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COMMONWEALTH of AUSTRALIA
Patents Act 1952

APPLICATION FOR A STANDARD PATENT

I/We

Yokogawa Electric Corporation

of

9-32 Nakacho, 2-chome, Musashino-shi, Tokyo 180, Japan

hereby apply for the grant of a Standard Patent for an invention entitled:

Vibrating type transducer and manufacturing process thereof

which is described in the accompanying complete specification.

Details of basic application(s):-

Number	Convention Country	Date
88-129671	Japan	27 May 1988

The address for service is care of DAVIES & COLLISON, Patent Attorneys, of 1 Little Collins Street, Melbourne, in the State of Victoria, Commonwealth of Australia.

DATED this ELEVENTH day of APRIL 1989

To: THE COMMISSIONER OF PATENTS

Keith [signature]

a member of the firm of
DAVIES & COLLISON for
and on behalf of the
applicant(s)

Davies & Collison, Melbourne

M008089 11/04/89

APPLICATION ACCEPTED AND AMENDMENTS
ALLOWED 15 - 8 - 90

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

DECLARATION IN SUPPORT OF CONVENTION OR NON–CONVENTION APPLICATION FOR A PATENT

Insert title of invention.

In support of the Application made for a patent for an invention entitled: **"VIBRATING TYPE TRANSDUCER AND MANUFACTURING PROCESS THEREOF"**

Insert full name(s) and address(es) of declarant(s) being the applicant(s) or person(s) authorized to sign on behalf of an applicant company.

I ~~We~~ Takashi Yamanaka
of **YOKOGAWA ELECTRIC CORPORATION**
of 9-32, Nakacho 2-chome
Musashino-shi, Tokyo 180
JAPAN

Cross out whichever of paragraphs 1(a) or 1(b) does not apply
1(a) relates to application made by individual(s)
1(b) relates to application made by company; insert name of applicant company.

do solemnly and sincerely declare as follows :–

1. ~~(a) I am / We are the applicant...~~

or (b) I am authorized by

YOKOGAWA ELECTRIC CORPORATION

the applicant............ for the patent to make this declaration on its ~~their~~ behalf.

Cross out whichever of paragraphs 2(a) or 2(b) does not apply
2(a) relates to application made by inventor(s)
2(b) relates to application made by company(s) or person(s) who are not inventor(s); insert full name(s) and address(es) of inventors.

2. ~~(a) I am / We are the actual inventor...~~

or (b) Kinji **HARADA**, Kyoichi **IKEDA**, Hideki **KUWAYAMA**, Takashi **KOBAYASHI**, Tadashi **NISHIKAWA**, Tetsuya **WATANABE** and Takashi **YOSHIDA** all c/- Yokogawa Electric Corporation, of 9-32, Nakacho 2-chome, Musashino-shi, Tokyo 180, JAPAN

~~is~~ are the actual inventor........... of the invention and the facts upon which the applicant........... is ~~are~~ entitled to make the application are as follows :–

State manner in which applicant(s) derive title from inventor(s)

The applicant would, if a patent were granted on an application made by the said actual inventors be entitled to have the patent assigned to it. The applicant has the consent of Shozo Yokogawa to claim priority.

Cross out paragraphs 3 and 4 for non-convention applications. For convention applications, insert basic country(s) followed by date(s) and basic applicant(s).

3. The basic application........... as defined by Section 141 of the Act was ~~were~~ made

in Japan on the 27 May 1988
by Shozo Yokogawa
in .... on the ....
by ....
in .... on the ....
by ....

4. The basic application.......... referred to in paragraph 3 of this Declaration was ~~were~~ the first application.......... made in a Convention country in respect of the invention the subject of the application.

Insert place and date of signature.

Declared at Tokyo Japan this 29th day of May, 1989

Signature of declarant(s) (no attestation required)

Note: Initial all alterations.

[signature]
Takashi Yamanaka, President

DAVIES & COLLISON, MELBOURNE and CANBERRA.

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(56) Prior Art Documents
US 4841775
US 4229979

(57) Claim

1. A vibrating type transducer comprising:

a silicon substrate having a thin diaphragm formed in a central portion thereof;

an H-shaped vibrator body having first and second vibrators, disposed in parallel and each with opposite ends fixed on said diaphragm, and a third vibrator mechanically coupling central portions of said first and second vibrators, said vibrator body in use vibrating as a whole such that the opposite ends of said first and second vibrators are used as fixed ends of vibration;

a magnetic field generating means for applying a DC magnetic field across said vibrator body;

an excitation means for vibrating the vibrator body on a mutual action with said DC magnetic field by conducting an alternating current through said first vibrator or from one end of said first vibrator to the same end of said second vibrator;

.../2

a vibration detection means for detecting an electromotive force generated across said second vibrator or between the other end of said first vibrator and the other end of said second vibrator; and

an amplification means connected between said excitation means and said vibration detection means.

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COMPLETE SPECIFICATION

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COMPLETE SPECIFICATION FOR THE INVENTION ENTITLED:

Vibrating type transducer and manufacturing process thereof

The following statement is a full description of this invention, including the best method of performing it known to me/us:-

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a vibrating type transducer and manufacturing process thereof, and is particularly concerned with a vibrating type transducer and manufacturing process thereof, wherein a beamlike vibrator formed on a silicon substrate is kept vibrating on natural vibration frequency of the vibrator, and a physical quantity such as force applied to the silicon substrate, pressure, differential pressure or the like is detected from a change in the natural vibration frequency which may arise correspondingly to the physical quantity.

More specifically, the invention relates to a vibrating type transducer high in S/N ratio and capable of generating a self-oscillation stably and also to its manufacturing process.

Description of the Prior Art

Fig. 1 to Fig. 4 are block diagrams representing one example of a prior art vibrating type transducer.

Fig. 1 is a perspective view of the vibrating type transducer which is used as a pressure sensor, Fig. 2 is a block diagram wherein section A in Fig.

1 is enlarged and a vibration detection circuit is connected thereto, Fig. 3 is a sectional view taken on line A - A' of Fig. 2, and Fig. 4 is an explanatory drawing wherein the construction shown in Fig. 2 is represented by an electrical equivalent circuit.

As shown in Fig. 1, a reference numeral 10 denotes a silicon single-crystal substrate having a (100) plane on the top, which is 10^{15} atoms/cm^3 or below, for example, in impurity concentration and p-type in conduction mode. A diaphragm 11 is dug up from the back through etching and so formed thin on one side of the substrate 10.

A peripheral thick-wall part 12 of the diaphragm 11 is joined to a pedestal 14 having a pressure hole 13 at the center, further the pedestal 14 has a pressure pipe 15 joined so as to communicate with the pressure hole 13, and a pressure P to measure is introduced to the pressure pipe 15.

An n^+ diffusion layer (not indicated) 10^{17} in impurity concentration is formed partly on a surface of the side of the diaphragm 11 indicated by a reference character A which is not etched, and a vibrator 16 is formed on a part of the n^+ diffusion layer in the direction of <001> (Fig. 2). The vibrator 16 is obtained, for example, from processing

n^+ layer and p-layer formed on the diaphragm 11 on photolithography and underetching.

A reference numeral 17 denotes a magnet provided over the vibrator 16 almost at the center thereof orthogonally to the vibrator 16 and also in the state not in contact therewith, and 18 denotes an SiO_2 film working as an insulating film (Fig. 3).

Reference characters 19a, 19b denote metallic electrodes such as, for example, Aℓ and the like, one end of the metallic electrode 19a is connected to the n^+ layer extended from the vibrator 16 through a contact hole 20a provided by way of SiO_2 layer, and the other end is connected to a comparison resistance R_0 almost equal to a resistance value of the vibrator 16 through a lead wire and also to an input end of an amplifier 21. An output signal is generated from an output end of the amplifier 21, which is connected to one end of a primary coil L_1 of a transformer 22. Another end of the coil L_1 is connected to a common line.

On the other hand, another end of the comparison resistance R_0 is connected to one end of a secondary coil L_2 of the transformer 22 with the mid-point connected to the common line, and another end of the secondary coil L_2 is connected to the n^+ layer through the metallic electrode 19b and a contact hole 20b formed likewise on another end of the vibrator 16.

In the above construction, when a reverse bias voltage is impressed to insulation between the p-type layer (substrate 10) and the n^+ layer (vibrator 16), and an alternating current is carried to the vibrator 16, an impedance of the vibrator 16 rises in a resonance state of the vibrator 16, and if then impedance is R, then an equivalent circuit is obtainable as shown in Fig. 4.

Accordingly, the secondary coil L_2 with a center point C_0 connected to the common line, the comparison resistance R_0, and an impedance R_0 will constitute a bridge, therefore if an unbalanced signal due to the bridge is detected on the amplifier 21 and the output is fed back positively to the primary coil L_1 through a feedback line 23, the system will generate a self-oscillation on a natural vibration frequency of the vibrator 16.

In the aforementioned construction, the impedance R of the vibrator 16 rises at the natural vibration frequency. The impedance R may be expressed by the following equation.

$$R \doteqdot (1/222) \cdot (1/(Eg\gamma)^{1/2}) \cdot (AB^2\ell^2/bh^2) \cdot Q + R_d$$

where E: modulus of elasticity

g: gravity acceleration

γ: density of material of which vibrator is constituted

A: constant determined by vibration mode

B: magnetic flux density

ℓ: length of vibration beam

b: width of vibration beam

h: thickness of vibration beam

Q: quality factor

R_d: DC resistance value

According to the above equation, since Q of the vibrator 16 takes valves of ~~vales~~ several hundreds to several ten thousands, a large amplitude signal is obtainable as an output of the amplifier 21 in resonance state. Thus, from taking gain of the amplifier 21 satisfactorily large to positive feedback, the system of the vibrating type transducer is self-excited to vibration on the natural vibration frequency.

Then, that of p-type obtained from diffusing, for example, B (boron) on an n-type silicon substrate at 4×10^{19} atoms/cm^3 or over through selective etching may be used for the vibrator.

However, in such vibrating type transducer, a counter electromotive force generated on the vibrator

16 is detected from an unbalanced voltage of the AC bridge, and since the component of an excited current cannot thoroughly be suppressed by the DC bridge as a matter of fact, a voltage according to the excited current component is multiplied on a bridge output. Thus, S/N ratio deteriorates from a voltage on a change in impedance of the vibrator being superposed on a voltage of the excited component, and hence a stable output signal is not obtainable.

SUMMARY OF THE INVENTION

According to the present invention there is provided a vibrating type transducer comprising:

a silicon substrate having a thin diaphragm formed in a central portion thereof;

an H-shaped vibrator body having first and second vibrators, disposed in parallel and each with opposite ends fixed on said diaphragm, and a third vibrator mechanically coupling central portions of said first and second vibrators, said vibrator body in use vibrating as a whole such that the opposite ends of said first and second vibrators are used as fixed ends of vibration;

a magnetic field generating means for applying a DC magnetic field across said vibrator body;

an excitation means for vibrating the vibrator body on a mutual action with said DC magnetic field by conducting an alternating current through said first vibrator or from one end of said first vibrator to the same end of said second vibrator;

a vibration detection means for detecting an electromotive force generated across said second vibrator or between the other end of said first vibrator and the other end of said second vibrator; and

an amplification means connected between said excitation means and said vibration detection means.

According to the present invention there is also provided a manufacturing process for vibrating type transducers, wherein a beamlike vibrator is formed integrally on a thin diaphragm, formed on a silicon single-crystal substrate, said vibrator being spaced from the diaphragm by a first predetermined gap except at its ends, and being covered by a shell spaced from said vibrator by a second predetermined gap, characterised in that:

a protective coat is formed on an upper surface of said silicon substrate;

said protective coat is selectively removed to form an H-shape;

an H-shaped recess having portions etched underneath its marginal regions is formed on the substrate by etching the substrate region corresponding to said H-shape opening in the protective coat;

a first epitaxial layer to be used for a first gap corresponding part, a second epitaxial layer, a third epitaxial layer to be used for a second gap corresponding part and a fourth epitaxial layer to be used for a part of said shell are formed in order from the bottom of said recess;

an injection port for an etching reagent is formed by removing said protective coat;

said first and third layers are removed through etching with said etching reagent from the injection port to form an H-shaped vibrator body from said second epitaxial layer; then,

said injection port is closed to airtightness.

According to the present invention there is further provided a vibrating type transducer comprising:

a silicon substrate having a thin diaphragm formed in a central portion thereof;

an H-shaped vibrator body, to which a predetermined initial tension is given, having first and second vibrators disposed in parallel and each with opposite ends fixed on said diaphragm, and a third vibrator mechanically coupling central portions of said first and second vibrators, said vibrator body in use vibrating as a whole such that the opposite ends of said first and second vibrators are used as fixed ends of vibration;

a magnetic field generating means for applying a DC magnetic field across said vibrator body;

an excitation means for vibrating the vibrator body on a mutual action with said DC magnetic field by conducting an alternating current through said first vibrator or from one end of said first vibrator to the same end of said second vibrator;

a vibration detection means for detecting an electromotive force generated across said second vibrator or between the outer end of said first vibrator and the other end of said second vibrator; and

an amplification means connected between said excitation means and said vibration detection means.

In the aforementioned construction, if an external force is applied to the diaphragm on the substrate, a natural vibration frequency of the vibrator body changes according to the external force. A vibration of the vibrator body is detected by the vibration detection means and a change in the natural vibration frequency is extracted as an output signal. Thus, a physical quantity applied to the diaphragm is detected from the change in natural frequency.

~~the diaphragm on etching and semiconductor technique according to a characteristic of the single crystal.~~

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view showing a prior art construction wherein a vibrating type transducer is used as a pressure sensor;

Fig. 2 is a block diagram wherein section A in Fig. 1 is enlarged and a vibration detection circuit is connected thereto;

Fig. 3 is a sectional view taken on line A - A in Fig. 2;

Fig. 4 is an explanatory drawing wherein the construction shown in Fig. 2 is represented by an electrical equivalent circuit;

Fig. 5 is a general block diagram showing a general construction of one embodiment of the invention;

Fig. 6 represents a construction of the main part of vibrator body shown in Fig. 5, wherein Fig. 6 (A) is a top view when a shell is removed, Fig. 6 (B) is a sectional view taken on line B - B of Fig. 6 (A);

Fig. 7 is a drawing showing a characteristic of the result obtained through measuring S/N ratio of the vibrating type transducer shown in Fig. 1;

Fig. 8 is a block diagram showing a main part of variant of the embodiment shown in Fig. 5;

Fig. 9 is a drawing showing a process for manufacturing the vibrating type transducer shown in Fig. 5;

Fig. 10 is a drawing showing a part of process for forming the H-shaped vibrator body shown in Fig. 5;

Fig. 11 is a drawing showing a process for enhancing and stabilizing a yield of the vibrator in the process shown in Fig. 9;

Fig. 12 is a drawing for illustrating an improvement of the process in Fig. 9;

Fig. 13 is a drawing for illustrating an effect of auxiliary epitaxial layer in Fig. 11;

Fig. 14 is a drawing showing the main part of a manufacturing process for realizing a structure of the vibrator body keeping a shell vacuum interiorly;

Fig. 15 is a characteristic drawing for extracting a gas to keep the shell vacuum interiorly in Fig. 14;

Fig. 16 is a process drawing wherein the process shown in Fig. 14 is partly modified;

Fig. 17 is a sectional view showing the main part construction of a vibrating type transducer for which an initial tension is given to the vibrator;

Fig. 18 is a characteristic drawing representing a relation of a covalent bond radius R_i of each impurity with the covalent bond radius R_i of various impurities and a covalent bond radius R_{Si} of silicon;

Fig. 19 is a characteristic drawing showing a change of lattice constant to impurity density;

Fig. 20 is a drawing showing a main part of a manufacturing process for the vibrator body which is a main part of the vibrating type strain sensor shown in Fig. 17;

Fig. 21 is a circuit diagram showing a detailed construction of the amplifier shown in Fig. 5;

Fig. 22 is a characteristic drawing representing an effect when a circuit configuration of the amplifier shown in Fig. 21 is employed;

Fig. 23 is a block diagram of a circuit when the field effect transistor shown in Fig. 21 is removed and short-circuited to make a driving force constant (drive on a constant supply voltage).

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The invention will now be described in detail with reference to the accompanying drawings representing preferred embodiments thereof.

Fig. 5 is a block diagram showing a general construction of one embodiment of the invention. Fig. 6 shows a construction of a main part of the vibrator body shown in Fig. 5, Fig. 6 (A) is a top view when a shell is removed, and Fig. 6 (B) is a sectional view taken on line B - B of Fig. 6 (A).

A vibrator body 24 comprises an H-shaped vibrator and others which is constituted of first vibrators 26A, 26B and a second vibrator 27 of p-type silicon which are formed integrally on a diaphragm 25 made of silicon single crystal n-type, for example, in conduction mode.

As in the case of diaphragm 11 shown in Fig. 3, the diaphragm 25 is formed through etching and thinning the central portion of a lower surface of the n-type silicon substrate having a thick-wall part (not indicated) around, and is displaced as a whole from having a measuring pressure impressed thereon. An H-shaped recession 28 in which each vibrator is contained is formed through etching on a part of crystal face (100) on an upper surface of the diaphragm 25.

The beamlike first vibrators 26A, 26B are formed in p-type integrally with the diaphragm 25 in parallel with a crystal axis <001> each as striding over the recession 28, and these central portions are coupled by the p-type beamlike second vibrator 27 rectangularly to these vibrators, thereby forming an H-shaped vibrator.

Electrodes 29 and 30 are formed on opposite ends of the first vibrator 26A, and electrodes 31 and 32 are formed on opposite ends of the first vibrator 26B.

A magnet 17 is disposed on an upper portion of the second vibrator 27 in parallel therewith, thus generating a magnetic field rectangularly on the first vibrators 26A, 26B.

An output terminal of an input transformer 33 functioning as the excitation means is connected to the electrodes 29, 30, one end of input terminal 34 is connected to an output terminal 35, and the other end is connected to a common line.

An input terminal of an output transformer 36 functioning as the vibration detection means is connected to the electrodes 31, 32, and output terminals 37, 38 are connected to an input end of amplifier 39.

Then, in Fig. 5 and Fig. 6, the shell covering an upper portion of the diaphragm 25 is excluded for the convenience of description, however, as will be described hereinlater, the first vibrators 26A, 26B and the second vibrator 27 are practically covered around integrally with the diaphragm 25 through a predetermined gap on a semiconductor technique such as epitaxial growth or the like, and further the gap is kept vacuum internally to maintain a high Q-factor to a vibration of the vibrators.

In the above construction, the first vibrator 26A is excited to vibrate on a voltage inputted to the input transformer 33 from the amplifier 39 according to a mutual action with a magnetic field of the magnet 17. The vibration then vibrates the first vibrator 26B through the second vibrator 27, and the vibration makes the output transformer 36 generate an electromotive force e on the input end through a mutual action with the magnet 17. The electromotive force e is inputted to the amplifier 39 through the output transformer 36, amplified, and is then extracted to the output terminal 35. The amplified voltage is fed back positively to the input transformer 33, which is repeated to a self-oscillation of the system.

As described above, the vibrator body 24 is divided into the first vibrator 26A for excitation and the first vibrator 26B for detecting electromotive force, and the first vibrators 26A, 26B are coupled together mechanically at loops of vibration by the second vibrator 27, therefore the excited current component is not superposed on the electromotive force e, and a high excited component removing ratio (S/N ratio) is obtainable.

Fig. 7 shows a result obtained through measuring S/N ratio of the vibrating type transducer constructed as above.

In Fig. 7, the axis of abscissa indicates a frequency 1 KHz per graduation, and the axis of ordinate indicates an attenuation 5 dB per graduation. The resonance frequency when a pressure impressed on the diaphragm 25 is zero is 71,551.1 Hz, the point indicated by a marker × is -13.3 dBm with a reference level as -7.0 dBm, coming gradually near to the line indicating a -52 dBm noise line according as it comes off the resonance point. S/N ratio is represented as a difference of these, and thus S/N ratio coming in 30 to 40 dB which is far better than ever before is obtained.

Fig. 8 is a block diagram showing a main part of another embodiment of the invention.

In the embodiment, the construction is such that a secondary side of the input transformer 33 is connected to one same end side of the two first vibrators

26A, 26B, and a primary side of the output transformer 36 is connected to the other same end side of the first vibrators 26A, 26B.

Then, the above-described embodiment has referred to the second vibrator 27 as p-type silicon, however, it is not necessarily limited thereto, and hence may be, for example, that for which a conductor such as aluminum or the like is evaporated on silicon oxide (SiO_2) or silicon nitride (Si_3N_4).

Further, such vibrating type transducers have the vibration frequency changed according to a temperature coefficient of the elastic modulus of silicon, therefore these can be utilized as a thermometer from being contained in a vacuum vessel and also as a densimeter other than pressure gauge.

As described, the vibrator body 24 is divided into the first vibrator 26A for excitation and the first vibrator 26B for detecting electromotive force, and further the first vibrators 26A and 26B are coupled mechanically together by the second vibrator 27 at loops of vibration, therefore an excited current component is not included, and thus a high excited component removing ratio (S/N ratio) is obtainable.

Consequently, according to the embodiment given in Fig. 5, a vibrating type transducer satisfactory in S/N ratio and stable in frequency output signal may be realized.

Fig. 9 is a drawing showing a process for manufacturing the vibrating type transducer shown in Fig. 5. Then, for simplicity of the description, the process refers to manufacturing the beamlike first vibrator 26A to which the second vibrator 27 is not coupled instead of the vibrator body 24.

Fig. 9 (a) shows a process for forming a protective coat and opening one part thereof.

A protective coat 41 such as silicon oxide, silicon nitride or the like is formed on a crystal face (100) of an n-type silicon single-crystal substrate 40, and then an opening 42 is formed on a part of the protective coat 41 by means of a mask with a pattern along a shape of the first vibrator 26A formed thereon.

Next, the process goes forward to Fig. 9 (b), wherein a recession is formed in the substrate.

A recession 43 is formed in the substrate 40 corresponding to the opening 42 through etching on hydrogen chloride in an atmosphere of 1,050 °C hydrogen (H_2).

In this case, an anisotropic etching may be employed by means of an alkali solution 40 °C to

130 °C, for example, instead of hydrogen chloride.

Fig. 9 (c) shows an epitaxial process.

Hydrogen chloride is mixed in a source gas in an atmosphere of 1,050 °C hydrogen (H_2) to a multi-layer selective epitaxial growth. In this respect, a further description will be given in detail as follows.

(1) For the first step a first epitaxial layer 44 functioning as a lower half of the gap corresponding part is subjected to a selective epitaxial growth on the recession 43 by means of p-type silicon $10^{18}cm^{-3}$ in boron concentration.

(2) For the second step a second epitaxial layer 45 corresponding to the first vibrator 26A is subjected to a selective epitaxial growth on a surface of the first epitaxial layer 44 so as to close the opening 42 by means of p-type silicon $10^{20}cm^{-3}$ in boron concentration.

(3) For the third step a third epitaxial layer 46 functioning as an upper half of the gap corresponding part is subjected to a selective epitaxial growth on a surface of the second epitaxial layer 45 by means of p-type silicon $10^{18}cm^{-3}$ in boron concentration.

(4) For the fourth step a fourth epitaxial layer 47 corresponding to the shell which will be described

hereinlater is subjected to a selective epitaxial growth on a surface of the third epitaxial layer 46 by means of p-type silicon $10^{20}cm^{-3}$ in boron concentration.

In this case, however, n-type silicon $10^{17}cm^{-3}$ in phosphorus concentration may be used for the third epitaxial layer 46.

Fig. 9 (d) shows a process for forming an injection port through which an etching reagent is injected.

In the process the protective coat 41 is etched and removed by means of hydrofluoric acid (HF), and an injection port 48 through which an etching reagent is injected is provided on a side of the fourth epitaxial layer 47.

Fig. 9 (e) shows a selective etching process for forming a clearance between the vibrator and the substrate and others.

A positive pulse voltage is impressed from a pulse supply E_p so that the n-type substrate 40 will be reverse-bias to the p-type fourth epitaxial layer 47, an alkali solution is injected through the injection port 48 as protecting the substrate 40, and thus the first epitaxial layer 44 and the third epitaxial layer 46 are removed through selective etching.

Then in this case, n-type silicon $10^{17}cm^{-3}$ in phosphorus concentration may be used for the third epitaxial layer 46, and p-type silicon $10^{20}cm^{-3}$ in boron concentration may also be used for the fourth epitaxial layer 47. The phenomenon that the etching action will be suppressed from the boron concentration exceeding $4 \times 10^{19}cm^{-3}$ is utilized therefor.

Lastly, the process shifts to that for sealing shown in Fig. 9 (f).

In the process, n-type silicon is subjected to an epitaxial growth in the atmosphere of 1,050 °C hydrogen (H_2), an epitaxial layer 50 is formed on outer surfaces of the substrate 40 and the fourth epitaxial layer 47 to construct a shell 51 partly and close the injection port 48 to sealing.

Then, other than the above method, the sealing process may comprise (1) closing the injection port 48 by heat oxidation, (2) closing the injection port 48 by filming the injection port 48 with polysilicon according to CVD process or sputtering, (3) filling up silicon in the injection port 48 according to vacuum evaporation of the epitaxial process, or (4) filling up an insulating material such as, for example, glass (SiO_2), silicon nitride, alumina or the like in the injection port 48 according to CVD process, sputtering or evaporation.

While not so indicated, the diaphragm 25 is formed thereafter by turning up the substrate through etching from a bottom side of the substrate 40.

The aforementioned manufacturing process may then realize the following effects.

First, since the substrate 40, the second epitaxial layer 45 functioning as the first vibrator 26A and the shell 51 are formed integrally, it is not necessary to bond the substrate 40 and the shell 51 together, thus avoiding instability due to bonding.

Second, the air and the vibrators can be isolated by a simple structure, therefore miniaturization can easily be realized.

Third, since a semiconductor process technique is utilized, accurate position, thickness and shape of the vibrators and shell can easily be realized.

Fig. 10 shows a part of the process for forming the H-shaped vibrator body.

In this case, the process shown in Fig. 10 is substituted for those of Fig. 9 (a) and (b), and other process is identified with that of Fig. 9, thereby realizing the H-shaped vibrator body 24.

First, as shown in Fig. 10 (a), a protective coat 52 such as silicon oxide, silicon nitride or the like is formed on an upper surface of crystal plane (100) of the silicon substrate 40, and then the protective coat 52 formed on a surface of the substrate 40 is removed to an H-shape through photolithography by means of a mask having an H-shaped opening, thus forming an H-shaped opening 53 on the protective coat 52.

The H-shaped opening 53 is disposed so that H-shaped beams formed by each of the first vibrators 26A, 26B and the second vibrator 27 face in the direction <001> of the substrate 40 and also in the direction rectangular thereto.

Next, as shown in Fig. 10 (b), an H-shaped recession 54 corresponding to the opening 53 is formed on the substrate 40 from etching the protective coat 52 having such opening 53.

Then, the H-shaped vibrator body 24 shown in Fig. 5 is formed according to the process shown in Fig. 9.

Fig. 11 shows a process for enhancing and stabilizing a yield of the vibrators in the manufacturing process shown in Fig. 9.

The process is almost same as the process shown in Fig. 9 barring Fig. 11 (c).

The process of Fig.11 (c) comprises forming a boron high-concentration P^{++} p-type epitaxial layer 71 thin at 1 μm or below on a surface of the recession 43 formed as shown in Fig. 11 (b). In this case, the concentration will be set preferably to the limit of etching the p-type epitaxial layer 71 with etching reagent, or, for example, at $3 \times 10^{19} cm^{-3}$ or so.

The process then shifts to that for etching of Fig. 11 (f) through epitaxial process of Fig. 11 (d) and that for forming an etching reagent injection port of Fig. 11 (e).

In the process, an etching reagent is injected from the injection port 48 to etch and remove the first epitaxial layer 44 equivalent to the gap corresponding part and the third epitaxial layer 46. In this case, the auxiliary epitaxial layer 71 is p-type and high in concentration, inherently therefore it is not etched, however, since it is very thin, a boron concentration deteriorates and ready for etching by an alkali solution according to autodoping at the selective epitaxial process and diffusion at the heating process, and thus n-type face of the substrate 40 comes out on the surface.

The aforementioned process will further be described in detail with reference to Fig. 12 and Fig.

13.

In the process of Fig. 11 (c), where there is no auxiliary epitaxial layer 71 present, p-type Si remains islandlike on a pn junction between the n-type substrate 40 and the p-type first epitaxial layer 44 at the etching process of Fig. 11 (f).

A p-type residue 72 (Fig. 12) remaining islandlike as mentioned forms an n-type inversion layer 73 inverted to n-type at a boundary with the alkali solution which is an etching reagent during etching, thus a path through which a current i_ℓ flows from the pulse supply E_p (Fig. 11 (f)) as indicated by an arrow is formed to protect a surface of the residue 72 from etching, which is capable of causing a problem that a lower portion of the vibrator is partly not etched.

Now, therefore, the auxiliary epitaxial layer 71 which is a p-type high-concentration P^{++} ($3 \times 10^{19} cm^{-3}$ or so) boron dope layer thin at 1 μm or below is formed on a top of the substrate 40, the leakage current i_ℓ is interrupted to keep the residue 72 from being formed and a stable etching is secured, thus enhancing productivity.

The ensuing process is for forming the shell as in the case of Fig. 9 (f).

Fig. 14 is a process drawing showing a main part of the manufacturing process for realizing a structure of the vibrator body keeping the shell vacuum internally.

For detecting pressure and others in high sensitivity as keeping a high Q-factor, it is necessary that the vibrator be kept vacuum around. In this case, however, some contrivance will be required for the manufacturing process in such vibrating type transducer with structure wherein the beamlike vibrators 26A, 26B, 27 are formed integrally on the diaphragm 25.

The case wherein the first vibrators of the vibrator body shown in Fig. 5 are kept vacuum around will be taken up for description in Fig. 14.

The process coming in Fig. 9 (a) to Fig. 9 (e) remains same, and thus the etching result of Fig. 14 (a) equivalent to Fig. 9 (e) is obtained.

In the process of Fig. 14 (b), outer surfaces of the substrate 40 and the fourth epitaxial layer 47 are subjected to an n-type epitaxial growth at temperature of 1,050 °C generally in the atmosphere of hydrogen (H_2) or in vacuum. The injection port 48 formed between the substrate 40 and the fourth epitaxial layer 47 is filled by the epitaxial growth, the shell 51 is thus formed, and the vibrator body for vibrating type transducer having, for example, the first vibrator 26A formed of the second epitaxial layer internally.

In this case, an n-type layer equivalent in thickness to a clearance (t) of the injection port 48 is formed around the first vibrator 26A and also on the inside of a hollow chamber 74.

In the process of Fig. 14 (b), since the epitaxial growth is effected in the atmosphere of hydrogen (H_2), the hollow chamber 74 formed between the substrate 40 of silicon single crystal and the shell 51 is charged with hydrogen (H_2).

Now, as shown in Fig. 14 (c), a vibrating type transducer having the vibrator body is put into the atmosphere kept vacuum at 900 °C, and the hydrogen (H_2) is extracted to vacuum through a crystal lattice of silicon. The degree of vacuum thus obtained is 1×10^{-3} Torr or below.

Then, a similar result has been obtained in inert gas and nitrogen gas with less hydrogen partial pressure.

Next, the hydrogen extraction will be described with reference to Fig. 15. In Fig. 15, the axis of abscissa indicates temperature, and the axis of ordinate indicates dissociation pressure. Then, the straight line drawn obliquely from origin indicates a boundary to separate a domain wherein hydrogen is absorbed in silicon of the substrate 40 and a domain wherein it is extracted externally from silicon.

According to the illustration, when left as it stands in vacuum T_1 or, for example, 1,200° K for a long time, hydrogen within the shell 51 is absorbed in silicons of the shell 51 and the substrate 40 and diffused thereinto, and hydrogen having reached the surface is dissociated and discharged if the ambient pressure is P_1 or, for example, 10^{-3} Torr or below.

Thus, the hollow chamber 74 may be retained at the degree of vacuum of, for example, 10^{-3} Torr internally.

The above may be so understood from a result obtained from carrying out a test according to the aforementioned process that a value at 3×10^4 or over which is Q-factor of the first vibrator 26A corresponding to about 10^{-3} Torr has been obtained for the hollow chamber 74 within the shell 51.

Fig. 16 is a process drawing having modified a part of the process shown in Fig. 14.

The process up to Fig. 14 (a) remains same, and the process then shifts to that of Fig. 16 (a).

While the injection port 48 is formed through etching in the process of Fig. 14 (a), the process of Fig. 16 (a) is that for sealing the injection port 48.

In the process, oxygen is substituted in a gap formed by the fourth epitaxial layer 47 working as the first vibrator 26A to the second epitaxial layer 45 and the silicon substrate 40, and then the injection port 48 is sealed through spattering amorphous silicon, thereby forming a shell 75.

Then afterward, the process shifts to Fig. 16 (b) to extraction. In the process, the vibrating type transducer including the vibrator body is placed in vacuum at 900 °C or over, an inside wall of the hollow chamber 74 is oxidized by oxygen filled in the hollow chamber 74 at the process of Fig. 16 (a), or oxygen in the silicon is diffused to come out of the silicon surface partly, thereby stepping up the degree of vacuum.

According to the above-described preferred manufacturing process of the invention, the vibrators are formed integrally with the silicon substrate with a predetermined gap left thereto, and then a vacuum is realized through a predetermined process, therefore a vibrating type transducer superior in both pressure and temperature characteristics may be realized.

Fig. 17 is a sectional view showing a main part construction of the vibrating type transducer with an initial tension applied to the vibrators.

The vibrator body is constructed such that the opposite ends are fixed, for example, on the n-type silicon substrate 40, the p-type vibrator 13 is fixed with a predetermined gap retained to the substrate 40 barring the opposite ends, which is covered by the silicon shell 51 integrally with the substrate 40, and the hollow chamber 74 is formed surroundedly thereby. The hollow chamber 74 is retained vacuum internally.

Then, a measuring pressure P_m, for example, is impressed on the diaphragm 25, and a resonance frequency of a vibrator 76 with the opposite ends fixed on the diaphragm 25 which corresponds to a strain arising on the vibrator 76 is measured, thereby obtaining the measuring pressure P_m.

Meanwhile, unless an initial tension is given even at the time when the measuring pressure P_m is zero, a buckling will be caused on the vibrator 76 by the measuring pressure P_m, which is not ready for measurement, and unless a dispersion of the initial tension is controlled, a dispersion of sensitivity may also result therefrom.

The following description will refer to this respect. Fig. 18 represents a relation between a covalent bond radius R_i of various impurities, and covalent bond radius R_i of each impurity to a covalent bond radius R_{Si} of silicon. Fig. 19 shows a change of lattice constant to an impurity concentration. As will be understood from Fig. 18, while the covalent bond radius R_{Si} of silicon (S_i) is 1.17Å, that of phosphorus (P) is 1.10Å and boron (B) is 0.88Å, which are rather small. Accordingly, when boron or phosphorus is injected in silicon, the portion is subjected to a tensile strain. From Fig. 19, therefore, where concentration of boron is $10^{20}cm^{-3}$, for example, change of the lattice constant is 2×10^{-3}Å, and since the lattice constant of silicon is 5.431Å, the strain is about 4×10^{-4} ($= 2 \times 10^{-3}/5.431$). For the strain at 4×10^{-4} or over, boron will be injected double or at $2 \times 10^{20}cm^{-3}$, then an initial tension at 8×10^{-4} will be generated in proportion to the injection rate. Accordingly, an arbitrary initial tension may be given from injecting an arbitrary concentration of boron.

An initial tension is given to the vibrator 76 shown in Fig. 17, accordingly.

For the strain less than 4×10^{-4}, a phosphorus concentration of the n-type silicon substrate 40 is raised, or the vibrator 76 is oxidized to segregate boron on the surface of vibrator into the oxide film, and from removing the oxide film by HF, the boron concentration in the vibrator 76 is decreased to adjust the strain at 4×10^{-4} or below. Then, as will be apparent from Fig. 19, it is presumed that the strain will almost not arise at the boron concentration of $10^{17} cm^{-3}$ or so.

Fig. 20 is a process drawing showing a main part of manufacturing process for the vibrator body which is a main part of the vibrating type strain sensor of the invention.

Fig. 20 (a) shows the state where the recession 43 is formed through HCℓ etching in the process coming in Fig. 9 (a) and Fig. 9 (b).

Next, as shown in Fig. 20 (b), a $10^{18} cm^{-3}$ concentration of boron (p-type) is subjected to a selective epitaxial growth into the recession 43 in the atmosphere of hydrogen H_2 at 1,050 °C, thereby forming the first epitaxial layer 44.

Then thereafter, as shown in Fig. 20 (c), boron (p-type) adjusted to be a concentration at $10^{20} cm^{-3}$ in the atmosphere of hydrogen H_2 at 1,050 °C is subjected to a selective epitaxial growth on the first epitaxial layer 44, thereby forming a second epitaxial layer 77 working as the vibrator 76.

A covalent bond radius of silicon is 1.17Å, and that of boron is 0.88Å, therefore if boron is partly injected into silicon, the portion is subjected to a tensile strain, which is utilized for giving a necessary initial tension thereto through adjusting boron density of the second epitaxial layer 77 working as the vibrator 76.

Next, as shown in Fig. 20 (d), a $10^{1.8}cm^{-3}$ concentration of boron (p-type) is subjected to a selective epitaxial growth on the second epitaxial layer 77 in the atmosphere of hydrogen H_2 at 1,050 °C, thereby forming the third epitaxial layer 46.

Further, as shown in Fig. 20 (e), a $10^{20}cm^{-3}$ concentration of boron (p-type) is subjected to a selective epitaxial growth on the third epitaxial layer 46 in the atmosphere of hydrogen H_2 at 1,050 °C, thereby forming the fourth epitaxial layer 47.

Fig. 20 (f) shows an etching process for removing the first epitaxial layer 44 and the third epitaxial layer 46 in the state wherein the SiO_2 protective coat 41 has been removed (process not indicated) through etching by hydrogen fluoride HF after the process for selective epitaxial growth shown in

Fig. 20 (e).

While not so illustrated, the whole is soaked in an alkali solution in this etching process, and a positive pulse voltage 5V in peak value and 0.04 Hz or so in repetition frequency is impressed from the DC pulse supply E_p so that the n-type silicon substrate 40 will be plus potential to the p-type second epitaxial layer 77. Since the n-type silicon substrate 40 and the fourth epitaxial layer 47 have an insoluble film formed on the surface each to a passive state according to the voltage impression, the etching rate becomes considerably low compared to the first epitaxial layer 44 and the third epitaxial layer 46, which is utilized for removing the first epitaxial layer 44 and the third epitaxial layer 46. Further, when concentration of a doped boron is greater than 4×10^{19}, the etching rate is considerably reduced from that of normal case where silicon is not doped, and such phenomenon is utilized for realizing the construction wherein the injection port 48 is provided partly, and further a gap is secured between the silicon substrate 40 and the second epitaxial layer 77 as a whole, leaving the second epitaxial layer 77 as shown in Fig. 20 (g).

The ensuing process is same as that of Fig. 9

(g) or Fig. 14 (b) to Fig. 14 (e). A main part of the vibrator body shown in Fig. 17 is formed through such process.

For further adjustment of an initial tension of the vibrator 76, a phosphorus density in the n-type silicon substrate 40, for example, will be adjusted, thereby adjusting the initial tension on a relative strain of the substrate 40 and the second epitaxial layer 77.

Or otherwise, an apparent initial tension may be reduced by subjecting a low-concentration n-type silicon to an epitaxial growth on the vibrator 76 in a proper thickness. Further, a heat oxidation may generate a compression strain in a hot oxide film, thereby adjusting the apparent initial tension. Still further, the initial tension can be adjusted likewise through CVD, sputtering, evaporation or other means.

An atom to inject has been specified as boron or phosphorus for description of the embodiments given as above, however, the invention is not necessarily limited thereto. Then, the vibrating beam is also not limited to silicon only.

The aforementioned vibrating type strain sensor has been described on a pressure measurement, which may be applied to acceleration sensor, differential pressure sensor and others likewise.

As described concretely above, according to the invention, an initial tension can be provided to the vibrating beam through a construction simple as compared with the prior art, and further the tension can easily be adjusted.

Next, the amplifier shown in Fig. 5 will be described in detail.

In the prior art vibrating type transducer shown in Fig. 4, since the vibrator is constructed to oscillate in a nonlinear domain, an oscillation frequency changes from limiting an amplitude on, for example, Zener diode, and a construction to control a driving voltage is capable of changing so often an amplitude of the vibrator according to boundary conditions of junction with other resonance system or with measuring fluid, which prevents a generation of accurate resonance frequency. Such problem may be solved by using the amplifier shown in Fig. 21.

Fig. 21 is a circuit diagram showing a detailed construction of the amplifier 39 shown in Fig. 5.

A reference character AMC1 denotes an amplifier circuit with its input ends (+), (-) connected to output ends 37, 38 of the vibrator body 24. Then, its output end is inputted further to an amplifier circuit AMC2 through a coupling capacitor C_5 and its output voltage is generated to a junction J. The output is then generated to a gain adjusting circuit GAC through a phase adjusting circuit PHC. An amplification output of the gain adjusting circuit GAC after amplification on its first stage is impressed on a resistance R_{10}, a field effect transistor Q_1, a series circuit of a transformer T, and an output voltage controlled for the magnitude is generated to the output terminal 40 from a secondary side winding of the transformer T.

On the other hand, a voltage V_J of the junction J is inputted to a half-wave rectifier circuit HWR, converted into a DC voltage E_J corresponding to a magnitude of the voltage V_J, and then inputted to an inversion input end (-) of a comparator CMP. A reference voltage V_R is impressed on a non-inversion input end (+) of the comparator CMP from an amplitude setting circuit ASC, and the comparator CMP amplifies a deviation between the DC voltage E_J and the reference voltage V_R, impresses the differential voltage on a gate of the field effect transistor Q_1 from its output end, controls a resistance between drain and gate, thus controlling a current flowing to the transformer T.

Then in these circuits, a phase is adjusted by a capacitor C_6 and a resistance R_{17}, and an amplitude of the voltage generated on the output side 40 is set by a resistance R_{26}.

In the above construction, when a voltage is impressed on the input transformer 29 from the amplifier 39, a current i flows to the first vibrator 26A from the output, and thus the first vibrator 26A vibrates on an electromagnetic force operating with a magnetic field by the magnet 17. The vibration operates on the first vibrator 26B through the second vibrator 27, however, since a magnetic field is impressed on the first vibrator 26B from the magnet 17, a voltage e is generated on the first vibrator 26B and inputted to the amplifier 39 through the output transformer 36. The amplifier 39 amplifies the voltage and generates the amplified voltage on its output terminal 35.

The amplified voltage is impressed again on the input transformer 33 and further impressed on the first vibrator 26A as a greater voltage.

From repeating the above a loop coupling the amplifier 39 and the vibrator body 24 makes a self-oscillation. Then, from setting a gain of the loop at 1 or over, the self-oscillation becomes lasting.

In this case, a voltage amplitude of the self-oscillation is controlled so as to come in a constant error to the reference voltage V_R.

That is, when the DC voltage E_J corresponding to the junction voltage V_J is great to the reference voltage V_R, an internal resistance of the field effect transistor Q_1 is increased on an output of the comparator CMP according to these deviations, a current flowing to the transformer T is minimized, and a voltage generated on the output terminal 35 is minimized. As a result, a voltage impressed on the vibrator body 24 is minimized, and a voltage inputted to the amplifier 39 is also minimized.

On the contrary, when the DC voltage E_J corresponding to the junction voltage V_J is small to the reference voltage V_R, the operation is reversed.

Thus the oscillation amplitude operates to coincide with the reference voltage V_R within the range of constant error. The error is determined by (output voltage/gain of comparator CMP) of the comparator CMP. Accordingly, where a gain of the comparator CMP is large, the error may be disregarded in value, and an amplitude of the vibrator operates to be equal to the reference voltage V_R at all times.

Next, an effect when the circuit configuration shown in Fig. 21 is employed will be described with reference to Fig. 22 and Fig. 23.

Fig. 22 indicates an effect when the circuit configuration shown in Fig. 21 is employed, and Fig. 23 indicates an effect when the prior art circuit configuration wherein the field effect transistor Q_1 shown in Fig. 21 is removed to short-circuiting and a driving force is kept constant (drive on a constant supply voltage) is employed. A span is 1 kg/cm^2 in either case, and the axis of abscissa indicates pressure, the axis of ordinate indicates indexed value.

As will be understood from the results, while the fluctuation is ±0.005% or so in the case of Fig. 22, the fluctuation at ±0.025 max. or so is indicated in the case of Fig. 23, providing an improvement coming about five times or so.

As described concretely above, the invention comprises detecting an amplitude of self-oscillation halfway of the amplifier, comparing the detected amplitude with a preset reference voltage, adjusting a gain controlling means provided on the rear stage for the amplitude to coincide with the reference voltage, thereby retaining the amplitude constant, therefore the oscillation amplitude is retained constant at all times without being influenced by the external conditions, a fluctuation will not be brought on the self-oscillation frequency, and thus a high precision vibrating type transducer can be realised.

As described concretely above along with the embodiments, the invention may provide the following effects:

(a) In preferred constructions described, the vibrator body is divided into the first vibrator 26A for excitation and the first vibrator 26B for detecting electromotive force, and further loops of the first vibrators 26A and 26B are coupled mechanically by the second vibrator 27, therefore an elimination ratio (S/N ratio) of high excitation component is obtainable without including an exciting current component, and thus a vibrating type transducer wherein a stable frequency output signal is obtainable may be realised.

(b) Also in the described construction, the direction of a vibrator beam is limited correlatively to an axis of the silicon single crystal, thereby expecting a similar effect to the above mentioned.

(c) According to the preferred construction as described, since the substrate, the second epitaxial layer functioning as first vibrator and the shell are formed integrally, the substrate need not be bonded to the shell, and thus an instability due to junction can be avoided. Also, since the vibrator can be isolated from the air through a simple structure, a miniaturisation can easily be realised. Furthermore, since a semiconductor process technique is utilised, accurate position, thickness and shape of the vibrator and shell can easily be realised.

(d) In the construction described, the vibrator is formed integrally with the silicon substrate through a predetermined gap, and then kept vacuum simply on a predetermined process, therefore a vibrating type transducer superior in both pressure and temperature characteristics may be realised.

(e) According to a preferred embodiment of the invention, an initial tension can be given to the vibrator through a simple construction as compared with the prior art, and further the tension can easily be adjusted.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A vibrating type transducer comprising:

a silicon substrate having a thin diaphragm formed in a central portion thereof;

an H-shaped vibrator body having first and second vibrators, disposed in parallel and each with opposite ends fixed on said diaphragm, and a third vibrator mechanically coupling central portions of said first and second vibrators, said vibrator body in use vibrating as a whole such that the opposite ends of said first and second vibrators are used as fixed ends of vibration;

a magnetic field generating means for applying a DC magnetic field across said vibrator body;

an excitation means for vibrating the vibrator body on a mutual action with said DC magnetic field by conducting an alternating current through said first vibrator or from one end of said first vibrator to the same end of said second vibrator;

a vibration detection means for detecting an electromotive force generated across said second vibrator or between the other end of said first vibrator and the other end of said second vibrator; and

an amplification means connected between said excitation means and said vibration detection means.

2. A vibrating type transducer as defined in claim 1, said H-shaped vibrator body having each of said first and second vibrators formed like a beam in the direction of <001> to a crystal plane (100) of the substrate on which said vibrators are formed, and said third vibrator formed rectangularly to these vibrators.

3. A manufacturing process for vibrating type transducers, wherein a beamlike vibrator is formed integrally on a thin diaphragm, formed on a silicon single-crystal substrate, said vibrator being spaced from the diaphragm by a first

predetermined gap except at its ends, and being covered by a shell spaced from said vibrator by a second predetermined gap, characterised in that:

a protective coat is formed on an upper surface of said silicon substrate;

said protective coat is selectively removed to form an H-shape;

an H-shaped recess having portions etched underneath its marginal regions is formed on the substrate by etching the substrate region corresponding to said H-shape opening in the protective coat;

a first epitaxial layer to be used for a first gap corresponding part, a second epitaxial layer, a third epitaxial layer to be used for a second gap corresponding part and a fourth epitaxial layer to be used for a part of said shell are formed in order from the bottom of said recess;

an injection port for an etching reagent is formed by removing said protective coat;

said first and third layers are removed through etching with said etching reagent from the injection port to form an H-shaped vibrator body from said second epitaxial layer; then,

said injection port is sealed so as to be airtight.

4. A manufacturing process for vibrating type transducers as defined in claim 3, wherein a conduction mode of said substrate is n-type, a conduction mode of said first and second gap corresponding parts is p-type, and said vibrator and said shell are each p-type in conduction mode and high in doping concentration to a degree that they are not etched by said etching agent.

5. A manufacturing process for vibrating type transducers as defined in claim 3, including a process for forming an H-shaped recession in which an H-shaped vibrator body is enclosed through etching said substrate by means of an H-

shaped etching mask in the direction of <001> to a crystal plane (100) of said substrate and also rectangular thereto.

6. A manufacturing process for vibrating type transducers as defined in claim 3, wherein a protective coat of silicon oxide or nitride is formed on said substrate and is partly removed through etching to leave a recess.

7. A manufacturing process for vibrating type transducers as defined in claim 4, wherein an auxiliary epitaxial layer 1μm or less in thickness and high in p-type dopant concentration is formed on the surface of said recess on said substrate, said first epitaxial layer being formed thereon.

8. A manufacturing process for vibrating type transducers as defined in claim 3, wherein said first and second gap corresponding parts are removed through etching to form a hollow chamber, then said injection port is sealed in a gas atmosphere and maintained at high temperature, thereby keeping said hollow chamber vacuum.

9. A manufacturing process for vibrating type transducers as defined in claim 8, wherein hydrogen is used for said gas atmosphere.

10. A manufacturing process for vibrating type transducers as defined in claim 8, wherein oxygen is used for said gas atmosphere.

11. A vibrating type transducer comprising:

a silicon substrate having a thin diaphragm formed in a central portion thereof;

an H-shaped vibrator body, to which a predetermined initial tension is given, having first and second vibrators, disposed in parallel and each with opposite ends fixed on said diaphragm, and a third vibrator mechanically coupling central portions of said first and second vibrators, said vibrator body in use vibrating as a whole such that the opposite ends of said first and second vibrators are used as fixed ends of vibration;

a magnetic field generating means for applying a DC magnetic field across said vibrator body;

an excitation means for vibrating the vibrator body on a mutual action with said DC magnetic field by conducting an alternating current through said first vibrator or from one end of said first vibrator to the same end of said second vibrator;

a vibration detection means for detecting an electromotive force generated across said second vibrator or between the other end of said first vibrator and the other end of said second vibrator; and

an amplification means connected between said excitation means and said vibration detection means.

12. The vibrating type transducer as defined in claim 11, wherein a predetermined initial tension is given to said vibrator body by implanting another impurity atom with a bond radius smaller than that of a silicon atom.

13. A vibrating type transducer as defined in claim 1, wherein said amplification means comprises:

pre-amplification means for amplifying a signal generated from said vibrator body;

comparison means for outputting a control signal by which the voltage amplitude of self oscillation generated from said pre-amplification means is controlled so as to become to a predetermined reference value by comparing said voltage amplitude of self oscillation with said reference value; and

gain control means for controlling said voltage amplitude of self oscillation to a constant value based upon said control signal and for conducting feedback of said voltage amplitude signal to said vibrator body.

14. A vibrating type transducer substantially as hereinbefore described with reference to the drawings.

15. A manufacturing process for a vibrating type transducer substantially as hereinbefore described with reference to the drawings.

DATED this 31st day of July, 1990.

YOKOGAWA ELECTRIC CORPORATION
By its Patent Attorneys
DAVIES & COLLISON

Fig. 1 (Prior Art)

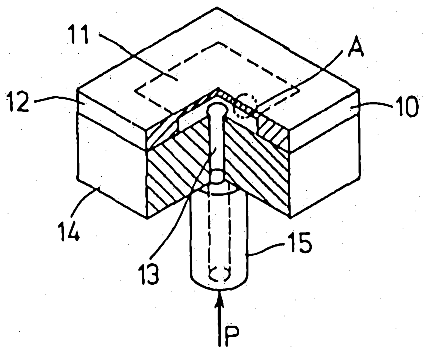

Fig. 2 (Prior Art)

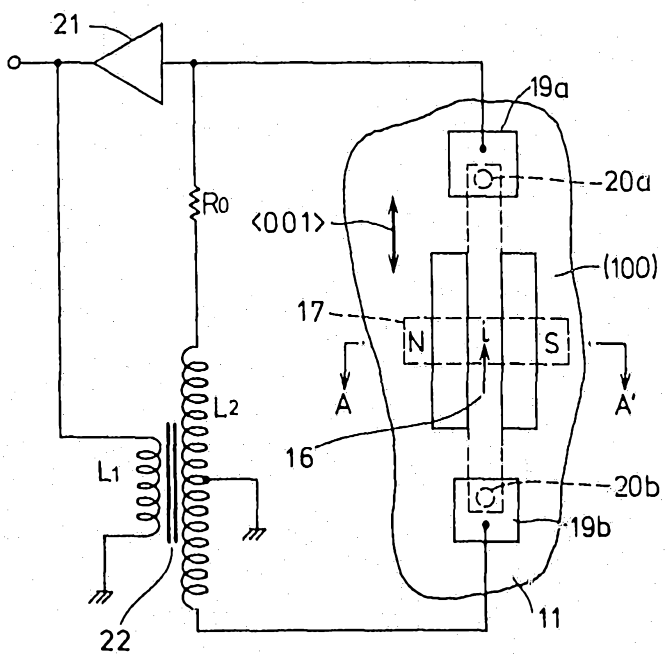

Fig. 3 (Prior Art)

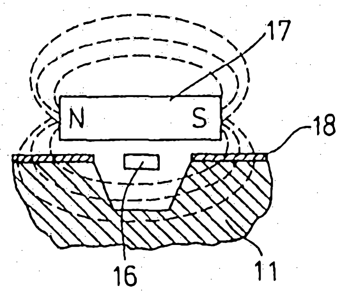

Fig. 4 (Prior Art)

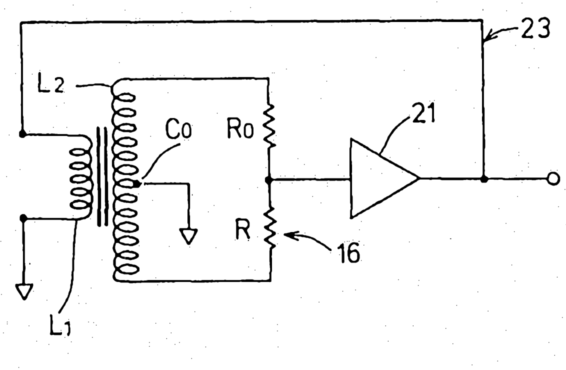

Fig.5

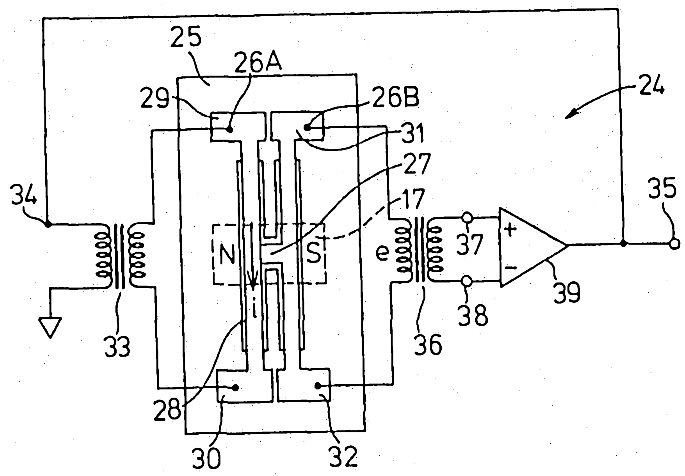

Fig.6(a)

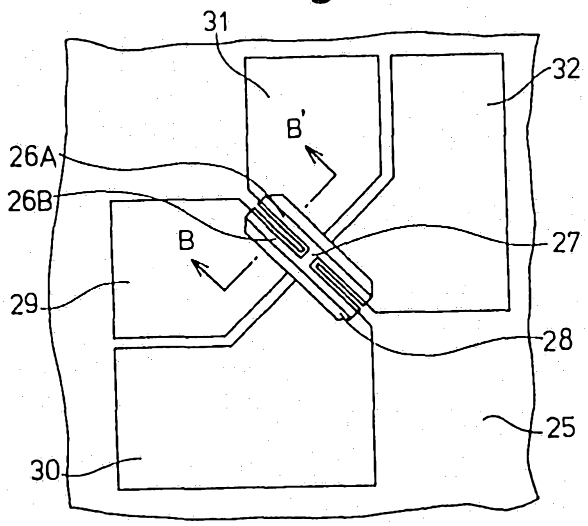

Fig.6(b)

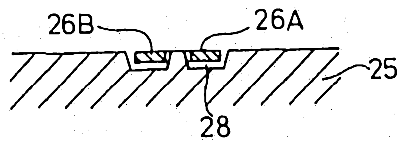

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Fig. 7

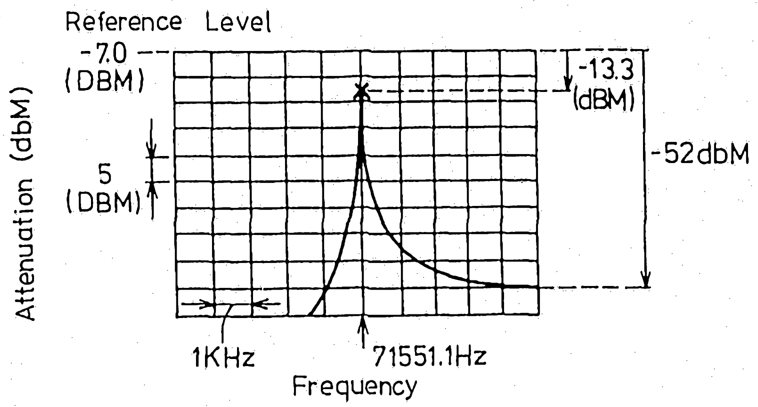


Fig. 8

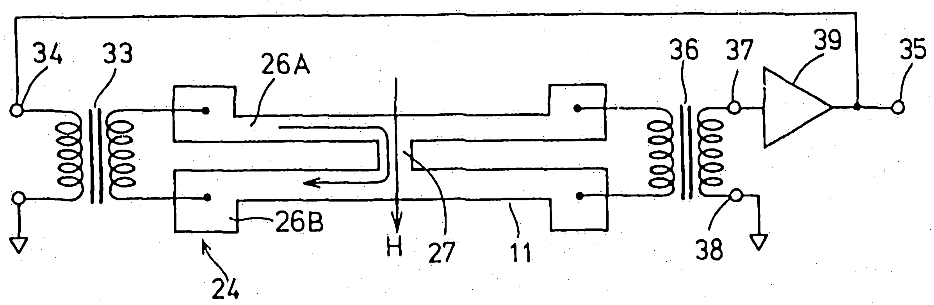


Fig.9(a)

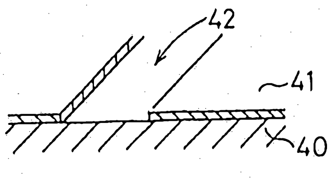


Fig.9(b)

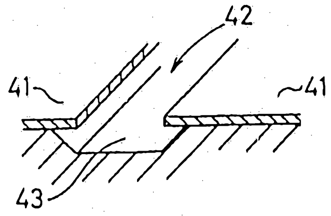


Fig.9(c)

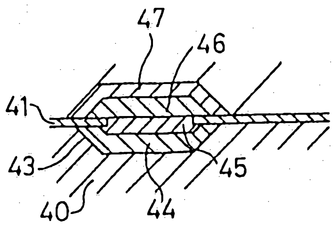


Fig.9(d)

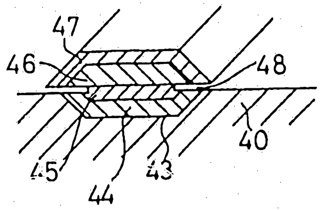


Fig.9(e)

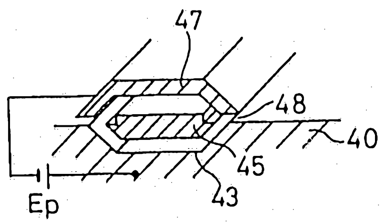


Fig.9(f)

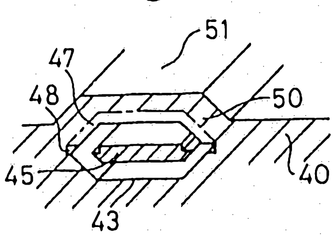


Fig.10(a)

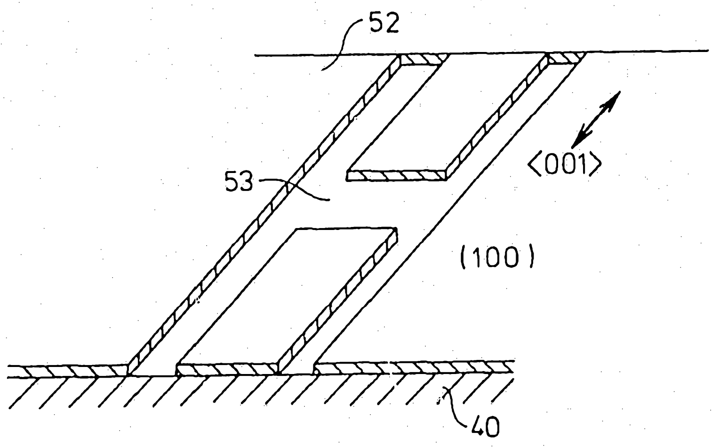


Fig.10(b)

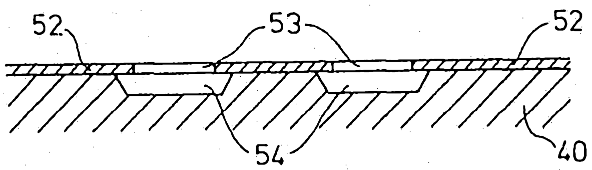


Fig.11(a)

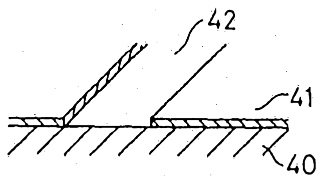


Fig.11(b)

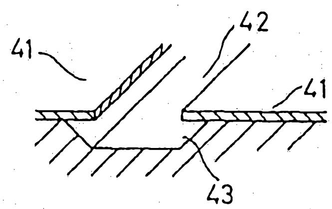


Fig.11(c)

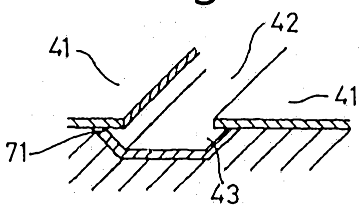


Fig.11(d)

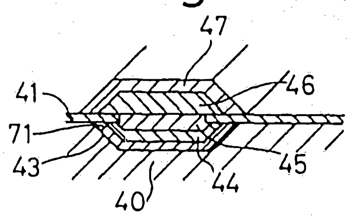


Fig.11(e)

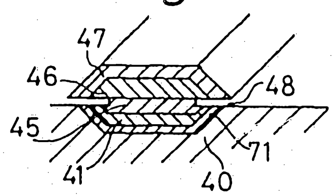


Fig.11(f)

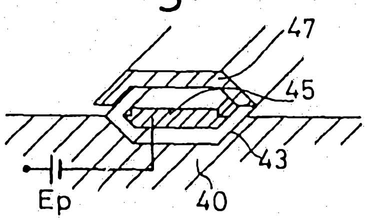


Fig.12

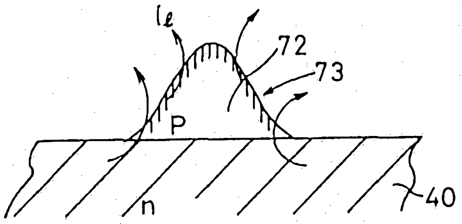


Fig.13

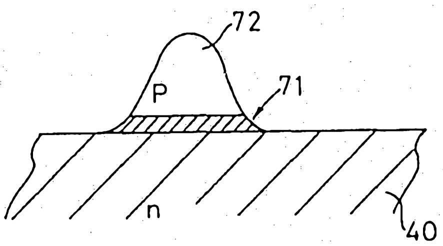


Fig.14 (a)

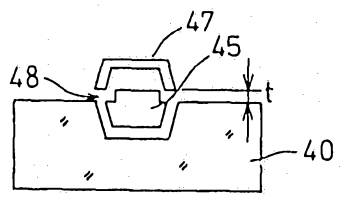


Fig.14 (b)

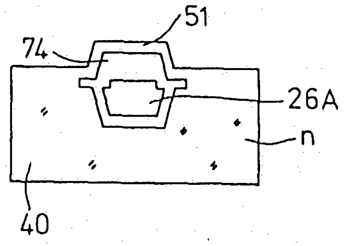


Fig.14 (c)

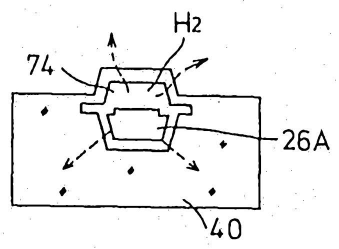


Fig.15

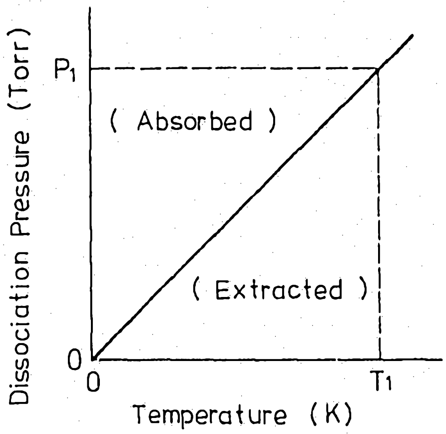


Fig.16 (a)

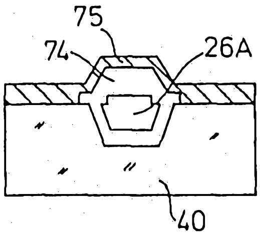


Fig.16 (b)

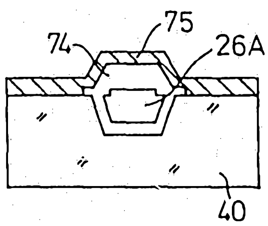


Fig.17

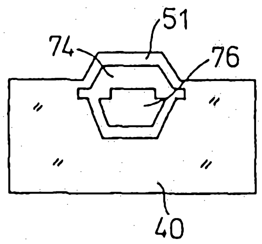
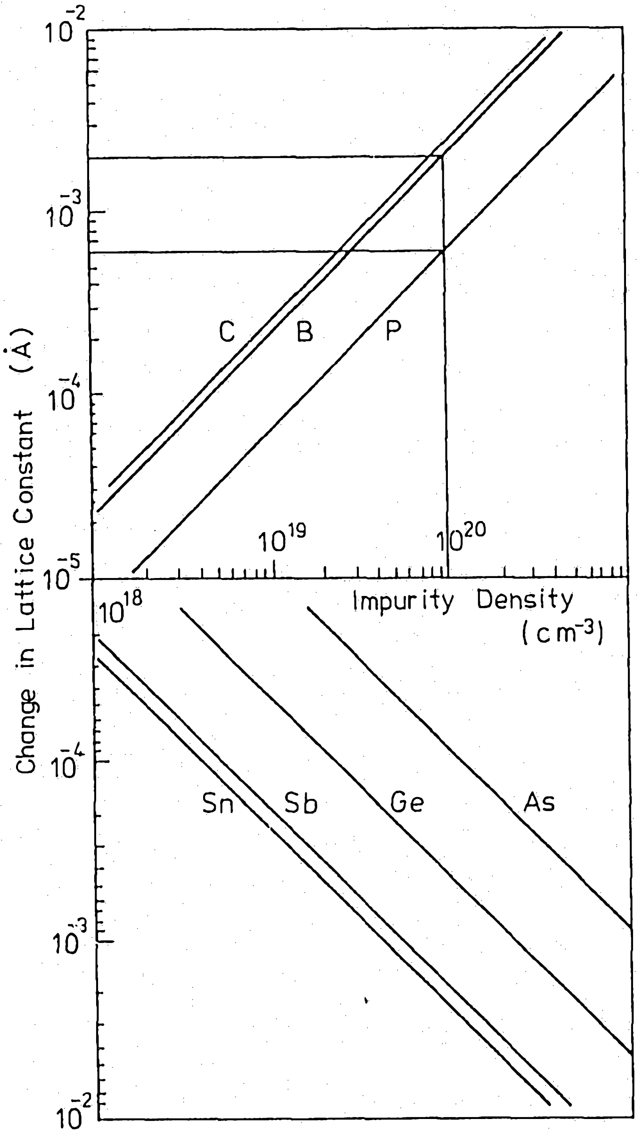


Fig.18

Impurity	Covalent Bond Radius Ri(Å)	Ri/Rsi
P	1.10	0.940
As	1.18	1.001
Sb	1.36	1.162
B	0.88	0.752
C	0.77	0.658
Si	1.17	1
Ge	1.22	1.043
Sn	1.40	1.197

Fig.19



10^{-2}
10^{-3}
10^{-4}
10^{-5}
C
B
P
10^{19}
10^{20}
10^{18}
Impurity Density
(cm^{-3})
Change in Lattice Constant (Å)
Sn
Sb
Ge
As

Fig. 20(a)

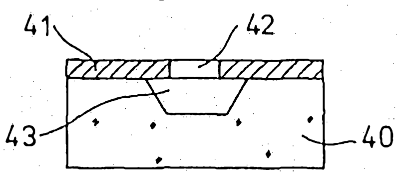


Fig. 20 (b)

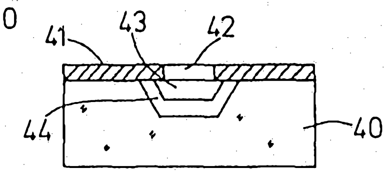


Fig. 20 (c)

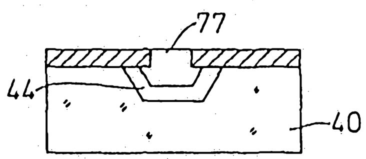


Fig. 20 (d)

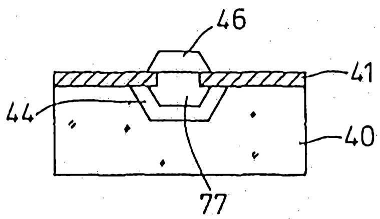


Fig. 20 (e)

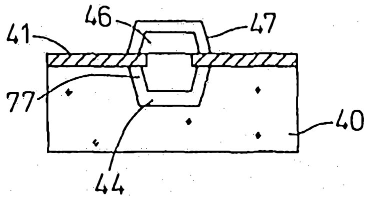


Fig. 20 (f)

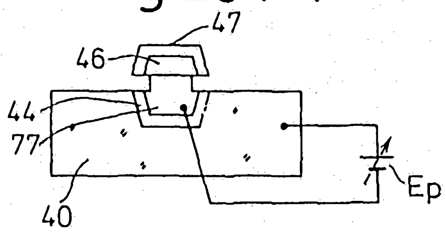


Fig. 20 (g)

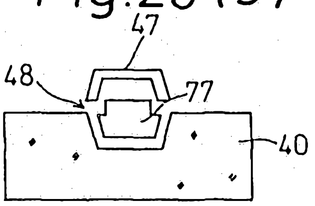
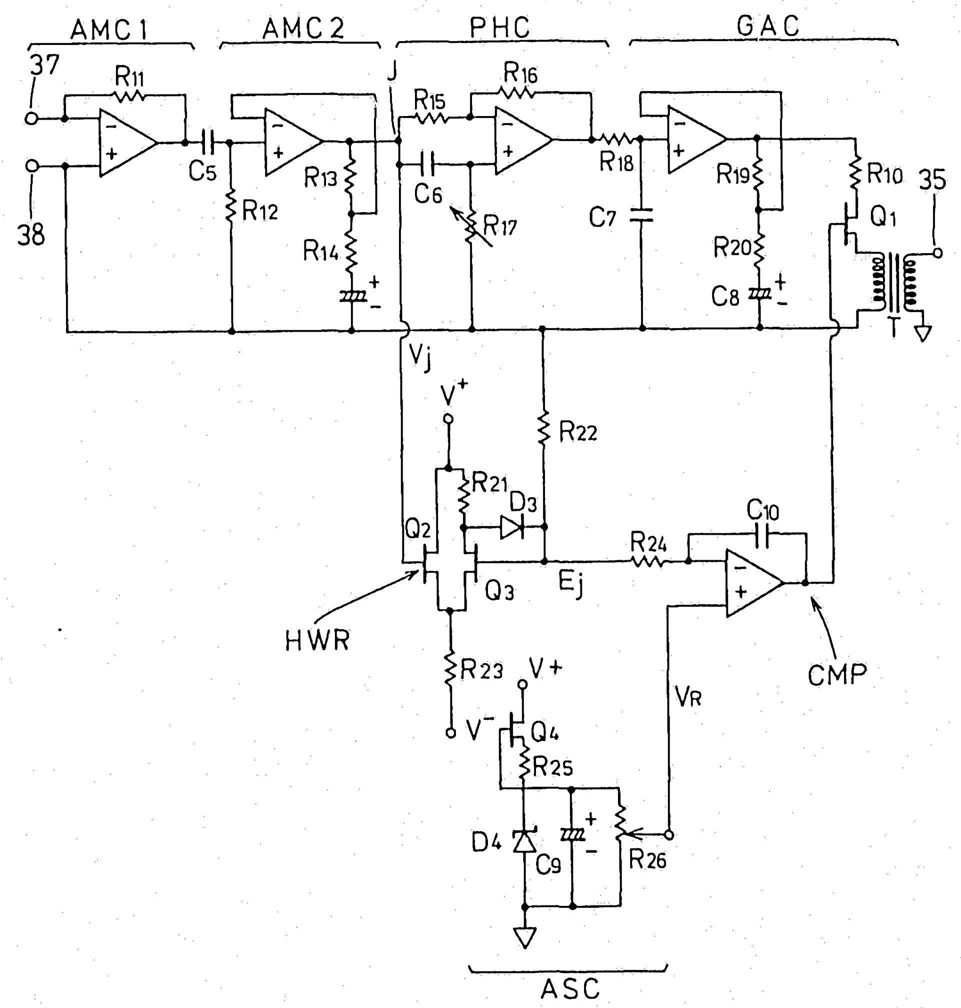
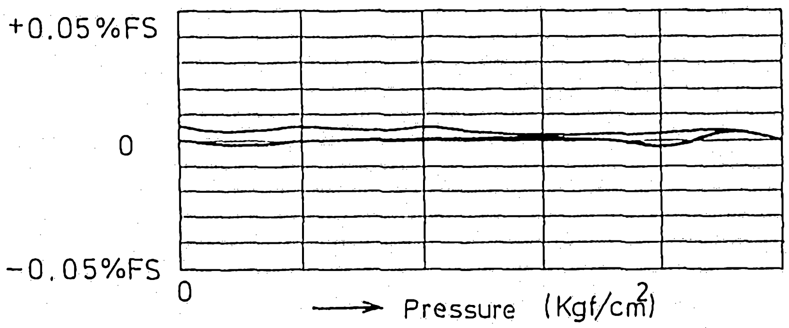


Fig. 21



AMC1
AMC2
PHC
GAC
37
38
R11
C5
R12
R13
R14
J
R15
R16
C6
R17
R18
C7
R19
R20
C8
R10
Q1
35
T
Vj
V+
R22
R21
D3
Q2
Q3
Ej
R24
C10
HWR
CMP
R23
V+
V-
Q4
R25
VR
D4
C9
R26
ASC

Fig.22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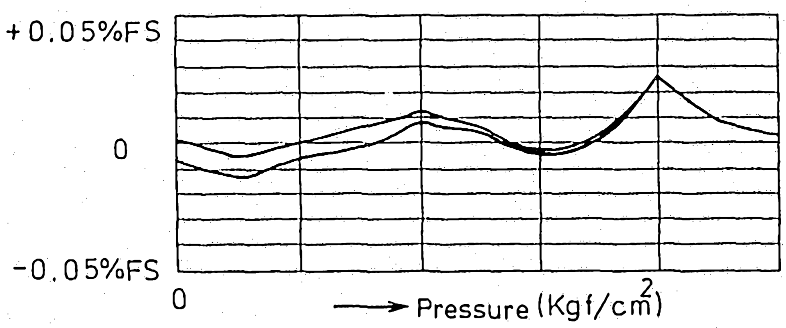
Pressure (Kgf/cm2)

Fig.23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Pressure (Kgf/cm2)