computers, and transcutaneous energy transmission systems, plus physiological chaos control algorithms, etc., that will integrate these technologies. Currently, a nanosensor for organism information sensoring is under development, and to ensure an even further leap in development; development through topping diamond-like carbon with several tens of gold molecules is also becoming a concrete reality. With a nano-sized gold cluster senor configured with mechanisms on the molecular and nanometer levels, already sensitive thermosensors, etc., have been realized, and have now entered the animal testing stage.

Artificial myocardium differs from a device such as an artificial heart that is constantly driven with full strokes, and thus involves a high risk of thrombosis. Since artificial myocardium can be operated only when needed, one can expect it to have good endurance characteristics. Nevertheless, here, sensing becomes an essential requirement, and progress in this field is needed. For the nanosensor, pressure sensing with optical fiber has been realized with membrane pressure at 700 nanometers, and investigation of endurance characteristics is currently in progress. Research has been performed on several devices that are candidates as artificial myocardium actuators that will enable further miniaturization.

One of these is a ball screw motor.

This has superior endurance characteristics, and has even been used in the space shuttle. As the results of animal testing performing during the present fiscal year, observation has been made of its effectiveness as artificial myocardium for assisting the right ventricle, and within hemodynamic recordings, its cardiac assistance effects have been confirmed. For this, a polycarbonate pack for serving as a myocardium cover has been newly developed, and by wrapping of the heart, assistance effects have been obtained. Nevertheless, unfortunately, with the current ball screw actuator, although right heart assistance effects exist, sufficient stroke and propulsion have not been obtained to the extent that left ventricle assistance effects could be confirmed, and currently, design improvements are underway. For the artificial hearts being developed at the University of Utah and the National Cardiovascular Center, hydraulic systems with external actuators are the design being pursued, and thus there is no absolute need to integrate the actuators within the system. Here, we have also thus attempted actuator development for a hydraulic system. Compared with the method of direct in-suturing of the actuator, here, equipping is extremely easy. Since the suture attachment portion of the artificial myocardium can be freely set without reference to anatomical structure, it was determined that for support of the contractual strength of only the sites of infarction in a myocardial infarction, etc., this type has extremely high-level effectiveness. The results of hemodynamic recordings via animal tests have confirmed that the cardiac assistance effects of electrohydraulic artificial myocardium are exceptional, and in addition to effective left-heart assistance effects, including an obvious increase of cardiac output and the raising of arterial pressure, etc., within right heart system circulation as well, support effects have been confirmed. Thus, there are major expectations that the clinical effectiveness of such will be high. Even within a state of induced cardiac arrest, through operation of the system, a certain arterial pressure and cardiac output was obtained. With the current structure, when cardiac arrest has been induced, although its strokes are somewhat short, improvements with dual-side cardiac effects and artificial myocardium patches can be expected, and design changes are currently being performed. As the control system for an artificial myocardium actuator, an artificial bionic arterial baroreflex system modeled after the human organism has been embodied, and stable control is aimed at in current animal testing; here, the plan is to place such on a microchip. Optimization of a transcutaneous energy transmission system is slated for after the actuator has been realized, and currently, investigations are being made of basic settings. Further, three-dimensional contraction dynamics are under analysis in current clinical cases, and embodiment of flow simulation is expected in the upcoming days.

If such is actually realized, it will become possible to analyze, within clinical cases, exactly how to support each individual contraction, and the development of "order-made" artificial myocardium will become a reality.

E. Conclusions

Currently, diligent research of each separate part is underway, and three years from now, we expect that the embodiment of nano technology integrated artificial myocardium that can be supplied for preclinical testing can be realized.

Nanosensor Development

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Purpose of Research

As low-invasive diagnostic and treatment technology, research and development is are to be performed on an active guide wire and active catheter for inserting small-shaped medical devices intravascularly plus related sensors. Development is to be made of a high sensitivity sensor via an ultra-thin oscillator having thinness of micrometer order and of a chip for DNA analyses having a nanostructure, and basic research toward (single) cell MRI is to be performed.

Research methods

In order to make an active guide wire and active catheter to be driven by air pressure, a structure is worked by processing a super-flexibility alloy within a tube using a femtosecond laser.

As for each type of sensor to be used with this active catheter, a sensor for detecting the location and orientation of the catheter tip within the body, a frontal viewing ultrasonic endoscope that uses ultrasonic reflection, and a micro-miniature optical fiber pressure sensor with a 125 μm diameter, etc., are to be developed.

The structural body can also be formed through chemical vapor deposition (CVD) of a thick film. Technology for embedding with CVD deep grooves formed via reactive ion etching (RIE) such that there are no gaps [apertures] is to be employed for the DNA-analyses chip.

Eight (8) 1-3 composite-type PZT piezoelectric transducers are to serve as the intravascular frontal viewing ultrasonic endoscope to be attached to the catheter tip, and frontal observation will be enabled by sending ultrasonic pulses and receiving reflected waves.

By using this, a physician who is to perform a surgical operation can have the feeling of having actually "entered" herself within a blood vessel so as to operate the catheter accordingly. This is to be a chip for DNA separation using electrophoresis. This is to be made by the following process: after polysilicon (poly-Si) that has been grown on a quartz substrate has been worked using RIE, silicon oxide is grown via plasma CVD using tetraethyl orthosilicate (TEOS) and ozone, and a deep groove is embedded.

Finally, the poly-Si is removed using sacrificial layer dry etching. By using resonance frequency changes of a thin silicon bridge, a high sensitivity sensor at the extreme tip can be realized. The magnetic force of iron particles having a diameter of 1.5 μm attached to the thin silicon bridge is detected with high sensitivity using resonance frequency changes of the bridge, and development of single cell MRI is to be performed using this as a high-sensitivity magnetic force sensor. Although consideration is also being given to ethical aspects, it is desired that renewed care for such be made during the clinical application phase of the present research.

Research results

A device was made such that, when suction of internal portions is performed using an active catheter of 1 mm diameter, the tip portion of the tube is crushed, and it becomes blocked and bends. By using an ultrasonic transducer that is hemispherically shaped as the piezoelectric transducer, compared with the case of using a flat-plate shaped unit, the directivity characteristics become weaker, and the unit could be given capabilities appropriate for a synthetic aperture.

A micro-miniature pressure sensor with a thin diaphragm formed at the end terminal of an optical fiber with a 125 μm external diameter was developed. Diaphragm changes due to pressure are detected using changes in the optical interference spectrum, and there is also no noise contamination due to bending of the optical fiber, etc.; here, responses were made up to 70 Hz.

A microscopic column for DNA separation is formed at the channel portion, and a DNA analyses chip was made through formation of silicon oxide onto a quartz substrate.

Through further development of the developed oscillating-type magnetic sensor, the aim is single cell MRI (magnetic resonance imaging). Here, the atoms of the portion for resonating with the frequency of electromagnetic waves and the strength of the magnetic field are detected as magnetic force changes via resonance frequency changes of the beam, and such can be imaged using the principles of computed tomography. To achieve such, an ultra-thin oscillator was made using quartz crystal. It is noted that, in ordinary MRI, electromagnetic waves reflected from resonating atoms are used.

Discussions

With micromachining, mass production is also possible, and in the case of a micro-miniature pressure sensor, around 100,000 diaphragm units can be made on a 4-inch silicon wafer, making this also appropriate for disposable uses.

Conclusions

It was empirically proven that the active use of the characteristic strong points (small structures, high sensitivity, etc.) achieved with micromachining and nanomachining can enable major contributions to medical therap

Research Concerning Nanoactuator and Sensor Testing

Youichi HAGA
Tohoku University

Summary: Using micro- and nanomachine technology, development has been performed of a microsensor for control of nano artificial myocardium with embedded nanosensors.

A. Purpose of research

The development of micro- and nanomachine technology.

B. Research methods

By attaching an ultrathin diaphragm structure created with micromachining technology to the terminal surface of an optical fiber, a micro-miniature diameter pressure sensor with an external diameter of only 125 μm was developed. Modifications of the diaphragm at the nanometer level due to pressure are detected as changes in reflected light as the result of the optical interference phenomenon. A white light source is used, and its operation as a pressure sensor was confirmed. Since it can be inserted within narrow spaces, it can assist in direct monitoring of hemodynamics at local sites within the body.

Currently, in tests of inserting the micro-miniature diameter sensor within animals, there are no problems in regards to animal protection and ethics.

C. Research results

Using the developed micro pressure sensor, placement was made within the aorta and cardiac chambers of goats, and the device could measure the hemodynamics at microscopic scales, and its effectiveness as a sensor could be confirmed.

D. Discussions

Even thought its effectiveness as a sensor was confirmed, there were worries concerning thrombosis accompanying long-term placement as well as temperature effects due to air becoming inserted within the space between the diaphragm and the optical fiber terminal surface. To resolve such issues, improvements are being performed, including coating with a polymer having antithrombotic properties and low-vacuum sealing, etc.

E. Conclusions

The possibilities of control of nano-sized artificial myocardium using this sensor was successfully confirmed, and the problem points this time, as well as the future orientation ([for research)], was clarified.

Research concerning the Development of Nano- and Micro-scale Actuators

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Summary: The purpose of the present research is the development of a small-sized actuator combining a shape memory alloy and a Peltier element that can be applied as fully embedded-type, assistance-type [sic] artificial assistance myocardium. By using a Peltier element that can actively cool and heat a shape memory alloy, an operating speed of 1 Hz was realized for the made prototype artificial myocardium. Further, towards an increase in the output and displacement of the actuator, fiber-shaped shape memory alloy was adopted, and development was performed accordingly.

Purpose of research

The purpose of the present research is the development of a small-sized actuator combining a shape memory alloy and a Peltier element. If the shape memory effects of a shape memory alloy are used, then its shape can be changed by heating and cooling the shape memory alloy. In other words, the heating/cooling capabilities do not become regular, and the smaller the size of the alloy, the faster the obtainable operating speed.

Conventionally, actuators employing shape memory alloys have consisted of heating via electricity passage and natural cooling or water cooling. With this type of heating and cooling system, energy consumption on the heating side, and cooling speed, are problematic.

Further, in the case of water cooling, the apparatus becomes complex, making miniaturization difficult.

Thus, as an apparatus that enables active heating/cooling and miniaturization, through the employment of a Peltier element in combination with shape memory alloys, it is expected that artificial myocardium with a simple structure and compact size can be realized.

Also, it is known that the force outputted at the time of deformation of the shape memory alloy has a larger value per unit volume compared to other actuators.

A Peltier element is, in general, a circuit whereby multiple thermoelectric semiconductors are connected via electrodes.

When direct current is made to flow within this circuit, the movement of heat through the thermoelectric semiconductor elements is enabled due to the Peltier effect.

Also, by changing the current flow, this heat movement direction can also be changed.

Therefore, this circuit can be created on the shape memory alloy, and by causing a flow of alternating current at around 1-3 Hz within the circuit, the shape memory alloy can be continuously heated and cooled, and the repeated performance of iterated movements, such as expansion and bending, is enabled.

By suturing this actuator into a heart and operating it, it can be expected that heartbeats can be assisted from a site external to the heart, and heart ventricle assistance operations can be performed without fear of thrombosis.

Also, by limiting this to a system that can be operated only when needed in an emergency, such as during a seizure, the device can be used without concern for degradation of the shape memory alloy, thus making this an embedded-type assisted myocardium apparatus.

Currently, together with the development of microprocessing technologies, thin-film creation with thermoelectric semiconductor elements on a nanometric scale is becoming a possibility.

In the future, when working of shape memory alloys into fiber shapes also becomes possible, one can also expect the development of artificial muscle fiber that can be actively controlled.

B. Research methods

As characteristics for evaluating the operation capabilities of artificial muscle, one can list output, operating speed, displacement, etc.

In the present research, we were to perform creation of artificial myocardium, and experimentally evaluate its operation capabilities. Using the temperature dependencies of deformations from among shape memory effects, by determining through numerical analysis the non-stationary temperature distribution in the internal portion of the artificial myocardium, theoretically, a capability evaluation could be performed.

Finally, using mountain goats, live organism tests were to be performed, and clinical application capabilities were to be evaluated accordingly.

Research results

In the first fiscal year, by using a Peltier element with the shape memory alloy actuator, we performed production with improved operating speed characteristics.

When electricity is passed through a shape memory alloy, since Joule heating also occurs within the shape memory ally at the time of cooling due to the Peltier effect, large temperature changes cannot be obtained.

Thus, it is necessary to insulate the Peltier element and the shape memory alloy.

However, when the heat transfer amount among these two items is small, then the displacement amount of the shape memory alloy becomes small; thus, it is desirable that the electricity insulator that is adopted be a good conductor for heat.

Although ceramic plate is commonly used as the insulator for a Peltier element and heating and cooling purposes, in the case of an actuator where elasticity is required, such a plate cannot be used. Thus, thin insulation property double-sided adhesive sheet of 50 μm thickness was used to insulate the Peltier element and the shape memory alloy.

This sheet was attached to the surface of both sides of a shape memory alloy rod 1 mm high, 0.8 mm wide, and 100 mm long, and the Peltier element was arranged on this. The thermoelectric semiconductor used for the Peltier element was a Bi-Te series material with a 1 x 1 mm2 cross-section and was 0.8 mm high; 50 of these units were used.

A copper alloy heat sink configured in a C-shape was used; this served the role of electrode, and also fulfilled a role of pressing the thermoelectric semiconductor elements to both side surfaces of the shape memory alloy.

Tests of the created prototype artificial myocardium were performed using the operation test apparatus.

As the result of operation tests performed within an electric insulation solution maintained at 40° to mimic the temperature in the human body interior, operation at 1 Hz was realized for the actuator at power consumption of 1 W.

Meanwhile, numerical analyses of non-stationary temperature changes within the Peltier element interior were performed, the states of temperature changes of the shape memory alloy were calculated, and simulation was performed to evaluate from the warp-temperature relationship the operating state of the artificial myocardium.

Also, measurements of shape memory alloy temporary changes during operation of the artificial myocardium via actual tests were used to make comparisons with the numerical calculations; here, the validity of the simulation was shown.

Further, animal tests using mountain goats were performed, and an investigation was made of suturing methods for artificial myocardium.

Next, in the present fiscal year, actuator creation with concentration on output and displacement improvements was performed. In order to further increase operation amplitude, we performed creation of a shape memory alloy having flexibility characteristics and a Peltier element. The shape memory alloy was changed from a rod with a cross-section of 1 mm x 0.88 mm to the lining up of seven (7) fibers, each having a diameter of 150 μm. By making the shape memory alloy more compact, the crystal orientation becomes uniform, and a greater deformation is obtained. To do so, multiple shape memory alloys, each of small unit volume, were used, thus ensuring an actuator with larger displacement and greater output. Also, in order to give the circuit flexibility characteristics, we change the electrodes from a linear shape to an ohm symbol (Ω) shape. The result of this was a configuration whereby, even during bending, the shape memory alloy and the Peltier element were in close contact the temperature change amounts of the shape memory alloy increased and, as a result, improvements were confirmed not only for displacement, but also for operating speeds.

Discussions

The structure of an actuator using a Peltier element and a shape memory alloy is comprised of a Peltier element for the supply of heat, which is used as the medium, and a shape memory alloy, which receives that heat and transforms it into mechanical energy. In order to perform heat reception without loss, fitting both of these together in contact would be beneficial; however, doing so would naturally make the mechanical operation jerky, or even suppress such altogether. To resolve that contradiction, one must surely either give the circuit flexibility characteristics or reduce the dimensions of the thermoelectric semiconductor elements.

Also, the creation of an actuator specialized to have specific functions is thought to be a method of reducing the time to practical application. For example, although increasing the number of memory alloys would boost output, since the thermal capacity would also increase, temperature changes would occur more slowly, resulting in a slower actuator speed. Nevertheless, if one were to arrange multiple artificial myocardium units such that the operation cycle of each half were staggered by a half cycle, then it would be possible to give the heart twice as many heartbeats for the number of operating oscillations generated by each artificial myocardium. Also, if one were to reduce the number of shape memory alloy to be used for each artificial myocardium unit and increase operating speed, even if the power outputted by each one unit would be small, by increasing the number of artificial myocardium units, the power received by the heart could also likely be increased. If arrangement methods were performed carefully in this way, even if it might still not be possible to achieve a perfect, all-purpose artificial myocardium actuator, surely improvements could be realized.

Conclusions

Prototype creation of an artificial

myocardium using a shape memory alloy and a Peltier element was performed, and an operating speed of 1 Hz was confirmed. Also, it was confirmed that by using multiple shape memory alloys, each of a small unit volume and having the flexibility characteristics of a fiber shape, the output and displacement of the actuator could be increased.

Application and registration information for intellectual property rights "Assistance Artificial Myocardium" (Application Heisei-11292727)

Eiji OKAMOTO
Hokkaido Tokai University

Summary of Research:

An artificial myocardium assistance apparatus is an apparatus to be equipped at one or both cardiac ventricles requiring assistance, and from outside the ventricle, through fluid operating pressure, is to directly contract the ventricle(s), thereby ejecting blood and assisting the ventricle(s). Sought for here is the capability to resist pulmonary arterial pressure or aortic pressure, and to cause within the ventricle from outside the ventricle a volume change equivalent to a single cardiac output. Thus, in the present research, we performed development of an embedded-type actuator for artificial myocardium use that uses a brush motor and ball screw appropriate for use as an artificial heart actuator.

A. Purpose of research

An artificial myocardium assistance apparatus is an apparatus to be equipped at one or both cardiac ventricles requiring assistance, and from outside the ventricle, through fluid operating pressure, is to directly contract the ventricle, thereby ejecting blood and assisting the ventricle. Sought for here is the capability to resist pulmonary arterial pressure or aortic pressure, and to cause within the ventricle from outside the ventricle a volume change equivalent to a single cardiac output.

Thus, in the present research, we performed development of an embedded-type actuator for artificial myocardium use that uses a brushless motor and ball screw appropriate for use as an artificial heart actuator.

B. Research methods

B1. Development of an implantable-type artificial myocardium actuator

A ball screw (Kuroda Precision Industries, Ltd., GZ0603EDS-ZANR-0035X0026- C5F (custom design model), Japan) is introduced to within a brushless motor (Inland, MBS-1308, USA), forward and reverse movements of the motor are changed to reciprocating linear motion of the screw axis of the ball screw, a pump portion filled with working [drive] fluid is operated, and a myocardium assistance operation portion equipped at the ventricle is operated with working fluid.

The implantable-type artificial myocardium actuator is designed such that, with the prerequisite of removing ribs and implant subcutaneously in the thorax, it is given a pump stroke of 8 mm, it has a ball screw lead of 6 mm to enable responses to large numbers of heartbeats, and with reciprocating 1.3 rotations of the motor, it completes a single beating process.

The frame of the actuator for an artificial myocardium assistance apparatus is made using duralumin so as to be lightweight, but the motor stuffing for supporting the rotation axis is made using titanium with the aim of improving durability. With the designed and developed artificial myocardium actuator, as the result of performing a design such that the volume change amount applied to the ventricle is around 60 ml in consideration of the standard physique of a Japanese person, a single time ejection amount of the incompressible working fluid pump becomes 58 ml. Finally, the size of the artificial myocardium actuator in the completed design became, including the pump portion, 101 mm diameter, 54 mm thickness, and 277 ml volume.

B2. Development of an autonomous distributed object-type drive control system

Measurements of the motor rotation angle and rotation speed, indispensable for control of an actuator for a cardiac ventricle assistance apparatus, were performed using information from three. Hall sensors equipped within the brushless motor. The drive control system is comprised of an actuator control portion using a 32 bit RISC one-chip microcomputer (Hitachi, SH7044, Tokyo) and an electrical power amplifier portion using a power-FET.

To enable easy addition to, and evolution of, control-portion functions, the actuator control portion for realizing software-like is configured with an autonomous object-type controller comprised of an assembly of objects that act independently as input-output elements similar to single cells. The autonomous object control is comprised of an input object layer, a measurement portion layer, a control layer, and an output layer, and is operated by the pacing of each autonomous object via an object manager.

Due to the fact that the unique characteristic of a cardiac ventricle assistance apparatus is its ability to assist cardiac ventricles only as necessary when such is required according to the state of a patient, it is essential that the experiences of physicians be reflected within the control of the artificial myocardium assistance apparatus. Actuator control is performed via motor position control and motor rotation speed control; in the present research, in order to have the experiences of physicians reflected in the control, fuzzy control was applied for motor position control and motor rotation speed control.

For the motor position control, with current motor rotation angle and pump ejection lapse time as input, a membership function was established on the basis of the experiences of physicians and engineers, and so that working fluid can be ejected within the set time, a target motor rotation speed is calculated via fuzzy inferences. Similarly for the motor speed control, fuzzy inferences—made as a membership function from current speed and speed variations —are used to calculate the electrical current required by the motor, and the motor is operated .

The actuator for artificial myocardium use was connected to the autonomous object-type controller, and the motor was operated. Under fuzzy speed control, when tests were made of forward and reverse motor operations, it was confirmed that the motor generates sufficient torque for operating the myocardium actuator.

C. Research results and Discussions

In the present research, in order to actively utilize a method for driving, via working fluid, the ventricle assistance portion to be equipped at myocardium, this time development was performed of an actuator for an implantable-type artificial myocardium assistance apparatus newly with a brushless DC motor and a ball screw. With the goal of cutting two ribs and implant subcutaneously in the thorax in the thoracic, the actuator was designed so as to be given a thin shape, and also with the goal of following a large number of beats, at the same time as the working fluid ejection pump was given the short stroke of 8 mm, the ball screw lead was set at 6 mm, and with a motor rotation angle of approximately 1.3 rotations, a full stroke is obtained.

As a result, the size of the actuator became 277 ml; this size is around the same size as a small-sized, implantable pulsating-type assistance artificial heart currently under development in Japan, and is considerably smaller than the TCI and Novacor model pulsating-type motor driven assistance artificial heart currently used clinically, and it is thought that this [newly developed] actuator will be sufficiently mountable within Japanese persons having small physiques.

In regards to the pump portion shape, the working fluid ejection port attachment site is at the outside of a rib; however, by arranging the pump shape such that the port is arranged such that it is orientated in the heart direction, by shortening the distance between the myocardium assistance portion, channel resistance can be reduced. Here, not only for anatomical compatibility, but also to aim at improving actuator drive efficiency,

it is thought that it will be necessary to carry out further improvements of the pump-portion shape.
r control

D. Concluding words

By making the drive control system an autonomous-object type system, it becomes easier to increase/improve the functionality of the drive control system by adding or changing objects, each of which functions independently. Therefore, this is thought to be the optimal control system configuration within the present research, one which can be expected to be further developed into the future. Also, fuzzy control has been employed within the control layer with the purpose of actively utilizing within the control the experiences of physicians. From now on, the results of both in vitro tests and in vivo tests will be reflected so as to perform optimization of fuzzy rules, and we intend to carry out improvements in order to realize myocardium assistance suitable for living organisms.

DLC Nanosensor Development

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Yun LUO
Tohoku University

Summary: The present research portion aims for development of an organism sensor for ascertaining, in real time, heat and mechanical information of an organism, for use within a nanotechnology-integrated, embedded-type cardiac ventricle assistance apparatus. In the present fiscal year, evaluations were performed of diamond-like nanocomposite (DLN), with included metals, thin films for further development of this sensor's functions as a heat and pressure sensor. Evaluation was made of changes in thin-film structure due to metal content, as such is directly concerned with DLN functionality. Here, results obtained from temperature-dependency tests for resistance were used to consider the perspective of the conduction mechanism for electrons flowing within the thin film. Also, for functional evaluation as a temperature sensor, dimensionless temperature sensitivity, ST, was used, and in comparisons made with ordinary temperature sensors, we confirmed that this sensor has sufficient capabilities. Further, in order to show that the film functions as a pressure sensor, we measured changes in resistance resulting from changes in strain. From the measurement results of strain tests, it was shown that the thin film that was made can function as a pressure sensor.

A. Purpose of research

In order to ascertain, in real time, heat and mechanical information of an organism, by inclusion of metallic particles as a nanocomposite within diamond-like carbon thin film having organism compatibility, we aim for the development of diamond-like carbon nanocomposite (DLN) thin film, with application as a temperature sensor for use in organisms.

To accomplish this, we first evaluated changes in thin-film structure due to metal contents.

Further, results obtained from tests of the temperature dependency of resistance and three-point bending tests were used to consider the perspective of the transmission mechanism for electrons flowing within the thin film. Finally, functional evaluation of the developed DLN thin film as an organism sensor werewas performed.

B. Research methods

As the film-making method for the DLN thin film, the raw-material liquid siloxane was atomized from above the substrate, separation was performed using direct-current discharge, and such was then vapor deposited onto a polycrystal substrate. Within the film-making process, metals were intermixed via direct-current magnetron sputtering. The intermixed metals were tungsten (W) and niobium (Nb). After making the film, test materials were etched with argon plasma for four-terminal method measurements. For electrical resistance measurements, to reduce contact resistance, gold electrodes were vapor deposited onto the thin film. Further, the content of intermixed metals was measured using an electron probe microanalyzer (EPMA).

The internal structure of the thin film was evaluated using Raman spectral analysis. Measurements were performed in open air and at room temperature environments using an He-Ne laser (wavelength: 632.8 nm, output: 20 mW). The measurement scope was 800-1800 cm-1.

For the temperature dependency of resistance, a gas flow cryostat was used, and measurements were performed in the temperature range of 83-383 K. The measurement environment was within a vacuum.

Further, in order to show its possibilities as one further type of sensor, strain characteristics were measured using three-point bending tests. The measurement environment was near room temperature.

(Ethical considerations)

The diamond-like nano composite organism temperature sensor developed in the present research portion, inasmuch as it has good organism compatibility, is sensor technology for control of a nanotechnology-integrated,embedded-type cardiac ventricle assistance apparatus, and has no problems directly related to ethical aspects.

C. Research results

In the evaluations of thin-film structure according to metal content, when metal content is 20 at.% or less, the strength ratio does not change to a great extent. However, we found that at contents of 20 at.% or more, the strength ratio rapidly increases. Similar results were also obtained for the DLN with intermixed niobium (Nb-DLN).

The temperature dependency measurement results for test pieces intermixed with W are evaluated. As for the temperature dependency of resistance, since resistivity decreased as the temperature rose, it is thought that this was a classical conductor-insulator composite. Further, from the EPMA measurement results, resistivity and r(83)/r(300) at room temperature decreased in tandem with the increase in metal content; it was thus found that by changing metal content amounts, the characteristics [properties] of the thin film can also be changed. Similar results were obtained also concerning Nb-DLN thin film.

Next, three-point bending tests were carried out to measure changes in resistance accompanying deformation of the created metal film.

Together with the increase of applied strain amounts, resistivity from no-load states increased.

D. Discussions

As reasons for changes of thin-film structure due to metal content, for the created test pieces within an insulator, the metal that is a conductor dispersed so as to make a conductor-insulator composite; this fact is clear from the temperature dependency of resistance measurement results.

When the amount of contained metal is increased, a conductor-insulator transition is observed. Within the conductor-insulator transition, the temperature dependency of resistance on the insulator side is given by the following formula. Here, T0 is a constant, s is the conductivity, and T is the temperature. However, in the case where the metal content amount is large, the temperature dependency of resistance no longer follows the above formula, but instead can be shown using the following factorial rule. Here, s0, A, and n are constants. This formula coincides extremely well with test results.

Within a system where metal clusters are dispersed within an insulator thin film, the electrical conductance mechanism can be explained by the phenomenon that a potential barrier exists between two metal clusters, and electrons pass through the potential barrier.

In the case where the insulator portion is amorphous as with a DLN thin film with intermixed metal, within the potential barrier existing between two metal clusters, a localized state exists wherein electrons can temporarily exist. It is thought that, at this time, before and after an electron passes through a potential barrier, the energy state of the electron is not maintained, and it passes through inelastically. The mean number of electron localized states within the thin-film interior is given as "N". Here, n is a constant obtained with the previous formula. With metal contents less than the 20 at.% neighborhood. "N" decreased in tandem with an increase in the metal content. This is though to be because, if there is an increase in the metal content, the diameter of contained metal clusters increases, thereby eliminating the electron localization states. Next, at contents higher than the neighborhood of 20 at.%, N slightly increased in tandem with the increase in metal content.