 3+. They are located in the center of a heme, or a ferroporphyrin (Figure 1), in a cytochrome molecule. At the resting stage, the iron valence is maintained at three. Receiving an electron from a protein of high potential, it converts to Fe^{2+}, thus fulfilling its role. The important point is that the physical properties of a protein change with its valence.

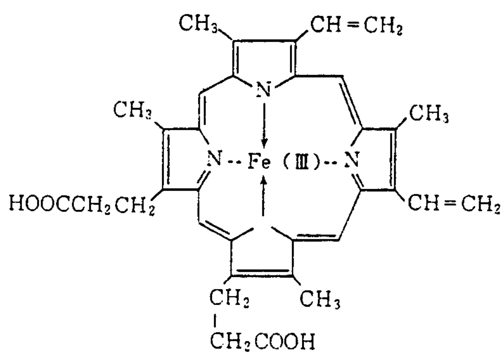


Figure 1. Natural Heme

If the differences in physical properties are increased, various basic functions such as biochips will be added to proteins.

Many cytochromes have similar structures, for instance cytochrome c, b, and f are very similar. However, as far as the switching function is concerned, the most interesting one is cytochrome c_3. Cytochrome c_3 has a very unique structure, having four hemes in one protein molecule. This is very different from other cytochromes having only one heme per molecule (Figure 2). Roughly speaking, these four hemes make a configuration similar to a regular tetrahedron. As a result, each of the four heme molecules has three heme molecules at the position very near it. In addition, if two or more cytochrome c_3 come near, one of the cytochrome hemes becomes very close to a heme of the adjacent cytochrome.

As the diameter of a cytochrome c_3 is only 30 Å, the distance between each two of the four hemes is very small, only a few Å between the edges. Therefore, electrons given to a heme can move, due to the tunnel effect, easily and quickly to another heme in that molecule. When two or more cytochrome c_3 molecules contact, electrons can move to a heme in another molecule. Thus, if a thin layer of cytochrome c_3 has electrons previously given to it the cytochromes will become conductive, although cytochrome c_3 itself is an insulator. If cytochrome c_3 associates are buried in an artificial membrane, a rapid flow of electrons from the surface to the reverse side of the membrane can be observed.

Being injected with small amounts of electrons, cytochrome c_3 becomes conductive, and along with the on switching function enables a large amount of electron flux to occur. There is a difference of 10^{10} in conductivity between on/off switching functions, which is very effective in carrying out the function.

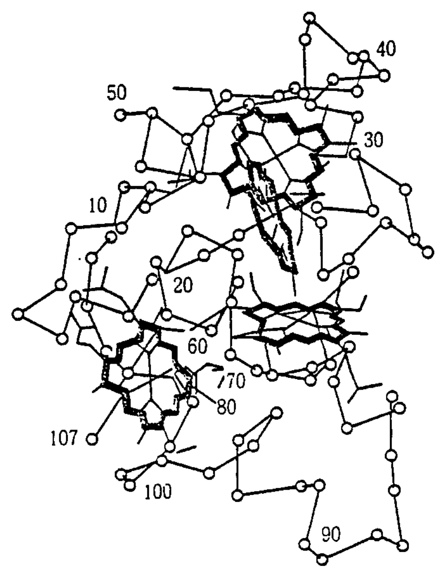


Figure 2. The Structure of Cytochrome C_3 Analyzed by X-ray (thick lines show hemes)

In living bodies, many kinds of signal compounds, such as hormones, are produced, transmitted, and received in order to control life activities. Proteins at the receptive positions distinguish a particular hormone molecule from many other similar molecules by strict molecular recognition, and then receive it. The details of molecular recognition have been reported several times, and no further discussion takes place in this report. When a receptor protein receives a signal compound, a prominent conformation change occurs, and the entire molecule is transformed. A receptor protein is tightly joined to a cell membrane and a part of it protrudes from the membrane. Therefore, transformation in the protein structure changes the form of its protruded portion. Consequently, the interaction with enzyme proteins within a cell changes, which sometimes leads to a change in enzyme activity, membrane permeability, and potential differences between the exterior and interior of the membrane (Figure 3).

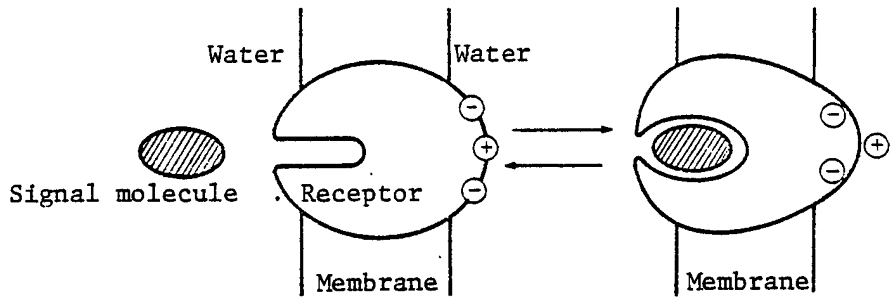


Figure 3. If a Receptor Molecule Recognizes and Captures a Signal Molecule, the Membrane Potential, and Enzymic Activities on Its Surface Change

Since there are only a small number of signal proteins in living cells, receptors are required to be extremely sensitive in order to convert molecular flux into changes in physical properties or voltage. For this reason, it is desirable to employ the proper amplifying mechanism as well as a powerful molecular recognition to effect changes in physical properties. In other words, a molecular device is required, in which one electron is converted to a large molecular flux, and one photon to a large electron flux. This is discussed in the next section. If these conditions are satisfied, biochip functions will become sophisticated.

3. Merits Obtained by Use of Molecular Elements

Basically, molecules can communicate with electromagnetic waves. They receive electromagnetic waves (resonance absorption), transform them, change their physical properties (on or off), and emit electromagnetic waves. In addition, they have flux conversion ability; they change luminous flux into electron flux as seen in photoionization, or molecular flux to potential as seen in a concentration cell. Moreover, in strictly designed molecules, intermolecular recognition works specifically, which brings about potential ability to achieve self-organization. Therefore, in principle, the functions of molecular elements are the same as those of biochips.

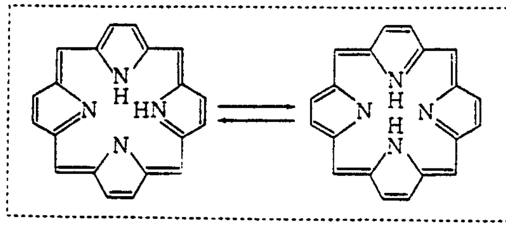
There is a question whether the use of molecular elements has any merit. Table 1 shows the difference in fundamental physical properties between biochips and expected molecular elements.

In the future, molecular elements will be used to compensate the defects of biochips. However, it is difficult to show from an engineering viewpoint how the application will be widened as there are no molecular elements with technological feasibility at present. Based on recent fundamental research, the extent of future market share each molecular element will have is discussed below.

Table 1. Comparison Between Biochips and Molecular Elements

	Biochips	Molecular elements
Stability	low	high
Price	rather expensive	rather cheap
Amount supplied	in most cases very limited	large supplies possible
Self-organization (self-wiring)	possible	sufficient R&D is required
Suitableness as materials	low	high
Efficiency expectability	expectable	expectable to some extent
Material improvability	difficult (protein engineering)	rather easy

The hole (burning) method is suggested for information-accumulating elements. In this method, the microdeformation of a molecule is brought about by strong electromagnetic waves, which are monitored by means of weak electromagnetic waves. The deformation of a molecule is shown in Formula (1). In principle, it is an excellent method; multiple memory is possible, writing is considerably fast, while reading is very fast. The biggest problem is that the deformation represented by Formula (1) can move reversely at an energy-barrier lower than room temperature. Therefore, unless it is operated at a temperature near $0^{\circ}K$, the rate of memory-erasure would become relatively high. If the energy barrier is increased, a larger unit energy for writing will be required, which will damage other parts of the material. For this reason, it is necessary to make the unit-energy low, writing is carried out at the recording site of a molecule in order not to damage other parts of the molecule. There is no way other than using a limited mass of molecules to prevent memory-erasure. One typical way is to use the lattice energy in a crystal. When placed in a lattice, the deformation in a molecular unit will inevitably destroy the surrounding lattice, therefore the deformation of a molecular unit in a lattice by a low energy barrier is very difficult. For this reason, scattered low energy does not cause the erasure of memory. Radiation of low energy at a limited area (long-wave resonance absorption energy) deforms all the units in the lattice simultaneously, which causes coordinated deformation of the entire molecule, leading to the deformation of the lattice itself. This enables selective quick recording of molecular elements, and the memory can be stored safely. This also enables safe memory-storage with a high S/N ratio, which can record and erase at low energy such as visible light and ultrared light, and which does not erase by mistake memory from erroneous information like scattered light. This molecular group theory has been proved by X-ray with the inclusion of cyclophane crystals and by the reaction rate theory. Following the theory, stable molecular recording was demonstrated with usable materials. Recording can be completed in a very short period of time with visible or ultrared lasers stored semieternally. Although a detailed



Formula (1) Example of Molecular Deformation Induced by IR Laser

explanation is omitted here, the minimum number of molecules required may be 10^2-10^3. Therefore, considering the average size of a molecule, the theoretically minimum shape of an element will be a cube or a square with an edge length of 20 or 30 angstroms. This is about the size of a protein, but a group of molecules is required for proteins to increase the S/N ratio, and make information more reliable. According to the theory mentioned above, the size of a molecular chip will be one-tenth of a biochip in length, and one one-hundredth in area.

Various flux conversion functions and control functions have been demonstrated with molecular elements. Table 2 shows typical functions of molecular elements. The functions will surely widen rapidly in the future, but presently the application merely for simple memory-recording is not taken seriously in modern chemistry.

Table 2. Flux Conversion Functions of the Representative Molecular Elements

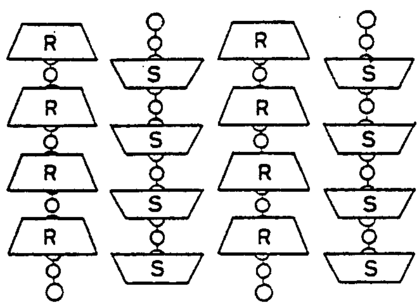
Molecular system	Function
Colloidal platinum	H_2 ↔ electron
Colloidal Cds	light ↔ electron
Artificial cells	electron ↔ ion
Luciferase in fireflies and sea-fireflies	molecule → light
Microphane inclusion crystal	light → molecular sequence
Molecule-recognizable LB membrane (chemical sensor)	molecule → current, potential
Artificial enzymes	molecule A ↔ molecule B
Transport-membrane-fiber (carrier molecules)	potential → molecule

4. Future Development of Molecular Elements

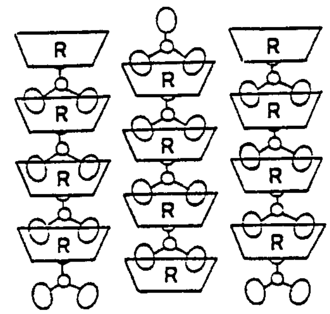
At the end of this report, several of the most important applications of molecular elements are discussed.

Molecular elements are too small to use jointly with conventional electronics. For this reason, they will be applied to optical reception, photoemission (chemiluminescence), and conversion between light and electron, all of which are necessary for the above application and have been studied in chemistry. Their technical development is urgently required.

The other large problem is the necessity of a powerful amplification system, because calculation and flux conversion with light or electrons weakens the system. A natural example of this is visual rhodopsin. Fortunately, its molecular mechanism for amplification was solved in 1985 and it is explained as follows: a photoexcited retina causes deformation of the surrounding protein and opsin, which activates phosphoric ester hydrolytic enzymes. Consequently, the hydrolysis of the signal compound, GMP, is accelerated. GMP helps Na^+ channel in the membrane to open. Cells have a pump to suck up Na^+ constantly, which balances with eluate from Na^+ channel. If GMP is hydrolized and the channel is closed, Na^+ accumulates quickly and generates pulse potential. Its rate of amplification is extremely large, 10^{10}- 10^{12} Na^+ per a photon. When such a system is constructed with simple molecules, an entire molecular device in an optical computer will be completed.



(a) Acetonytril inclusion forms rasemic crystals



(b) Chloroform inclusion forms photoactive crystals (R or S)

Figure 4. Cyclophane Changes Its Crystal Structure in the Presence of Inclusion Guest Molecules or Their Derivatives, Which Causes the Change in Physical Properties

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FUJITSU SCIENTIST REVIEWS RECENT GAAS COMPONENTS DEVELOPMENTS

Milan ALTA FREQUENZA in English No 3, May-Jun 86 pp 149-155

[Paper by Masumi Fukuta of Fujitsu presented at workshop on "GaAs Discrete and IC Devices: Trends in Telecommunications" in Milan, Italy, 20-21 February 1986]

[Text] 1. Introduction

The interest of Fujitsu on GaAs technology and components as alternative to silicon devices for microwave applications, started very early indeed. In 1973 the first 1.6 W GaAs power FET with 5 dB gain at 2 GHz was developed, while in 1976 the first C band Power FET's were commercialized. In 1980 the first high reliable microwave components for space applications were produced and, in the same year, the first internally matched 5 W, 6 GHzGaAsFET's were fabricated. In 1980 again, the first High Electron Mobility Transistors (HEMT) were invented in Fujitsu Laboratories, demonstrating the exceptional potential characteristics of these devices for future high speed and high frequency microwave applications. A great effort is now also dedicated to other GaAs applications as analog hybrid micromodules, digital and analog monolithic IC's.

2. Power FET's

There are mainly two types of devices in this field:

--internally matched power FET's
--Small/medium power FET's

Figure 1 shows 10-year history of the development of power GaAs FET's.

Mass production, of course, followed this evolution with same delay. This gap, however, is decreasing during these last years.

Nippon Electric Company (NEC) reported 25 W at 6 GHz in 1980, the highest power achieved as of today.

Figure 2 shows a GaAs FET with a total gate width of 60.8 mm on a chip carrier with internally matched circuits. The size of the single-chip

FET is 2.2mm x 0.7 mm. The low-loss capacitors were formed with a high dielectric ceramic plate, whose principal component is BaO-TiO2. Its relative dielectric constant is 39, and its loss tangent, 2X10-4. Use of this capacitor made it possible to obtain good low-loss matching and phase uniformity within multichip devices. The output network consists of bonding wires and microstrip stubs formed on alumina substrates.

Figure 3 shows input-output power characteristics of internally matched GaAs FET's with 60.8 mm gate width. An output power of 25 W at 3 dB gain compression and 5.8 GHz with 24 percent power added efficiency were achieved.

Technological improvements adopted for the fabrication of power GaAs devices are the Plated Heat Sink (PHS), via hole interconnection to ground, air bridge source-gate pad interconnections and Si_3H_4 final passivation.

Between more recent power products, a 8 W, internally matched GaAs FET, combining to chips, for a frequency up to 12 GHz and a 4 W FET internally matched GaAs FET, using one chip, up to 15 GHz are worth to be mentioned. In addition, very linear power FET's are produced for application in amplifiers for 64 QAM radio transmissions.

A new series of high power, internally matched multichip Power FET's is under development now. Some significant results are shown in Figure 4 and 5.

This new set of high power microwave transistors will be alternative, for telecommunications systems, to traditional Travelling Wave Tubes with great advantages in terms of mechanical dimensions, weight and power consumption of microwave amplifiers.

Military equipment like Radar, Radio navigation and E.W. systems will certainly drive great benefit from these technologies both for reliability and performances.

Figure 6 shows the lists of various internally matched devices that are now commercially available.

3. Low Noise GaAs FET's

The HEMT (High Electron Mobility Transistors) was developed for the first time by Fujitsu in 1980. It is a GaAlAs-GaAs heterostructure containing ultrathin (5 nm) layers grown by Molecular Beam Epitaxy. In Figure 7 the basic structure of a HEMT and relative band diagram, are shown. There is a high doped, wide bandgap AlGaAs top layer followed by the formation of a two-dimensional high electron mobility gas and by an undoped GaAs layer.

The HEMT works more like a MOSFET where a Schottky barrier gate controls the number of electrons in the two dimensional gas rising and lowering the interface barrier. The thickness of the HEMT channel remains constant while only the number of carriers is modulated.

The electrons move parallel to the heterojunction interface in an ultrathin electron gas layer. Therefore the HEMT structure is characterized by a two dimensional electron transport, while it is three-dimensional in a conventional FET.

HEMT's are also characterized by an electron mobility at room temperature about twice as high GaAs FET's, due to the combination of high electron density in a very pure GaAs layer, containing very few scattering centers.

This effect is of course much more significant at low temperatures. Although the fabrication process of HEMT devices is more critically and expensive, the potentialities for high frequency and low noise performances already create a diffused enthusiasm around thses devices which be considered a real alternative to parametric microwave amplifiers, much better than conventional GaAs FET's.

The operating frequency of HEMT's, however, is mainly limited by the package itself, while the intrinsic frequency limit is probably higher than 60 GHz.

The HEMT heterostructure, of course, will not be dedicated exclusively to microwave devices, because also high performance digital IC's have been developed, with switching times which were possible, so far, only with Josephson junctions.

4. GaAs Microwave Hybrid Micromodules and Monolithic IC's

Microwave system people in all of the world are looking for the availability of basic modular elements, like micromodules, to be combined into custom subsystems.

Successful hybrid cascading FET modules named CASPAC" have been developed for microwave maplifiers assembly up to 20 GHz.

One example is reported in Figure 10 showing the package scheme and internal circuit, and in Figure 11 indicating the electrical characteristics of the same modules

The next Fujitsu target is a 30 dBm CASPAC amplifier.

The emerging alternative to hybrid microwave circuits is represented by Monolythic Integrated Circuits.

Large scale IC's will be possible with the above mentioned technologies.

Layout structures and relative small signal performances of a monolithic distributed amplifier operating up to 22 GHz, are shown in Figure 12 and 13.

With the actual state of the art, it is possible to realize a miniaturized amplifier module using a multichip version assembled within the same package.

Next, we are reporting a typical MMIC produced for the consumer market. As mentioned above, in the frequency range below 1 GHz, the MMIC is now available for industrial use.

Mathsushita is producing UHF-band MMIC's for TV tuners. Figure 14 shows a top view of this MMIC, and Figure 15 shows the circuit of the negative feedback amplifier used. R , the feedback resistance, and C , the capacitance, are included in the circuit to decrease dc current drain. In Figure 14, the feedback resistance, R , is made of the same expitaxial layer as the active layer of the FET; the cut-off capacitance, C , is composed of a Schottky junction fabricated under the gatebonding pad.

Figure 16 shows the noise figure and the small-signal power gain of this MMIC.

The applied drain voltage is 3 V, and I is 50 mA. The noise figure obtained is 1.7-2.2 dB in the frequency range of 50-1000 MHz. The increase in noise in the frequency below 100 MHz appears to be caused by the 1/ noise. The market of GaAs microwave frequency divider is getting wider.

The development of LSI for computers is also active. Figure 20 shows the layout scheme of a 1 K bit GaAs static RAM chip. This device can produce the performance of the access time 2 ns, the dissipation power 1.2 W. The chip size is 3.3 mm X 3.3 mm and this device is in a 24 pins flat package.

Figure 17 shows the block diagram of the divide-by-four counter. The maximum response frequency is 4.2 GHz, and has external 50 load driving capability. Figure 18 shows the toggle frequency test circuit.

Figure 19 shows the RF measured performance of the FMM100FG which is now commercially available.

5. Conclusion

The recent activity of Japanese companies in the GaAs microwave components has been briefly reviewed.

Significant progress has been made in GaAs technology towards the achievement of high power FET's low noise high frequency devices, and hybrid and monolithic amplifiers.

A predominant role will be probably sustained by HEMT devices both for low noise microwave applications and high speed digital IC's.

In this last case, new compound materials should be explored and relative technology investigated in order to improve the speed benefits or HEMT structures at room temperature where the great part of applications have to work.

Fig.1 - Ten-year history of the development of power GaAs FET's.

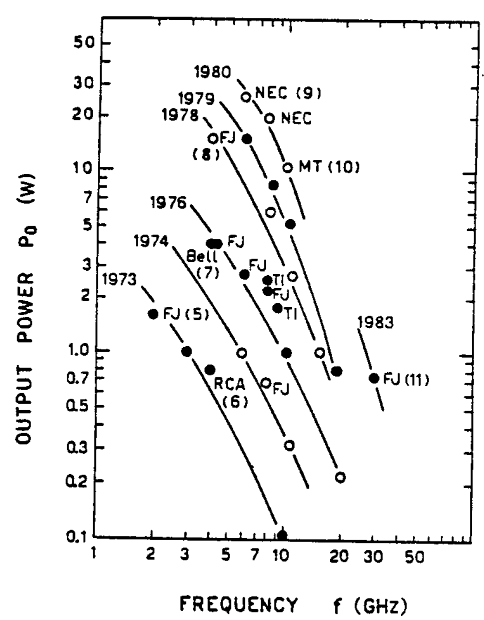


Fig.2 A GaAs FET with a 60.8 mm gate width on chip carrier with internally matched circuits.

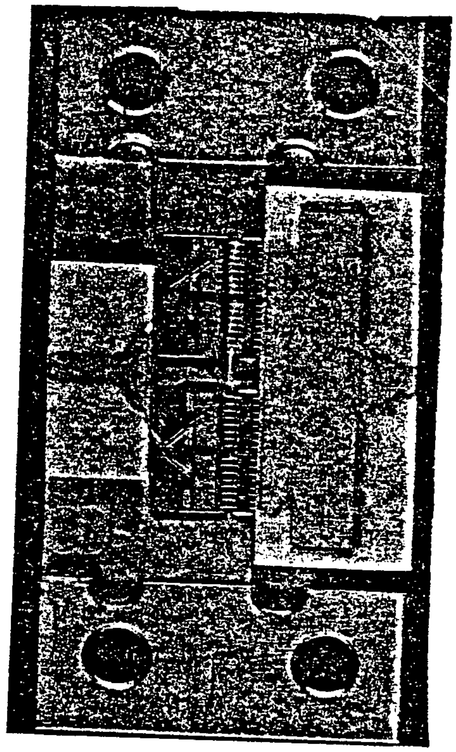


Fig.3 Actual status for internally matched Power FET's.

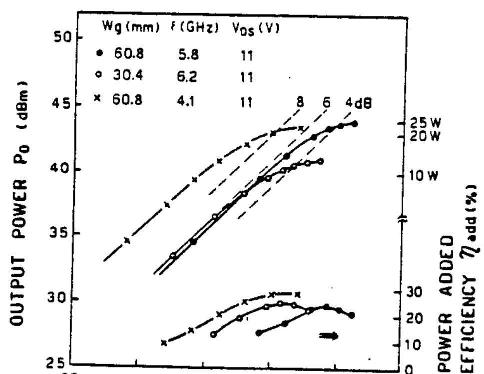


Fig.4 New generation FET chips for high power, internally matched devices.

Fig.5 Input-output characteristics of the two chip' internally matched devices.

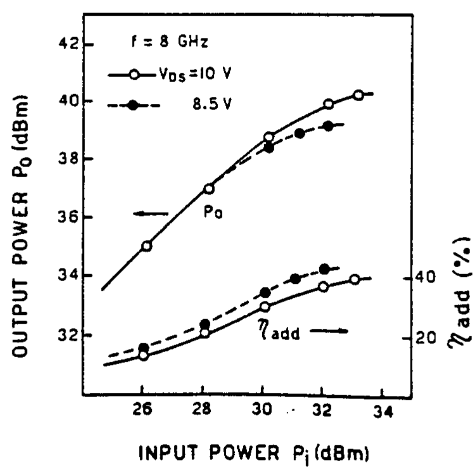


Fig.6 Various internally matched devices that are now commercially available.

PART NUMBER	FREQUENCY (GHz)	P1dB (typ) dBm	G1dB (typ) dB
FLM3742-4B	3.7 – 4.2	36	10
FLM3742-8B		39	9
FLM4450-4B	4.4 – 5.0	36	9
FLM4450-8B		39	8
FLM5359-4B	5.3 – 5.9	36	8.5
FLM5359-8B		39	8
FLM5964-4C	5.9 – 6.4	36	9
FLM5964-8C		39	8
FLM6472-4C	6.4 – 7.2	36	8
FLM6472-8C		39	7
FLM7177-4C	7.1 – 7.7	36	8
FLM7177-8C		39	7
FLM7785-4C	7.7 – 8.5	36	7
FLM7785-8C		39	6
FLM0910-2	9.5 – 10.5	33.5	7.5
FLM0910-4C		36	7.5
FLM1011-2	10.7 – 11.7	33.5	6
FLM1011-4C		36	6
FLM1112-4C	11.7 – 12.2	35.5	6
FLM1212-4C	12.3 – 12.8	35.5	5
FLM1213-4C	12.7 – 13.2	35.5	5
FLM1414-2	14.0 – 14.5	33.5	4.5
FLM1414-4C		35.5	4.5

Fig.7 HEMT structure and band diagram.

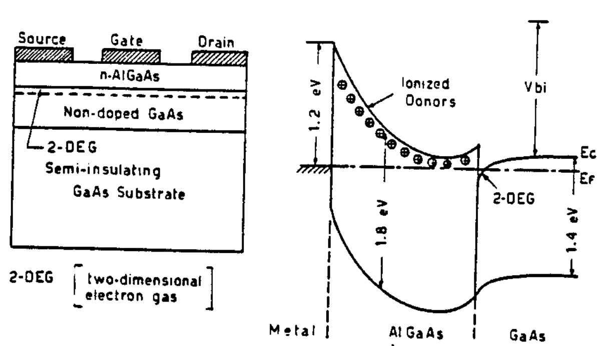


Fig.8 Top view of a low noise HEMT.

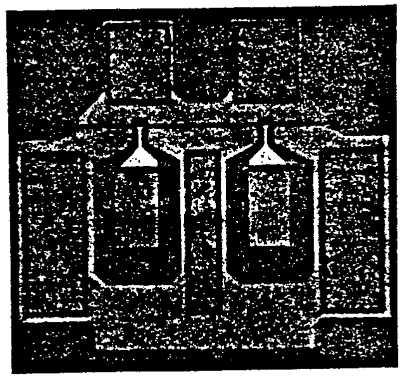


Fig.9 Noise Figure and Associated Gain of HEMT's of the type shown in Fig.8.

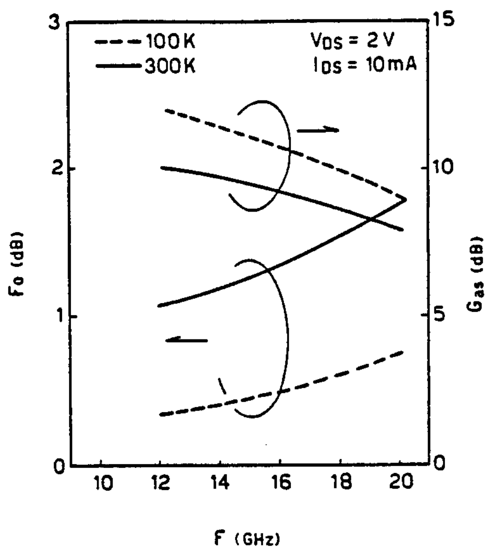


Fig. 10 Scheme of a CASPAC amplifier module.

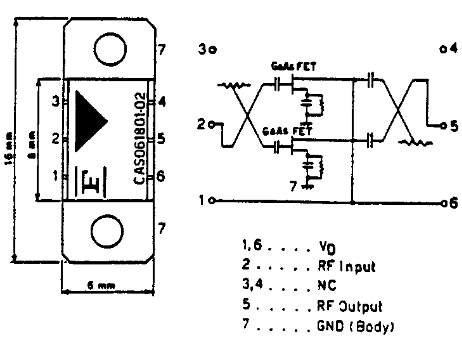


Fig.11 Performances of the hybrid module of Fig.10.

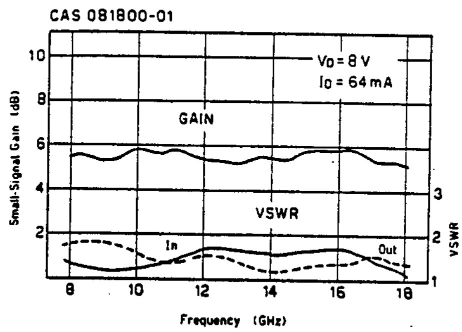


Fig. 12 Layout of a monolithic distributed amplifier.

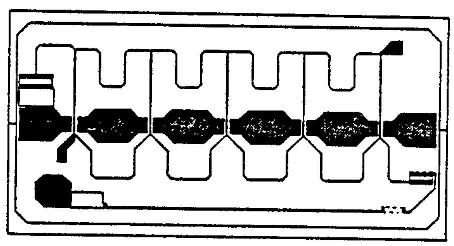


Fig.13 Experimental small-signal performances of the distributed amplifier shown in Fig.12.

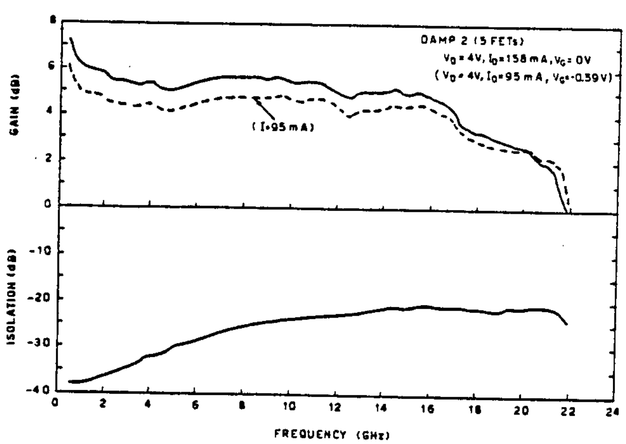


Fig.18 Toggle frequency test circuit.

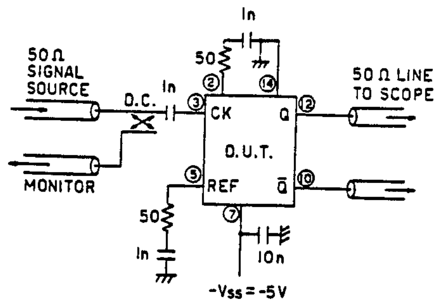


Fig.19 RF measured performance of the divider.

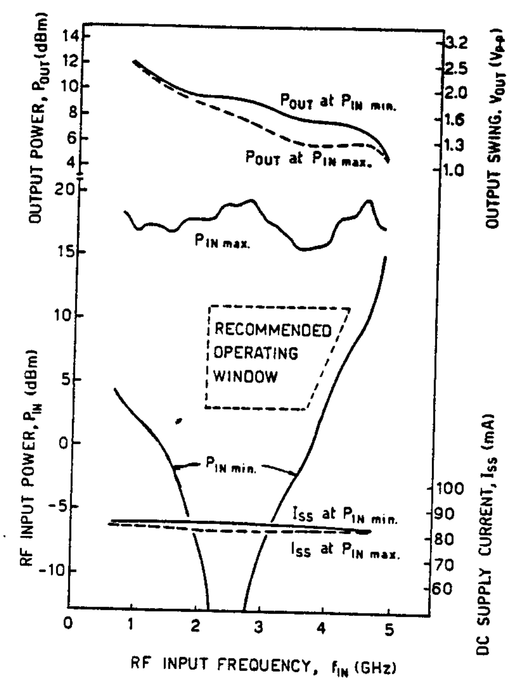


Fig.14 Top view of a monolithic microwave IC for the consumer market.

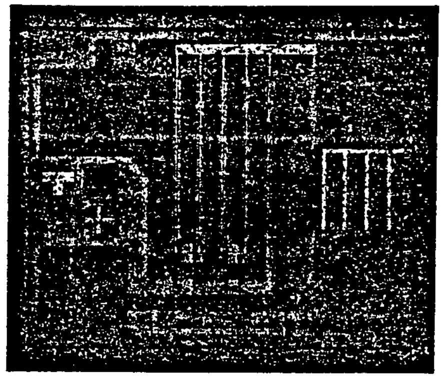


Fig.15 Scheme of the monolithic microwave IC shown in Fig.14.

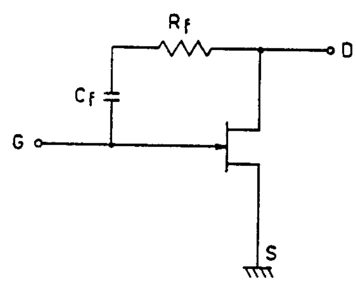


Fig. 16 Noise figure and small-signal power gain of the MMIC.

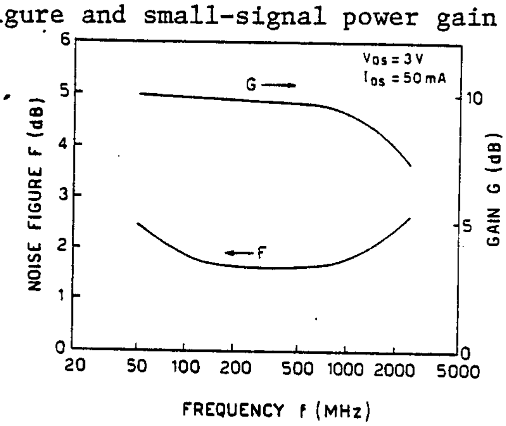


Fig.17 Block diagram of the divided-by-four counter.

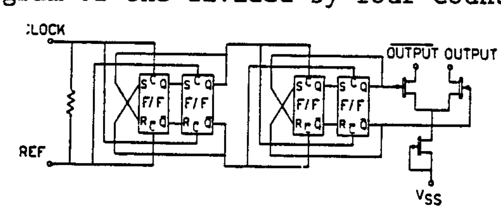
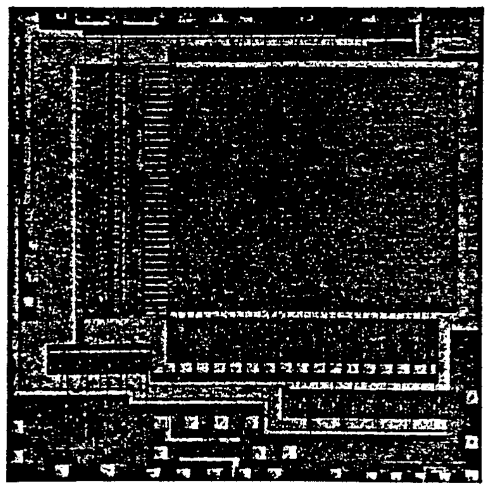


Fig.20 Pattern layout of a 1Kbit GaAs's RAM.



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DEVELOPMENT OF NEW BIOMATERIALS DISCUSSED

Tokyo NIKKO MATERIALS in Japanese Jul 86 pp 52-60

[Article by Tetsuya Tachiishi, Machine Engineering Laboratory, AIST]

[Text] 1. Requirements for Biocompatible Materials

Technologies for artificial internal organs and prosthetic materials have continued to evolve, with difficulties being resolved by the development of new biological materials. Orthopedics deals with biological materials in connection with mobile structures such as the muscular and skeletal systems, the artificial kidney deals with filtration of the arterial blood in which mechanical function is only of secondary importance. The conditions required for biological materials, hence, vary necessarily with applications; they, nevertheless, fall into two categories, the biological and the mechanical.

1.1 Biological Conditions

a) Chemical stability without toxic or allergic reactions involved
b) High biocompatibility
c) Freedom from carcinogenic and antigenic actions
d) Producing no blood coagulation and hemolysis
e) Producing no metabolic abnormality
f) Undergoing no deterioration and decomposition in organism
g) Undergoing no extraction by surrounding fluids
h) Causing no adsorption and producing no precipitates.

The term biocompatibility implies reciprocal action between a biological material and an organism and has recently been used in a broader sense which combines both the local reaction involving tissues surrounding the material and the general reaction. The material that does not produce these reactions is referred to as being biocompatible.

Tissue reactions observed when an implant material is introduced into the body are: reactions against soft and hard tissue damage as a result of surgical intervention; oxidation of the material surface caused by conditions inside the organism; biodeterioration of the material by hydrolysis; fatigue, breaks, and surface wear due to repeated stress; reactions of surrounding tissues to material corrosion (dissolution). Organisms provide biomaterials with a fairly harsh environment, together with repeating loads and impact loads exerted on the material, produces corrosion-fatigue and corrosion creep more frequently in the material than an ordinary environment would. The mechanism involved in these reactions, nevertheless, remains almost entirely unelucidated because of the time required for the quantitative assessment of the deterioration. Only very recently has research started to predict, in a short time, biodeterioration by means of an in vitro experiment.

1.2 Mechanical Conditions

a) Static strength (extension, compression, bending, shearing, etc.)
b) Proper modulus of elasticity and hardness
c) Resistance against fatigue
d) Resistance against wear
e) Lubrication characteristics

1.3 Other Conditions

a) Characteristics as functional material (e.g., permeability for particular substances)
b) Processibility
c) Adhesive characteristics, etc.

The Judet type artificial bone heads, made of methylmeta-acrylate and developed in 1946, proved to be incapable of long-term application because of a design drawback and low wear resistance. This is also true of a teflon-made acetabulum used by Charnley in 300 cases owing to a tissue reaction to the powder produced by the abrasion and also a polyacetal (Delrin) artificial hip joint. Of particular importance in connection with the application of the artificial joint is friction and wear; the friction coefficient for materials commonly available is higher than that of the natural joints of the body. Measurements by Duff Barclay in 1967 and Sasada in 1972, of relevant frictions indicated that a combination of high density polyethylene using a metal such as titanium, cobalt chromium alloy, or stainless steel, can give the best result. Though the question of raw material friction for use in artificial joints may thus seem almost resolved, the recent successive emergence of raw materials offers many new problems.

2. Titanium and Titanium Alloys

The metal titanium has been produced industrially only since 1937 when the chlorine method was completed; thus the relevant history is comparatively short. It is also rather recently that an application for the metal has been found in biological materials. The molding of titanium is effected by dissolving titanium sponge by means of an arc or plasma beam in a vacuum or inert atmosphere such that the metal turns into a block.

Pure titanium and the alloy Ti-6Al-4V concern largely biomaterial application. Tables 1 and 2 show compositions and mechanical properties for titanium, for

Table 1. Chemical Composition of Biocompatible Metal Materials Based on ASTM Standard

Titanium and Ti-6Al-4V			Stainless steel		Co-Cr alloy		
	Titanium (F67-66)	Ti-6Al-4V (F136-70)		SUS316L (F55-66)		Cast material (F75-67)	Machined material (F90-68)
N_2	0.07 below	0.05 below	C	0.03 below	Cr	27.0-30.0	19.0-21.0
C	0.10 "	0.08 "	Mn	2.00 "	Mo	5.0-7.0	-
H_2	0.013 "	0.013 "	P	0.03 "	Ni	2.5 below	9.0-11.0
Fe	0.30 "	0.25 "	S	0.03 "	Fe	0.75 "	3.0 below
O_2	0.30 "	0.13 "	Si	0.75 "	C	0.35 "	0.05-0.15
Al	-	5.5-6.5	Cr	17.00-20.00	Si	1.00 "	1.0 below
V	-	3.5-4.5	Ni	10.00-14.00	Mn	1.00 "	-
Ti	Bal	Bal	Mo	2.00-4.00	Co	Bal	Bal
			Fe	Bal	W	-	14.0-16.0
					Mg	-	2.0 below

Table 2. Mechanical Strength of Biocompatible Metal Materials Based on ASTM Standard

	Titanium and Ti-6Al-4V		Stainless steel	Co-Cr alloy	
	Titanium (F67-66)	Ti-6Al-4V (F136-70)	SUS316L (F55-66)	Cast material (F75-67)	Machined material (F90-68)
Tensile strength (MPa)	>414	>853	>482	>655	>855
0.2 percent proof stress (MPa)	>345	>770	>172	>448	>310
Elongation (percent)	> 18	> 10	> 40	> 8	> -

a titanium alloy, and for other biomaterials. Tables 3 and 4 show fatigue strengths and elastic moduli. The specific gravities and elastic moduluses of titanium and the titanium alloy are half those of other biomaterials; this implies that these material shave high specific strengths and an elastic modulus closer to those of natural bones.

The two materials also have high resistance against corrosion which is the major reason that makes them attractive for use as biomaterials. The mechanism involved is the formation of an oxidation film over the metal surface which covers the metal and makes it inert. The materials are, in particular, free

Table 3. Fatigue Strength of Biocompatible Metal Materials

	Titanium and Ti-6Al-4V		Stainless steel	Co-Cr alloy	
	Titanium (F67-66)	Ti-6Al-4V (F136-70)	SUS316L (F55-66)	Cast material (F75-67)	Machined material (F90-68)
Fatigue strength (MPa)	310-413	540-570	262	241-276	379-517

Table 4. Elastic Coefficient of Various Materials

	(10^3MPa)
Bone	20
316 L Stainless steel	200
Cast Co-Cr alloy	200
Wrought Co-Cr alloy	230
Pure Ti	100
Ti6 Al-4V	100
PMMA bone cement	2

of pitting and stress corrosion cracking, which are the characteristic drawbacks of stainless steel. Figure 1 shows anodic polarization curves obtained in Hank solution by means of the potentiostat for various raw materials.

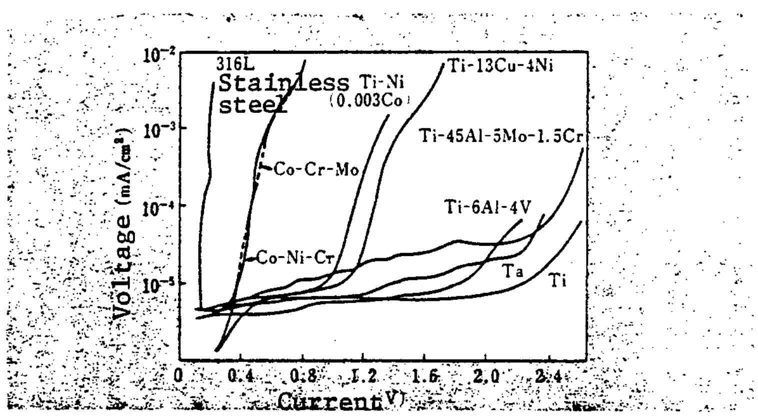

Figure 1. Anode Polarization Curves of Various Metals in Hank Solution Obtained by Means of Potentiostat

Among the drawbacks of titanium and the titanium alloy is, first of all, their low resistance to abrasion. Therefore, they barely function adequately when applied to contact parts of artificial joints, etc. There are also difficulties in casting because of their high reactivity. Research of their application as a reparation material for tooth crowns by means of an improved material for dies is underway. Titanium nickel alloy has recently been spotlighted because of its unique function. The alloy, which is an intermetallic compound including nickel and titanium in a 1:1 ratio, is capable of restoring its original shape as the temperature rises. This occurs after it has been deformed at a temperature below that of the martensite phase transition, provided the alloy memorizes its shape at the high temperature. This capability is referred to as "shape memory effect" of the metal. The alloy also regains its original shape after removal of the relevant load if it has been subjected to a major deformation at a temperature a little above that of the martensite phase transition, a phenomenon referred to as the "superelasticity effect." In connection with the clinical application of the "shape memory effect," the temperature at which an alloy regains its original shape after having been deformed below the martensite phase-transition point may be either equivalent to that of body temperatures of man, etc., or somewhat higher than that. In the first case, the original phase is regained at body temperature; in the second, however, the Ti-Ni alloy implanted into the body has to be subjected to radio frequency (induction) heating such that the alloy's temperature rises and its original phase and shape are restored.

The corrosion resistance of the Ti-Ni alloy is superior to that stainless steel and cobalt-chromium alloy but inferior to that of titanium and the titanium alloy as shown in Figure 1. The evaluation of the biocompatibility of the Ti-Ni alloy, in turn, has been carried out by means of animal experiments, with results better than for stainless steel.

Examples of the possible application of the Ti-Ni alloy are: internal splinters of metal for the treatment of bone fracture; clips, staples, etc., for binding and fixing; intramedullary fixation of artificial joints, artificial bones, and artificial toothroot; application as intramedullary nails and for the correction of scoliosis; application as filters for the removal of coagulated blood; application in artificial hearts; application in small pumps for artificial kidneys; application as wires for orthodontia; and as artificial tooth roots.

As can be seen from the above, much hope has been pinned on the Ti-Ni alloy as a biocompatible material because of its characteristic functions; its development, nevertheless, is still in the beginning stage and the establishment of its safety suitability for the living body currently makes it an object of research and investigation.

3. Porous Metals

The use of metals as implant materials involves such problems as damage due to relevant metal ions dissolving into the body fluids and breakage of the metal due to corrosion. Other problems of major importance, however, are loosening of its linkage to the bone in the case of artificial joint materials; polymethylmethacrylate, referred to as the bone cement, is generally used for fixing the implant materials to the bone. Cement in long-term application, involves such difficulties as loosening of the joint, fever due to the polymerization of the cement, and damage produced by residual monomers in surrounding and other tissues of the body.

One method for counteracting these difficulties involves the use of porous metals: powder of titanium and titanium alloy, stainless steel, or cobalt-chromium alloy are sintered, or subjected to a method called void metal composite (VMC), or plasma-sprayed, such that the metal surface grows porous. The bones grow into the surface pores, thereby producing firm bondage between them. The growth process of the bone structure, in turn, seems to be dependent on the diameter of the pore; Clenow suggested a relationship between the titanium pore diameter, that is, the diameter of the sintered particle and the shear strength at the metal and the bone interface (as presented in Figure 2), and pointed out an improvement of the interface shear strength in proportion to the extent of bone growth.

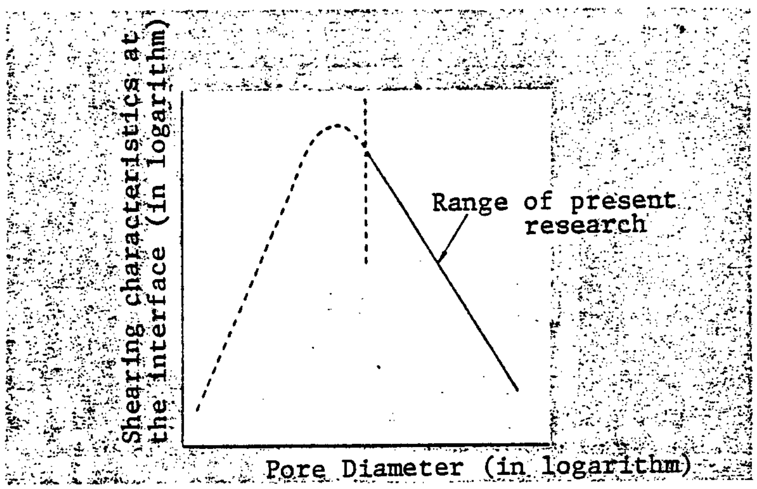

Figure 2. Plot of Shearing Strength at the Interface Versus the Diameter of Pores

For the present, the pore diameter of around 250 microns is regarded as the optimum for the growth of new bones.

4. Materials for Coating Metals

Among the metallic materials for artificial joints there are: stainless steel SUS316 (18Cr-12Ni-2.5Mo-0.06C, balance Fe), stainless steel SUS316L (18Cr-12Ni-2.5Mo, balance Fe), titanium (Ti), and titanium alloy (Ti-6Al-4V), cobalt chromium (Co-Cr) alloy (for die casting, Co-30Cr-7Mo; for processing, Co-21Cr-16W-11Ni). These find application primarily as the stem for artificial joints.

The metallic material for artificial joints is required to have sufficient mechanical strength, abrasion resistance, corrosion resistance, and biocompatibility. Though the bone cement (PMMA) has long been used, it has proved to have harmful effects on the body. Research, therefore, has recently been carried out on methods for coating or processing the metal surfaces such that the stem is fixed to the bone without applying the bone cement. Let us consider the coating of various base materials from the viewpoint of not only minimum dissolution reduction of relevant metal ions, which do damage to the body, but also enhancement of the regeneration of bone tissues and the capacity of the metal to link with bones. To begin with, the author refers to a method of mechanical interlocking in which the metal stem surface is subjected to a porous coating and the bone is allowed to grow and invade the pore.

It is conceivably impossible to strengthen the bondage of the metal stem to a bone by providing a rugged surface by means of machining because the rugged surface is too rough in comparison with bone tissues to form a mechanical interlocking. The porosity required for the interlocking, therefore, must involve a complex shape with pore diameter of 10^2-10^3 microns. Among the methods for producing such a porosity are flame spray, powder metallurgy, and metal-fiber sintering, the details of which are given below in terms of materials for coating metal.

4.1 Titanium Coating

Powder of titanium hydride, together with the carrier gas nitrogen containing 5 to 15 percent hydrogen gas, plasma sprayed over a piece of titanium such that a layer of a mixture of titanium and titanium dioxide at a thickness 0.8 mm, involving pore diameters 50 to 120 microns was formed over the surface. Titanium stems, ones with the above coating and others with no coating, were then implanted into the femur of sheep for 14 to 26 weeks and, subsequently, the shear strength at the interface between the stem and the bone was measured; the experiment proved the shear strength of those stems with the coating to be 60 to 80 times that for the stems with no coating.

4.2 Alumina Coating

Where highly biocompatible alumina is used for coating metals, the linkage between the metal and the bone again involves the mechanical interlocking effect. Because of the weak adherence of aluminum to metals to be coated, the method of finishing the surface of the metal in order to improve relevant adherence presents the major problem. Table 5 shows a comparison of the adherence of alumina to stainless steel SUS316 for various methods of surface finishing of the metal in case a powder mixture of 97.5 percent alumina and 2.5 percent titanium dioxide is sprayed over the metal using the acetylene oxygen flame spray method. It is evident that the adherence of alumina to the metal is more than twice for anodic polarization than it is for machine polishing. It has also been proved that the adherence of alumina to stainless steel SUS316L and the titanium alloy Ti-6Al-4V is over 20 MPa when α-alumina with a purity over 99 percent is sprayed with a 40 kw arc plasma apparatus over the metals which are being cooled with liquid CO_2 so that γ-alumina is formed at the interface.

4.3 Coating by Means of Bioglass and Hydroxi Apatite

Apart from biologically inert materials represented by alumina, some ceramics such as bioglass (Na_2O-CaO-SiO_2-P_2O_5) and hydroxiapatite (HAP) combine chemically with the bone. When the 316L stainless steel is coated with bioglass by means of the flame spray and implanted in monkeys for 6 months, the

Table 5. Relationship of Adherence of Flame-Sprayed Alumina to Various Methods of Surface Finishings for Stainless Steel

Surface roughening		Bond strength	
Reference	Method	α (max), psi	Failure location
Our studies	Anodic polarization	1,066	Ceramic-metal interface
Our studies	Machine roughening	504	Ceramic-metal interface
Our studies	Alumina grit sandblast	190	Ceramic-metal interface
N.N. Ault (1957)	Alumina grit sandblast	500	Ceramic-metal interface
M. Levy, et al. (1966)	Steel grit blast	408	Ceramic-metal interface

bioglass combines chemically with the bone to form a structure involving bioglass, An SiO_2 rich layer, a Ca-P rich layer, and the bone in that order; nevertheless, the adherence of bioglass to the metals again presents a critical problem here. One of the means of coating metals with hydroxi apatite, meanwhile, is by electro deposition, wherein particles of the hydroxi apatite suspended in an aqueous solution are forced, by the application of an electric potential, to migrate and deposit on the surface of a piece of titanium. Subsequent sintering of the material under pressure in an argon atmosphere or in a vacuum permits formation, at the interface, of a Ti-P rich layer with a thickness 2 to 5 microns and with high density, thereby improving the relevant adherence. The speed of bone regeneration and strength against shearing force at the interface between the bone and an implant have also been found to be improved when the 316L stainless steel, with stainless steel fiber coating, is coated with hydroxi apatite (i.e., the steel is immersed in an aqueous solution of hydroxi apatite and subsequently dried for 30 minutes at 80°C) and implanted in the femur of dogs.

5. Alumina Ceramics

5.1 Artificial Hip Joint

The complete artificial hip joint involving alumina is made up of an alumina ball fixed to a metal stem by inserting a taper pin and a socket of superhigh molecular weight polyethylene, in pair, generally. Onishi tested the strength of the alumina ball for the complete artificial hip joint of this type. "The tapering part of a stem is inserted into the alumina ball and subjected to a repeated load of up to 100 to 1,200 kgf 10^7 times or to the fall of a weight of 21.9 kg from a height of 1.39 m without any break of material" a report said; it also added that the strength drops when any foreign object such as a bone fragment is caught in the taper pin insertion part.

The surface of the alumina may be subjected to grinding, lapping, and polishing as required such that it may be provided with a mirror finish. Improved resistance against abrasion and fall in the coefficient of friction, are effected at the frictional surface of the artificial joint providing R max is 2 microns for grinding, 1.5 microns for polishing, and 0.3 microns for polishing. Figure 3 shows various types of artificial bioceramic materials for the replacement of hard biological tissues. Sawai studied a complete artificial hip joint in which an alumina ball is coupled with a socket of the insertion type made also of alumina, using old relevant artificial joints removed at the time of replacement. They also made a report on the study, by means of X-rays, of changes occurring with time between the interface of the joint and the bone; according to the report, this type of artificial joint, wherein a ceramic surface slips against a ceramic surface, produces abnormal movements due to instability between the ball and the socket and, hence, has particles of alumina crystals fall out, leading to severe body wear. Changes taking place at the border between the bone and the ceramic, in turn, are the process of bone remodeling and exhibit distinct differences in their extent between the loaded area and the unloaded, indicating that these border areas are under biomechanical control even when using alumina of superior biocompatibility. This points up the extreme importance of manufacture design of artificial joints, as it does the importance of raw materials. Many other clinical cases have also been reported.

Asada, meanwhile, reported manufacture and clinical application of a complete artificial hip joint wherein the head of the femur is covered with a cup made of alumina--referred to as the surface replacement type.

5.2 Artificial Knee Joint

Many reports have also been made on the development and clinical application of complete artificial knee joints made of alumina. Present artificial knee joints are largely of the so-called nonhinge type, which implies that the joint is similar to the human knee joint in structure. The joint surface alone is replaced by artificial components on the femur side and the sleeve portion alone is on the tibia side; the femur side components are made of metals and ceramics, and are coupled with the sleeve portion of the tibia generally comprised of polyethylene of superhigh molecular weight. These tibia-side components, made exclusively of polyethylene of superhigh molecular weight, seem to undergo major changes when pressure of the load is exerted on them, leading to the loosening of the bone cement polymethyl metacrylate. Some tibia side components, therefore, are lined with metals, etc., to prevent the above deformation.

Onishi, in this connection, reported cases wherein an artificial knee joint made exclusively of an alumina ceramic was used. They trial-manufactured the artificial joint with the object of fixing the artificial component to the bone assisted by the superior biocompatibility of the ceramic, without applying the bone cement. In this artificial joint, all metal components so far used are replaced by alumina including the metal lining of the superhigh-molecular weight polyethylene on the tibia side. Using the finite element method, they also analyzed the condition of stresses around the artificial components on the tibia for this type of artificial knee joint in cases where the components were installed on the tibia in the live body. Inoue also reported cases involving complete artificial knee joints made of alumina.

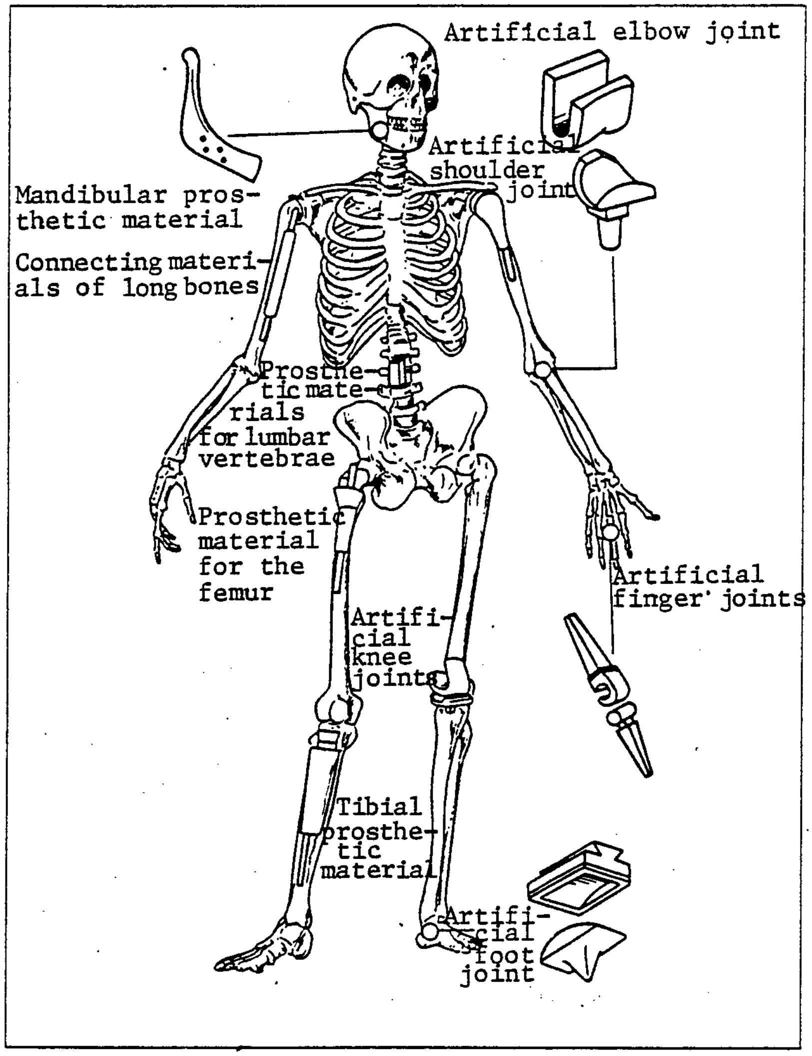

Figure 3. Areas of Application of Artificial Bones and Joints Made of Bioceramics

Onishi examined cases and conducted relevant mechanical analysis for complete artificial foot joints made of alumina ceramics wherein the artificial cement is not used to fix the artificial components to the bone. Sawamura has also reported on foot joints of the same type.

5.3 Other Artificial Bones and Joints

A large number of clinical cases of artificial joints involving the use of alumina ceramics and foregoing the use of the bone cement have been reported on. These include the shoulder joint, the elbow joint, the hand joints, the finger joints, etc. The treatment of bone malignancies, including bone sarcoma, in the past involved amputation of the limb affected; nevertheless, running parallel with the advancement in relevant chemotherapy, radiation therapy, etc., a method of treatment involving the resection in a wide range of the affected lesion and implanting therein a prosthesis of an artificial bone, so fabricated as to fit into the lesion, is being accepted as a means of saving the affected limb. Takehara reported on cases of such substitution treatment for bone sarcoma of the knee joint as did Suda.

The substitution of artificial bones for bone sarcoma has been performed as in parts of the body other than joints. Yamamuro reported a case of an enormous giant cell tumor which developed in the pelvis; the tumor was extirpated and an alumina prosthesis was implanted. Many other clinical cases have also been reported.

Sapphire, the single crystal of alumina, has found clinical application in bone screws already. It is being put to various clinical applications, including its orthodox application of fractured bone fixation, etc., because it can be buried in body tissues and left there without being removed. Kanie reported that in the surgery of artificial hip joint replacement, a sapphire bone screw was inserted into the acetabulum of the pelvis and the head of the screw used effectivelyas the anchor for bone cement which fixes the socket of the artificial joint to the bone. Kadowaki, on the other hand, reported cases wherein sapphire nails were used in fractured or fractured-and-shifted bone pieces. Besides the above, clinical applications of sapphire screws and technological research of its mechanical properties, etc., have been reported.

Alumina ceramics find application also in the vertebral bodies. Taguchi reported frontal fixation of the cervical vertebrae using a ceramic spacer.

Clinical applications are also numerous when alumina is used as a bone filler. Though examples quoted above successively are almost in the domain of orthopedics, various clinical applications are also made in other surgical regions. In brain surgery, Okumura reported cases where alumina ceramic was used for skull defects arising after surgical treatment, such as a craniotomy. Four cases so treated have been doing well. Autogenous bones or PMMA resin has been used to fill bone defects; these materials involve many difficulties such as poor merger to the live bone and excessive tissue reaction. In the otorhinology section, artificial auditory ossicles made of synthetic resins were substituted for relevant natural ones in the past in cases where an inflammation of the middle ear caused degeneration of the ossicles and resulted in poor hearing; this method of treatment, however, involved such difficulties as thrusting out, through the eardrum, of the replaced ossicles which, finally, is discharged. Yamamoto, in this connection, reported satisfactory results by the application of artificial auditory ossicles made of alumina ceramic.

Moreover, some basic research aimed at the application of alumina as prosthesis for circulatory organs has also been undertaken. Mitamura has reported sapphire is very satisfactory in terms of its antichrombotic property.

As can be seen from the above, alumina ceramics as a biocompatible material has a wide prospective field of application.

6. Zirconia Ceramics

Zirconia, of all the ceramic materials, has very high strength, high melting point, and superior chemical stability and, hence, has been applied in diverse areas.

Zirconia ceramic has three crystal modifications and undergoes phase transition with a rising temperature as follows: monoclinic system 1,170°C tetragonal system 2,370°C, cubic system 2,700°C melt.

The phase transition from the tetragonal to the monoclinic system involves the martensite type of modification and is accompanied by a volume expansion of around 4.6 percent due to the difference in density between the two systems. though the transition takes place at around 1,000°C for pure zirconia, the tetragonal system is maintained at room temperature semistably by the addition of such stabilizing agents as yttria, calcia, and magnesia. This type of ceramic, part stabilized zirconia, is capable of easing destructive forces exerted on its terminal part, where cracks usually progress, by expansion of its volume. This results from the martensite type modification, the tetragonal to the monoclinic system occurring as stress concentrates thereon. It implies that the ceramic requires increased energy for cracks to develop and thus a destructive surface is formed which has a high fracture toughness and an improved strength. The part stabilized zirconia has been applied in cutlery, tools, dies, sleeve components, etc., by virtue of its high fracture toughness and high strength.

The first requirement for zirconia, as for any other new material, in order to function in a live organ, is its environmental stability. In this connection, it has been observed that zirconia's strength deteriorates under certain circumstances if subjected to long hours of aging at low temperatures, around 200°C. This, conceivably, is a result of ceramic volume expansion accompanying its martensite transition from the tetragonal to the monoclinic system. It has been found that this phase transition, in turn, is dependent upon the crystal lattice size and the distortion extent of the tetragonal system and that the deterioration can be suppressed when the ceramic sintering condition is controlled in such a way that the grain size of the tetragonal system phase becomes small.

Aging of the tetragonal phase system zirconia ceramics involving grains of different diameters, for example, has shown that relevant ceramics with the average grain diameter 0.7 micron or less do not suffer any deterioration of strength. The addition of ceria as the stabilizing agent, in turn, suppresses notably the transition to the monoclinic system as in blending and dispersion of alumina, whereas aging in water accelerates it. The phenomenon of strength deterioration described above, takes place in a temperature range for exceeding the one where biocompatible materials are applicable, and measures to counteract the damage have largely been worked out, though detailed investigation of the mechanism and the cause of the deterioration is underway.

Results of research on the application of zirconia ceramics in biocompatible materials such as those for artificial joints were reported in 1984 at a meeting of the Ceramic Implant Research Association for Orthopedic Surgery. Matsuguchi, who did insertion experiments on adult mongrel dogs, reported that zirconia ceramic has a thin layer between itself and the bone with part of the bone structure making direct contact with the ceramic. Munemiya, in turn, reported that in their insertion experiments on rabbits, they found no shift at all, into the bone and bone marrow of zirconia, a raw material of the zirconia ceramic. Tachiishi used an artificial joint of the Charnley type coupling a zirconia ball with a stem made of a titanium alloy in order to make relevant destruction tests, i.e., to assess strength fixation where the ball fits into the stem, and to measure resistance against fatigue and changes in friction characteristics after damages accumulated. They concluded that the durability of the bone head made of zirconia is at least equal to the one made of alumina.

From the above research, one can see that zirconia ceramics, as a biocompatible material, is equal to and has durability better than alumina ceramics. One may reasonably hope that it may be put to use in a wide range as an implant material better than that of alumina, providing many research results are henceforth built up.

7. Apatite Hydroxide

Ceramics of the apatite hydroxide group, as opposed to alumina ceramics, are biologically reactive or bioactive materials. Whereas alumina is a biologically nonreactive or bioinert ceramic and exhibits excellent stability in the body, the ceramic apatite hydroxide activates osteogenic cells and induces bone regeneration.

Fixation of an artificial hip joint involves two major problems: one is the method of fixation of the metal stem that must be inserted into the femur; the other is fixation to the acetatulum, the socket that the head of the artificial femur must fit into. Polymethylmetacrylate, PMMA, which has currently been used as the cement seems to be the major cause of a second operation because the cement was apt to loosen or crumble. It is, therefore, necessary either to develop an artificial hip joint which permits satisfactory fixation using the cement currently available or to develop a new bone cement which permits better bone regeneration. In this connection, research is underway both at home and abroad and the mechanical characteristics of PMMA or HDPE (high density polyethylene) composite materials involving apatite hydroxide or calcium phosphate as the dispersion phase are being investigated. Of these materials, major ones are as follows:

1) With the idea to improve the mechanical properties of bone cement, Castaldini dispersed crystalline apatite powder in PMMA in the volume ratio of 0-0.25, and determined Young's modulus, etc., of relevant specimens.

2) Bonfield prepared a composite material in which apatite hydroxide particles were dispersed in HDPE in a volume ratio of 0.1 to 0.5 and compared the deformation and fracture characteristics of the material with bone cortices. They further investigated the cellular toxicity of the material and concluded that the material may possibly be available as a bioactive material for the

substitution of bone. Particles of alumina, zirconia, etc., as dispersion materials are also being studied besides those of apatite hydroxide and calcium phosphate (TCP); however, composite materials involving apatite hydroxide and TCP are superior to the others in their bondage strength to live bone.

Carbon fibers, meanwhile, have been used from early times for compounding and reinforcing artificial bones. Carbon has high biocompatibility and, hence, research on a composite of the substance and HDPE has been underway; nevertheless, the wettability between the two substances is poor and, furthermore, the composite is not suited for the acetabulum because carbon fibers come in contact with the surface as the polymer wears. Fibers from the more biocompatible calcium phosphate group of materials would make ideal reinforcements. Currently, however, only bioglass and substances of similar compositions, which are easily transformed into fibers, are used together with PMMA as composites. Major relevant materials are given below.

1) A tough glass involving unidirectional crystallized calcium phosphate developed by Abe has surmounted the disadvantage of fragility in conventional ceramics by virtue of a unidirectional crystallization of the $CaO-P_2O_5$ glass group. The glass also has improved chemical stability and biocompatibility by virtue of having its surface coated with apatite. Tests on animals have revealed that the ceramic makers partial direct contact with the bone 4 weeks after the ceramic has been inserted into the bone.

2) Kobayashi molded a composite material comprising glass fibers of the $CaO-P_2O_5-Al_2O_3$ group and polymethylmetacrylate (PMMA) and found, after the examination of relevant biological tissue reaction, that the new material is of high biocompatibility and, in terms of mechanics, has a high bending strength and a high bending fracture toughness.

It would, in turn, be most desirable if ceramic-ceramic composite materials of high toughness involving largely apatite hydroxide or calcium phosphate were developed. Major materials reported in this connection are presented below:

1) Kokubo has taken crystalline glass powder of the $Na_2O-CaO-P_2O_5$ group, molded and sintered it at 1,200°C, and obtained a composite raw material of high strength made of apatite, wollastonite, and TCP. The assessment of the composite by means of animal tests is that the composite has a high binding strength to bone and is equal to or better than natural bone in general mechanical strength.

2) Kondo has taken apatite hydroxide powder, with some fritting of TCP added, molded and sintered it at 1,200°C to 1,300°C, and obtained a sintered apatite of high strength comprised largely of apatite hydroxide crystals with a small amount of TCP added (Ca:P = 1.64:1, bending strength 205.8 MPa). Examination by tests on animals proved high biocompatibility.

3) Kawamura examined effects of the addition of silica to β-TCP with the idea of improving its strength and developed a material with a bending strength as high as 2,600 kgf per cm^2.

In addition to the above, research is underway for improving both the strength and biocompatibility of alumina ceramics and metals by coating their surface with apatite or TCP. Research on the application of the bioglass developed by Hench, which has high biocompatibility but poor strength, is being studied for use in the coating of and compounding with metals.

The progress of the artificial hip joint depends upon the solution of several difficulties. If an artificial hip joint is to be implanted surgically without the use of bone cement, the technology of compounding stem metals with apatite or TCP makes an important goal for developmental research. When joining ceramics to polymers or for compounding the two so that the socket in the acetabulum is stabilized, for example, the ball for the head of the bone, in turn, does not necessarily require highly biocompatible apatite or TCP, but alumina or zirconia will be selected by virtue of its high hardness, high resistance against abrasion, and mirror-finish capacity.

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NTT RADICALLY CHANGES MANAGEMENT SYSTEM

Tokyo TSUSHIN KOGYO SHIMBUN in Japanese 24 Nov 86 p 1

[Text] Nippon Telegraph and Telephone [NTT] has decided to entirely switch its personnel and wage systems for ordinary employees from the current, job classification based system, which is patterned after the government, to a system based on function and qualification, which is more appropriate for a private enterprise. This policy change was stated in NTT's reply to All-Japan Telecommunications Workers' Union's request to "radically revise [NTT's] wage system." The basic elements of this new policy are: (1) a "function and qualification system" based on individual ability and performance will be introduced everywhere, (2) new "function and qualification standards" will be adopted in line with the new system and each employee's rating, wage, and assignment will be decided accordingly, (3) a base salary will consist of the function based wage and employee based wage, with a third element, the job seniority wage, added to the base salary, and (4) the current system of five job groups will be abolished and reorganized into three function groups. Details will be worked out through negotiations with the labor union. Both sides may reach an agreement as early as next spring since both sides agree on basic issues. However, since this change involves a tremendous amount of work affecting every part of the company, actual implementation of the new system will occur sometime in the middle of next year (retroactive to the beginning of next year) or even in the year after the next.

NTT's current personnel and wage systems were inherited from the Nippon Telegraph and Telephone Public Corporation. These systems are based on job classifications and give priority to job posts. Since NTT became a private enterprise, the existing systems' shortcomings became more apparent because they were simply very bureaucratic systems. In particular, with the arrival of new and vigorous competitors, both the management and union became keenly aware of these system's problems.

Under the present job system, which rates an employee according to his post, a better employee is moved around more since he cannot be promoted in the same post. As a result, there is no possibility of producing an expert, which is indispensable in defeating business competition, and qualified people become scarce in the actual working level. Also, since there is only a limited number of posts, promotion channels become clogged resulting in, for instance, serious problems in rewarding the generation of employees hired in large numbers in the mid-sixties. Moreover, current job classification standards

(14 job groups, 47 job types) are already unfit for the rapidly developing world of electrocommunications. It has become clear that these standards are the culprits in obstructing the promotion of multifaceted businesses and flexible business management, which are the keys to dynamic private enterprises.

NTT's reply represents the company's effort to overcome these problems by switching to a function oriented system. The system's basic features listed below amount to accepting almost all the union's demands.

1. NTT will replace its current job classification system, which is based on jobs and posts, entirely with a function and qualification system, which is based on individual ability and performance.

2. For this purpose, current job classification standards (14 job groups, 47 job types) will be abolished and new function and qualification standards will be adopted. Performance evaluations will be based on these new standards, and evaluation results will be reflected in the ratings, wages, assignments, and training toward jobs.

These standards will assign points for an individual's ability to carry out a job and his performance, but the appropriate scale to be used for such evaluations will be studied further. To ensure fair evaluations, there will be several evaluators. Training of these evaluators will also be considered to be one of the most important tasks.

3. The first five job groups to switch to the new system will be general, communications, telephone exchange, line technology, and telegraph sales. At present, about 95 percent of current, ordinary employees belong to one of these five groups.

Grades (first-fourth, etc.) and job types in these five job groups will all be abolished and reorganized into three new functional groups.

The first of these three groups is the "planning function group," which requires the ability to plan and manage; the second one is the "specialized function group," which requires a highly specialized ability in a particular field; and the third is the "general function group," which combines the current general jobs (except for those who belong to the planning group), communications, telephone exchange, line technology, and telegraph sales. Also, the current special job group [as opposed to the general job group] will be divided into the planning function and specialized function groups.

Each function group will be subdivided further into qualification grades: three grades in the planning group, five grades (two more than the current three) for the specialized group, and four grades for the general group. (See chart on the next page.)

4. Definite "years of service in a grade" will be used for promotions. The minimum required length of service will be (a) in principle, two years for the third grade in the general function group and above, and (b) three years for a high school graduate in the fourth grade of the general function group. The

maximum length of service will be seven years in the third grade B of the general function group, seven years for the third grade A of the general function group, and five years for the second grade of the general function group.

Comparison of Function and Qualification Groups

<table>
<tr><td colspan="2" rowspan="2"></td><td rowspan="6">Specialized function group</td><td colspan="2">First grade</td></tr>
<tr><td colspan="2">Second grade</td></tr>
<tr><td rowspan="3">Planning function group</td><td>First grade</td><td rowspan="2">Third grade</td><td>A</td></tr>
<tr><td>Second grade</td><td>B</td></tr>
<tr><td>Third grade</td><td colspan="2">Fourth grade</td></tr>
<tr><td rowspan="5">General function group</td><td>First grade</td><td colspan="2">Fifth grade</td></tr>
<tr><td colspan="4">Second grade</td></tr>
<tr><td rowspan="2">Third grade</td><td colspan="3">A</td></tr>
<tr><td colspan="3">B</td></tr>
<tr><td colspan="4">Fourth grade</td></tr>
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5. The current "comprehensive wage system," which is a mixture of (a) job description, (b) years of experience, and (c) living cost, will be revised. The new basic salary will consist of personal wages and functional wages. The personal wage will be independent of an employee's function, grade, or length of service; it will solely depend on his age. The functional wage will reflect the individual's performance ability and achievement.

In addition, current special service wages will be re-examined and awarded as job bonuses only to those who hold particularly difficult jobs or responsibilities.

6. Concomitant with the introduction of these new systems, standards for new hirings and rules for training and changing assignments will be totally revised.

This is the outline of the new personnel and wage systems stated in NTT's reply to the labor union. The general direction of these new systems agrees with that of the union's demands, but many details do not. Hence, an agreement may be reached next spring at the earliest. Even after an agreement is reached, the new systems are likely to be implemented at best in the middle of 1987 but made "retroactive to the beginning of the year," since a great deal of work must be done.

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