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depends on the properties of the cantilever and the interaction of the AFM tip with a sample. Using the present invention, the oscillation of the cantilever does not depend on any uncontrolled factor.

A METHOD FOR THE EXCITATION OF THE CANTILEVER OF HIGH-SPEED ATOMIC FORCE MICROSCOPE

The present invention relates to a high-speed atomic force microscope and the excitation of the cantilever of such microscope.

Background

Atomic force microscopy (AFM) is a powerful tool to characterize sample surfaces with high resolution. A scanning probe comprising a sharp probe tip mounted on a cantilever is raster-scanned across a sample surface to measure pre-defined quantities in a serial manner.

AFM may operate in three basic modes according to how the AFM probe moves:

- contact mode, which is also called static mode, where the probe does not oscillate and is always in very close contact with the sample surface;
- tapping mode, which is a dynamic mode also called intermittent contact or semi-contact mode, where the probe oscillates such that the tip only comes into very close contact with the sample at the bottom of its oscillation;
- non-contact mode, which is also a dynamic mode where the probe oscillates above the sample without the tip coming into very close contact with the surface.

The most commonly used mode for imaging samples by AFM is the tapping mode because the oscillation of the probe minimizes the damage caused on the sample by the motion of the tip relative to the sample and it is relatively easy to implement. In the non-contact mode, the force and the damage applied to the sample is even lower than in tapping mode, nevertheless its implementation in aqueous environment is to date still challenging. In the tapping mode and non-contact mode, the cantilever is oscillated at or near its resonance frequency with an amplitude usually ranging from 2 nm to 50 nm. Other modes of operation, oscillate the cantilever at multiple resonance frequencies, this is the case of the bimodal multifrequency mechanical mapping.

Some AFM operation modes, as the non-contact mode and multifrequency mechanical mapping, require measurement of the resonance frequency and cannot be operated in liquids using an excitation of the cantilever oscillation by vibrating piezo-electric ceramics. The use of vibrating piezo-electric ceramics creates random changes of the

oscillation amplitude of the cantilever with respect to the excitation frequency, thus precluding the use of piezo-electric excitation for these applications.

An example of prior art AFM is illustrated in Fig.1. A laser beam 10 is reflected off a force-sensing cantilever 12, deflections of which are detected by a position sensitive detector 14. The cantilever 12 is scanned over the sample surface 16 by a piezoelectric transducer 18. The force-sensing cantilever is immersed in a fluid body 20 contained in a fluid cell 22. The latter is mounted on a second transducer 24 which can displace the fluid cell 22 and sample surface 16 relative to the scanning transducer 18.

An AC signal 26 is applied to the second transducer 24 to modulate the gap 28 between the force sensing probe tip 30 on cantilever 12 and the sample surface 16. The corresponding modulation of the laser beam position is detected by the detector 14. A synchronous detector 32 determines the amplitude and phase of the modulation. These signals are used to set the operating point of the microscope. For example, in the repulsive (contact) region of interaction between the atoms on the tip and the atoms on the sample surface, the tip deflection is in phase with the modulation and the amplitude decreased by closer contact with the surface. Thus, the height of the tip is adjusted to give a constant, in phase, reduction of the modulation signal as the tip is scanned over the surface. A plot of these adjustments as a function of the position of the tip in the plane of the surface constitutes a topographical map of the surface taken at constant interaction-force-gradient.

Similar results may be obtained by applying the modulation signal to the scanning transducer. This is illustrated in Fig. 2. The components are the same as those shown in Fig. 1, to the exception of the second transducer 24 which is omitted in this case. The gap 28 is modulated directly by a signal 26 applied to the scanning transducer 18.

In these prior arts, the frequency of modulation is limited by the low-resonant frequency of the parts that are being displaced in the case of Fig. 1, this is the entire sample cell and in the case of Fig. 2, it is the entire scanning assembly. Furthermore, these complex assemblies, have many uncontrolled resonances, not all of which cause the tip to be displaced with respect to the surface, that do not exclusively depend on the properties of the cantilever and the interaction of the AFM tip with the sample, thus not appropriate for the AFM operation modes that require measurement of the resonance frequency of the cantilever beam. In the following, the term “cantilever beam” or “cantilever beam section” is used to refer to

the part of the cantilever that extends beyond a base or a chip of an AFM or HS-AFM supporting the cantilever.

For tapping mode, alternatively, the cantilever beam can be oscillated. A tip-oscillator, commonly formed of piezoelectric materials, shakes the AFM probe, as illustrated in Fig.3 of US5,412,980 (reproduced as Fig.7 of the drawings). This approach, even if it allows higher oscillation frequencies adequate for HS-AFM operation, creates uncontrolled resonances that do not change smoothly with frequency, thus, not appropriate for the AFM modes of operation that depend on the variation of the oscillation of the cantilever beam with frequency.

Additionally, these schemes make use of piezoelectric transducers which require high voltages for their operation, a requirement that imposes constraints when the microscope is operated in electrically conductive liquids.

HS-AFM (High-speed atomic force microscope) has been developed for fast scanning and permits direct observation of structure dynamics and dynamic molecular and atomic processes generally at a sub-second up to sub-100 ms temporal resolution and a ~2 nm lateral and 0.1 nm vertical resolution.

Typically, cantilevers of HS-AFM have a length of between 1 and 3 mm and cantilever beams of HS-AFM have a length of between 5 and 20 microns. For example, according to “A high-speed atomic force microscope for studying biological macromolecules” by Ando, T., et al., (Proceedings of the National Academy of Sciences of the United States of America, 2001. 98(22): p. 12468-12472), to achieve high-speed atomic force microscopy operation, the cantilever beam dimensions required are Width (W): 1 μ m, Length (L): 7 μ m, Thickness (h): 0.1 μ m.

The relatively small size and thus small weight of HS-AFM cantilevers allows them to reach extremely high frequencies of oscillation, about 1000 times greater than the cantilevers of conventional AFMs. For example, they have a resonance frequency of between 300 to 1500 kHz for application in liquid and of between 1200 and 5000 kHz in air.

The imaging rate of current HS-AFM may typically reach 15–50 frames per second (fps) for a scan range of ~240 $\times$ 240 nm² with 100 scan lines.

US 6,330,824 teaches to image a sample present in a solution using photothermal excitation of an AFM cantilever. The method comprises applying photothermal energy to the cantilever to cause it to vibrate and detecting the amplitude of vibration of the cantilever.

The latter has at least one coating present thereon to absorb the photothermal energy. However, photothermal action on HS-AFM cantilevers in water presents a slow time-constant and problems of stability of the excitation and demands the integration of complex optical modules in the structure of the microscope, as detailed in the article “Tip-sample distance control using photothermal actuation of a small cantilever for high-speed atomic force microscopy” by Yamashita et al. (Review of Scientific Instruments 78, 083702 (2007)). Such slow time-constant and low stability of the excitation is detrimental for the imaging.

US 6,134,955 discloses an AFM in which a thin film of a magnetic material is applied to one or both faces of the cantilever. The cantilever is then placed between the poles of an electromagnet and a magnetizing field applied in the direction of a soft axis of the cantilever. The magnetic field is generated by an AC voltage and causes a time varying force to be applied to the cantilever. The corresponding modulation of the cantilever's position is sensed by reflection of a laser beam into a position sensitive detector and is consistent with operation in fluids. However, the coating of magnetic material reduces the resonant frequency of the cantilever, which is detrimental to high-speed imaging. Furthermore, a magnetic coating may be instable in aqueous solutions, and exposed to rusting for example. Also, since the size of a HS-AFM cantilever is relatively small, the magnetic interaction may not be powerful enough to provide sufficient force to oscillate the cantilever. Commercial fabrication of magnetically coated HS-AFM was therefore never reported.

US 2010306885 discloses a conventional AFM sensor that includes a substrate, a cantilever and an electrostatic actuator. The latter includes a first electrode coupled to the cantilever adjacent its proximal end and a spaced apart second electrode that is in a fixed relationship relative to the substrate. When a voltage is applied between the first and second electrodes, the first electrode is drawn to the second electrode, thereby causing the distal end of the cantilever to move. Such sensor is not adapted for HS-AFM. Since the two electrodes are placed on a U-shaped structure, wherein one of the arms of the U-shape constitutes the cantilever of the AFM, this sensor cannot be fabricated using the existing technology at the precision and dimensions of few tens of microns required for HS-AFM operation.

WO2010/040873 discloses an electrostatic actuator for an AFM probe. The AFM probe comprises a microlever forming a first electrode and a second electrode fixed to microlever by a layer of silver epoxy®. The microlever assembly comprises an assembly

body covered partially by a metallic coating. An AC+DC voltage is applied on the one hand to the assembly body and the base, and on the other to the metallic coating. WO2005/008679 discloses an AFM probe comprising an electrically conductive coating positioned within a sealed liquid environment. The design of these documents is based on a two parallel plate electrode configuration. For this design, the force between parallel plate electrodes is given by $F = \frac{\text{Area electrodes}}{d^2} \frac{\epsilon V^2}{2}$ (eq.1), where d is the inter-electrode distance. Therefore, to have sufficient force F on the cantilever to actuate it, eq. 1 shows that the distance d between electrodes needs to be comparable or smaller than the dimensions (width, length) of the cantilever. Since the designs of D1 and D3 position the sample stage between the two parallel electrodes, it implies that the designs of D1 and D3 would require, for HS-AFM operation, the sample stage to be around 1mm in diameter and of thickness smaller than a few tens of microns. Such sample stage would be mechanically instable therefore D1 and D3 are not adapted for HS-AFM.

“Quartz-crystal scanning probe microcantilevers with a silicon tip based on direct bonding of silicon and quartz” discloses a quartz-crystal cantilever attached to a silicon base. This design requires cantilever with an area as large as those of the conventional AFMs, otherwise it is not possible to place two separate electrodes onto a single cantilever. In the case of the dimensions of a few tens of microns of the cantilevers of the HS-AFM, two electrodes cannot be plated, and thus the design cannot be used for HS-AFM.

US 2011010809 discloses a device for excitation of the cantilever of an AFM comprising a semiconductor material. The cantilever comprises a beam section in the form of a leaf spring and a fastening section manufactured in one piece with the leaf spring. The leaf spring is at least sectionally connected to a metal layer to form a Schottky contact, to which an electrical AC voltage is applied, while the sample is connected to ground. When the AC voltage is applied in the Schottky contact range, free resonant oscillations form along the leaf spring. The beam section which has a length typically of 100 to 500 micrometres, cannot be minimized to the dimensions of few-microns required for HS-AFM operation. All the metal coated HS-AFM cantilevers in the market present metallic coatings deposited on both sides of the cantilevers to create an almost stress-free and bending-free coating of the HS-AFM cantilevers, as described in the specifications of the cantilevers USC sold by the company Nanoworld <https://www.nanoandmore.com/AFM-Probe-USC-F1.2-k0.15>. The HS-AFM cantilevers require small spring constant from 0.1 to 1N/m to avoid damaging the

soft biological samples under observation. Provided the small dimensions and small spring constant of the HS-AFM cantilevers, in the case of being metallically coated only on one side, as is the case in US2011010809, the HS-AFM cantilever would suffer asymmetric stress that would bend excessively the cantilevers and would deviate excessively the reflection of the laser beam on the cantilever, thus not allowing HS-AFM operation. US 2011010809 is not adapted for use in HS-AFM. Furthermore, the complex patterns of the electrodes of US2011010809 cannot be fabricated on the small (tens of microns) dimensions of the HS-AFM cantilever.

EP 0 646 787 teaches a cantilever assembly for an AFM; comprising a cantilever made from a silicon oxide film joined on a silicon base and covered with an electroconductive reflective film, wherein the cantilever beam section protrudes from the base by a length of 120 to 150 microns. As in other prior art, in the case of inclusion of protective plates for protecting the cantilever beam against mechanical damage, the design of the cantilever beam is too complex to be minimized to the dimensions of few microns required for HS-AFM operation. Furthermore, EP 0 646 787 does not teach any mechanism to excite the oscillation of the cantilever beam.

There thus remains a need to further improve HS-AFM, especially but not exclusively for use in liquids.

Summary of the invention

Exemplary embodiments of the present invention relate to a probe structure for an atomic force microscope (AFM), the probe structure comprising:

- a semi-conductor chip,
- a metallic coating in contact with the chip,
- a cantilever supported by the chip, and
- at least one electrode being connected electrically to the metallic coating, so that the cantilever is caused to vibrate when an AC voltage is applied to the electrode.

The probe structure of the invention, particularly advantageous for HS-AFMs and also adapted for conventional AFMs, allows imaging to be performed in a liquid. Furthermore, there is no need to connect the sample nor any other component of the HS-AFM machine to the AC voltage source.

The invention allows achieving a clean excitation of the cantilever. In particular, the amplitude of oscillation may change smoothly with the frequency of the applied AC

signal of excitation, and the change of amplitude may exclusively depend on the properties of the cantilever and the interaction of the AFM tip with the sample. The oscillation of the cantilever may not depend on any uncontrolled factor. Thus, the invention provides an easier to implement solution to create a clean frequency-dependency of the oscillation of the cantilever.

The invention is particularly advantageous for AFM in operation modes that require precise measurement of the change in frequency of resonance of the cantilever.

Preferably, a beam section of the cantilever protrudes in cantilever fashion beyond the chip along a longitudinal axis of the beam section, for example by a distance of between 5 and 20 microns. The beam section is caused to vibrate when an AC voltage is applied to the electrode.

Exemplary embodiments of the present invention also relate to a probe structure for a high-speed atomic force microscope (HS-AFM). The present invention also allows excitation of cantilever beams of minimized dimensions required for HS-AFM operation.

The semi-conductor chip and the cantilever may be made of different material.

The semi-conductor chip preferably comprises silicon, and may be constituted by silicon.

The cantilever may be made of a non semi-conductor material, more preferably quartz.

In a variant, the chip and the cantilever are made of a same material. For example, they can be both made from a semi-conductor material.

The length of the cantilever is preferably between 1 and 3 mm.

The cantilever may be in contact with a first face of the semi-conductor chip by a fastening section that does not protrude beyond the chip. The cantilever may comprise a layer of silicon dioxide and the chip may comprise a layer of silicon.

The cantilever may be produced by thermal oxidation. Thermal oxidation is the result of exposing a silicon wafer to a combination of oxidizing agents and heat to make a layer of silicon dioxide (SiO₂). This layer is most commonly made using hydrogen and/or oxygen gas, although any halogen gas can be used. Silicon dioxide growth takes place on wafers in ambient air to about ~20Å (angstroms) thick; however, for most specifications thermal oxide growth may use a heat source in order to catalyze this reaction and create oxide layers up to 25,000Å thick. A process for thermally growing a silicon dioxide on a

silicon wafer is for example taught at the following webpage <https://www.svmi.com/custom-film-coatings/thermal-oxide>.

In a variant, the cantilever may be etched out using alternative microfabrication lithography approaches.

5 The probe structure may comprise at least one, for example a single electrode, connected electrically to the metallic coating. The AC voltage is applied between the electrode and the ground.

10 The metallic coating may cover all exposed surfaces of the chip and the cantilever. In other words, the assembly of the chip and the cantilever may be covered entirely by the metallic coating.

15 In a variant, the metallic coating may leave an exposed region uncovered by the metallic coating. The probe structure may comprise two electrodes. One of the electrodes may be situated on the exposed region of the chip and the other may be connected electrically to the metallic coating, so that the cantilever is caused to vibrate when an AC voltage is applied between the electrodes. Use of two electrodes respectively situated on the exposed region of the chip and connected electrically to the metallic coating may be advantageous for electrically sensitive samples.

 The exposed region is for example situated on the first face.

20 The metallic coating may cover at least partially, or entirely a second face of the chip, opposite to the first face. The metallic coating may cover at least a part of or all the surface of the chip situated between the first and second faces. The metallic coating may cover all the surface of the chip other than the first face. This may facilitate the coating operation of the chip by the metal of the metallic coating.

25 The metallic coating may cover a top face of the cantilever, opposite to a bottom face of the cantilever by which the cantilever is fixed to the chip. The metallic coating may cover all the surface of the cantilever except a region of the bottom face of the cantilever by which the cantilever is fixed to the chip. The presence of the metallic coating on the cantilever allows a laser beam to be reflected and the oscillation of the cantilever to be monitored optically, as is conventional.

30 In one embodiment, the metallic coating covers at least a part of, or all the outer surface of the assembly of the cantilever and the chip, except said exposed region.

The probe structure may further comprise a layer of an electrically conductive glue in contact with the second face of the chip. The electrode being connected electrically to the metallic coating may be situated on this layer of conductive glue.

In the case of the cantilever beams of the HS-AFM, it is not possible to plate two electrodes on a single cantilever beam because of their small dimensions.

The metallic coating may comprise or be constituted by gold, aluminum; chromium-gold alloy; gold; chromium-cobalt alloy or conductive diamond.

The probe structure may comprise a tip, for example situated near a free end thereof. The tip is preferably situated on the top face of the cantilever.

The tip may be etched out using lithography microfabrication approaches. In a variant, the tip is deposited or grew using an electron beam and a carbon rich atmosphere, as taught in the article “Automated wafer-scale fabrication of electron beam deposited tips for atomic force microscopes using patter recognition” published on 1 July 2004, in Nanotechnology, Volume 15, Number under the number DOI: 10.1088/0957-4484/15/9/005. For the fabrication of the HS-AFM probes both approaches may be used.

The probe structure may comprise a liquid barrier, for example made of a waterproof material, situated above the cantilever and the chip. The liquid barrier is preferably hydrophobic. For example, the water barrier made be made from a PTFE paste. This hydrophobic paste may be spread on top of the chip and the cantilever.

The liquid barrier, when observed in top view along a direction perpendicular to the first face, preferably extends along a direction perpendicular to the longitudinal axis of the cantilever. The water barrier may be linear or curved when observed in top view.

The exposed region and the tip are preferably situated on different sides of the liquid barrier, so that the exposed region is not in contact with the liquid when the sample is immersed in the liquid when being scanned by the AFM.

For non-electrically sensitive samples, one electrode electrically connected to the metallic coating is possible, and the probe structure may be deprived of the water barrier in this case.

Exemplary embodiments of the present invention also relate to an atomic force microscope (AFM), in particular a HS-AFM, comprising a probe structure according to the invention.

Exemplary embodiments of the present invention also relate to a method for the excitation of a cantilever of an atomic force microscope (AFM) comprising a probe structure as defined above, where the cantilever is caused to vibrate by applying an AC voltage to the electrode(s).

5 The applied AC voltage has preferably a frequency of between 300 and 1500 kHz and an amplitude of between 20 and 200 V. The AC voltage is preferably a pure sinus waveform.

 The probe structure of the present invention may be obtained by modifying an existing probe structure. For example, the exposed region can be obtained by partial removal
10 of an electroconductive film on the chip. Such an electroconductive film is for example taught in EP 0 646 787. The electrode(s) and the liquid barrier if necessary may be added in order to obtain a probe structure according to the invention.

 In one variant, a portion of the cantilever may be scratched out at its end opposite to its free end, for example using a diamond pen, in order to expose the chip.

15 Exemplary embodiments of the present invention also relate to a method for scanning a biological or chemical sample immersed in a liquid using the atomic force microscope made in accordance with the present invention.

 Specific embodiments of the invention will now be described in some further detail with reference to and as illustrated in the accompanying figures. These embodiments
20 are illustrative only, and not meant to be restrictive of the scope of the invention.

Detailed description of the illustrated figures

- Fig.1 and Fig.2 already described are schematic views of atomic force microscopes of prior art;

25 - Fig.3 is a schematic view of a probe structure made in accordance with the present invention,

- Fig.4 and 5 shows a variant of a probe structure made in accordance with the present invention,

- Fig.6 is a bloc view of an example of AFM according to the present invention,

30 - Fig.7 is a functional bloc diagram of an AFM of prior art in tapping mode.

 An example of a probe structure 1 according to the present invention is illustrated in Fig.3.

As shown, the probe structure 1 comprises an assembly 12 comprising a cantilever 13 attached to a first face 81 of a chip 80 by a fastening section 17. The cantilever 13 comprises a beam section 19 protruding beyond the chip 80 in cantilever fashion along a longitudinal axis X.

5 The chip 80 may be made of silicon and the cantilever 13 of quartz.

A tip 30 is formed on a top face 51 of the cantilever 13 opposite a bottom face 52 by which the cantilever 13 is fixed to the chip 80.

The tip can be made of a same material as the cantilever.

10 In a variant, the tip can be made of a different material as the cantilever. For example, for the HS-AFM, the tip may be made of Electron Beam Deposited (EBD) Carbon. In a variant, a High Density Carbon or Diamond Like Carbon (HDC or DLC), or a mixture thereof may be used.

15 For example, an ultra-short cantilever (USC) for fast-/high-speed AFM of the type USC-F1.5-k0.6, USC-F1.2-k0.15 or USC-F0.3-k0.3 sold by the Company NanoWorld may be used. Details of these USC are for example taught on the webpage <https://www.nanoworld.com/ultra-short-cantilevers-afm-tips>.

20 In the illustrated embodiment, the cantilever 13 is covered by a metallic coating 42, preferably gold, all over its top face 51 and over the bottom face 52 of the beam section 76. The chip 80 is entirely covered by this metallic coating except where the fastening section 17 of the cantilever 13 is present and at an exposed region 78 on the first face 81.

The metallic coating extends over a second face 82 opposite the first face 81 and over the lateral surface 83.

In the illustrated embodiment, the second face 52 of the chip 80 is further in contact with a conductive glue 38, for example a silver-based glue.

25 Two electrodes 91, 92 are formed respectively on the exposed region 78 and on the conductive glue 38.

In a variant (not shown), the electrodes 91, 92 are formed respectively on the exposed region 78 and on the metallic coating directly.

30 The probe structure in the illustrated embodiment also comprises a liquid barrier 32. This liquid barrier 32 is situated above the fastening section 17 of the cantilever 13 and may extend in a direction perpendicular to the longitudinal axis of the beam section of the cantilever.

The liquid barrier 32 may have a height h greater than 500 microns.

The cantilever beam section 19 may protrude beyond the chip 80 by a distance d of between 5 and 20 μm , measured along its longitudinal axis X. Preferably, the cantilever 13 has a total length L of between 1 and 3 mm, measured along its longitudinal axis X. The thickness e of the HS-AFM cantilever beam section 19 ranges preferably from 0.05 to 0.2 μm .

The metallic coating 42 may have a thickness of between 5 and 50 nm.

Without being bound by a theory, when an AC voltage generated by an AC voltage source 62 is applied between the electrodes 91, 92, mechanical oscillations are generated by electrostatic repulsive interactions that propagate along the cantilever 13 and cause the tip 30 to oscillate, as further explained below. In the variant of Fig.4 and 5, the probe structure comprises a single electrode 92 connected to the metallic coating 42. The semi-conductor chip 80 is covered entirely by the metallic coating 42.

As shown in Fig.4, when a voltage is applied between the metallic coating 42 and the ground G, a layer of positive charge is formed on the metallic coating 42, which creates a repulsive force between the bottom face 52 of the beam section 76 and a section of the lateral surface 83 of the chip 14 adjacent to the bottom face 52 of the beam section 76.

Thus, when the voltage applied is an AC voltage, for example by an AC voltage source as illustrated in Fig.5, variation of the voltage results in variation of the repulsive force and therefore generate mechanical oscillations that propagate along the cantilever 13.

Fig. 6 is a bloc view of an example of an HS-AFM according to the invention. The HS-AFM may comprise an XYZ actuator 105 configured for moving the probe structure 1 in relation to a sample 115. A detector 125 which is preferably an optical detector, for example a photodiode, senses a laser beam generated by a laser 320 and reflected by the beam section of the cantilever 13, and therefore allows the position and motion of the cantilever 13 to be monitored.

A signal processor 130 processes signals from detector 125 and generates a cantilever deflection signal 135 or, for tapping, non-contact and multifrequency mapping operation AFM modes, a signal 135 of the oscillation of the cantilever beam at different frequencies. The signal processor may include, for example, low-pass filters, differencing circuits, trans-impedance amplifiers, etc.

An amplifier 145 may amplify the difference between the signal 135 from the cantilever and a set point input 141. The output of the amplifier 145 may be connected to the XYZ actuator 105, for example via a gain control 150 and high voltage amplifier 155, thus forming a feedback loop.

5 The feedback loop may be set to maintain a measured parameter, for example a force between the tip of probe structure 1 and the sample 115, constant. Closed-loop operation modes may incorporate feedback to keep a tip-sample interaction constant as the XYZ actuator 105 scans the cantilever and tip across a sample surface.

10 The HS-AFM may also operate in an open- loop mode. In this case a signal, for example a linear ramp, may replace the constant set point input 141 to amplifier 145, causing XYZ actuator 105 to move the tip relative to the sample without feedback control. Open-loop operation is useful, for example, during the acquisition of force curves, rapid characterization of cantilevers that are not interacting with a sample, or for other purposes.

15 The invention is not limited to any particular detection and processing of the oscillation of the cantilever.

 Various changes may be brought to the probe structure without departing from the scope of the invention.

 For example, the beam section of the cantilever may not be immersed in a liquid.

CLAIMS

1. A probe structure for an atomic force microscope (AFM), the probe structure comprising:

- 5 - a semi-conductor chip (80),
 - a metallic coating (42) in contact with the chip,
 - a cantilever (13) supported by the chip having a cantilever beam section extending beyond the chip, and
 - at least one electrode (92) being connected electrically to the metallic coating, so that
10 the cantilever beam section is caused to vibrate when an AC voltage is applied to the electrode.

2. The probe structure of claim 1, the semi-conductor chip (80) comprises silicon.

3. The probe structure of claim 1 or 2, the cantilever being made of a material
15 different from the chip.

4. The probe structure of any one of the proceeding claims, the cantilever (13) being made of a non semi-conductor material, preferably quartz.

5. The probe structure of any one of the proceeding claims, the cantilever (13) being fixed to a first face (81) of the semi-conductor chip (80) by a fastening section (17),
20 the metallic coating (42) covering at least partially a second face (82) of the chip (80), opposite to the first face (81), preferably, the metallic coating (42) covering at least partially the surface of the chip (80) between the first (81) and second (82) faces.

6. The probe structure of any proceeding claim, the length (L) of the cantilever (13) being preferably between 1 and 3 mm, a cantilever beam section (19) of the cantilever
25 (13) preferably protruding beyond the chip along a longitudinal axis (X) of the cantilever (13) by a distance (d) of between 5 and 20 microns, the thickness (e) of the cantilever beam section (19) ranging preferably from 0.05 to 0.2 μm .

7. The probe structure of any one of the proceeding claims, the metallic coating (42) covering all exposed surfaces of the semi-conductor chip (80) and the cantilever (13).

30 8. The probe structure of any one of the proceeding claims, the metallic coating leaving an exposed region (78) uncovered by the metallic coating, the probe comprising two

electrodes (91, 92), one (91) of which being situated on the exposed region (78) of the chip and the other (92) being connected electrically to the metallic coating.

9. The probe structure of the proceeding claim, the metallic coating (42) covering at least partially the outer surface of the assembly of the cantilever and the chip
5 except at said exposed region (78).

10. The probe structure of claim 8 or 9, comprising a liquid barrier (32) situated above the cantilever (13) and the chip (80).

11. The probe structure of claim 10, the exposed region (78) and a probe tip (30) of the cantilever being situated on different sides of the liquid barrier (32).

10 12. An atomic force microscope (AFM) comprising a probe structure according to any one of claims 1 to 11.

13. The AFM according to claim 12, the AFM being a HS-AFM.

14. A method for the excitation of a cantilever (13) of an atomic force microscope (AFM) comprising a probe structure (1) according to any one of claims 1 to 11, the frequency
15 of the applied AC voltage being between 300 and 1500 kHz, the amplitude of the AC voltage being between 20 and 200 V.

15. A method for scanning a biological or chemical sample immersed in a liquid using an atomic force microscope (AFM) of claim 12.

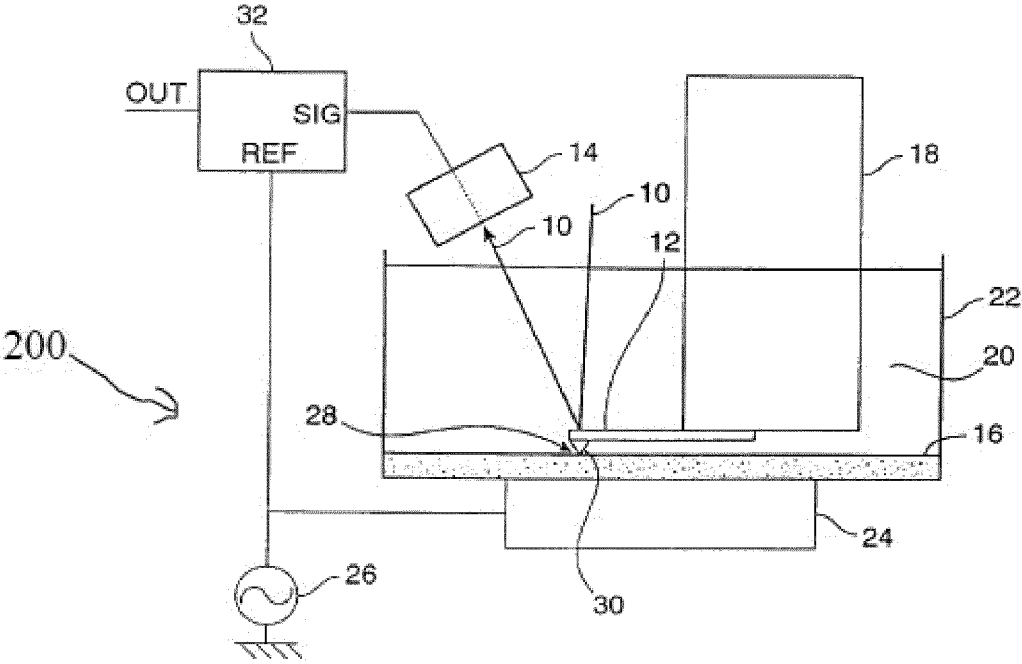


FIG. 1
PRIOR ART

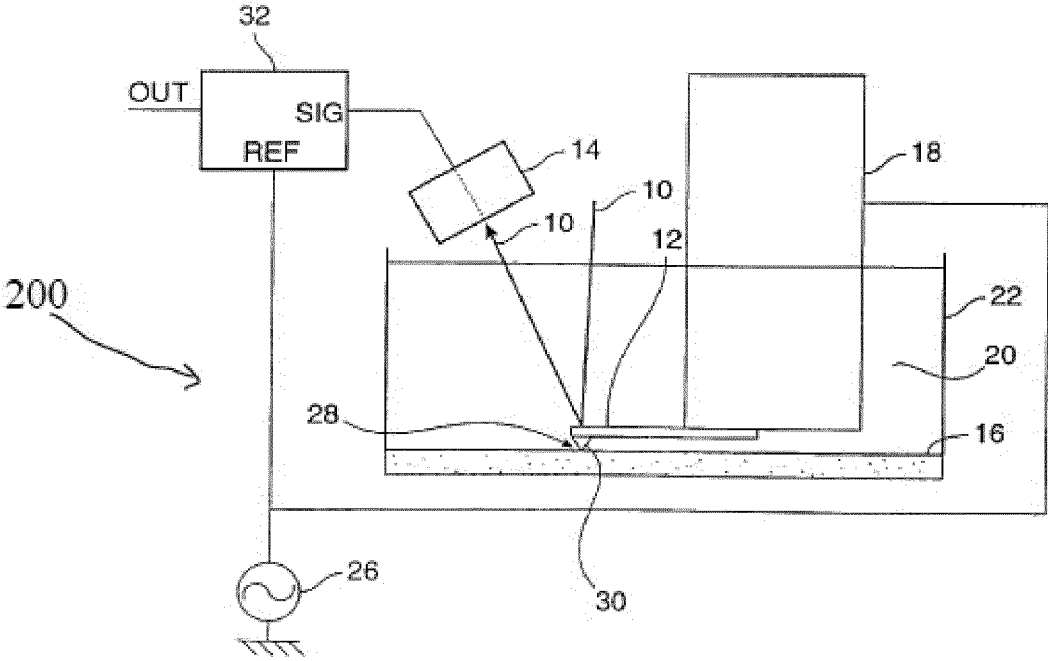
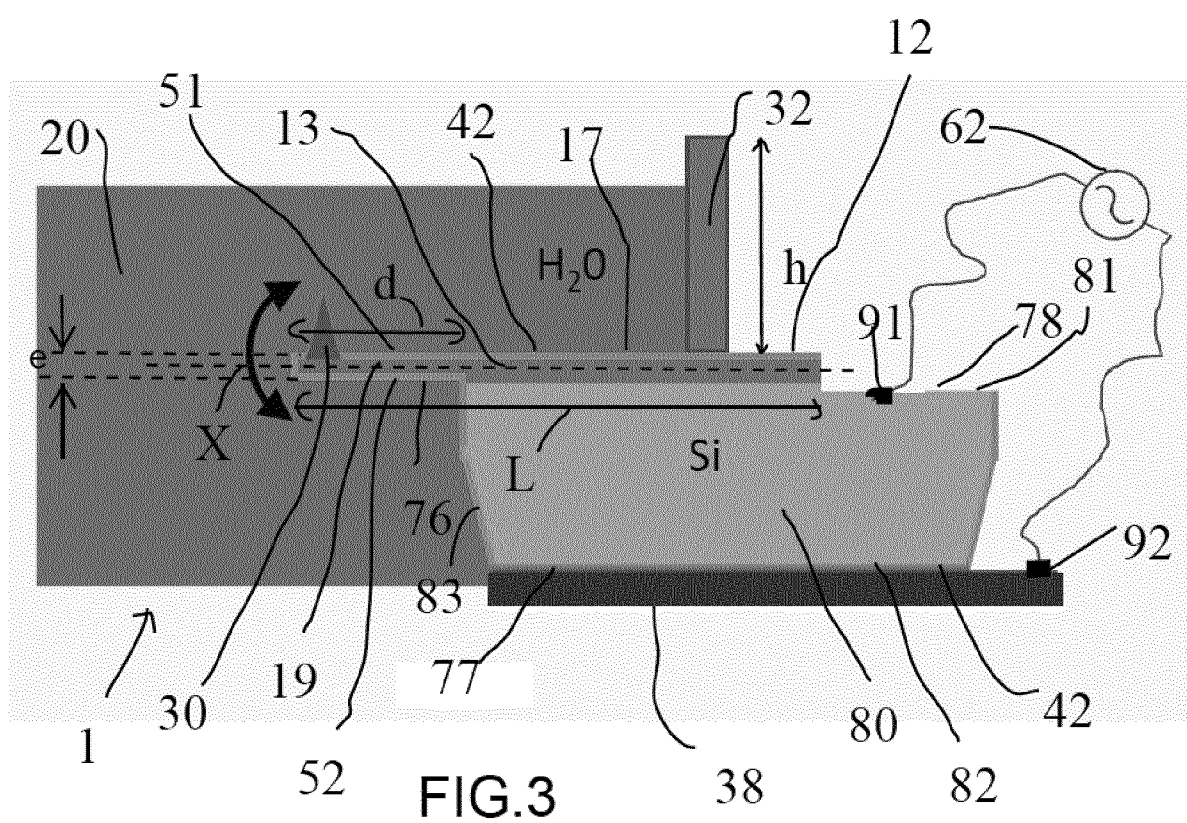


FIG. 2
PRIOR ART



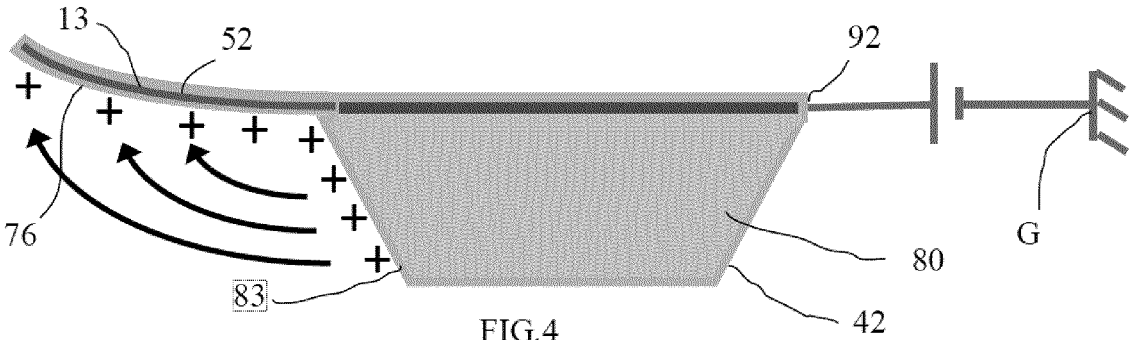


FIG.4

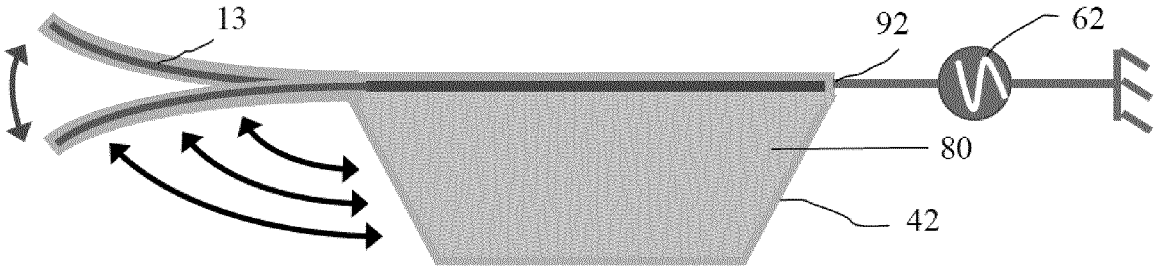


FIG.5

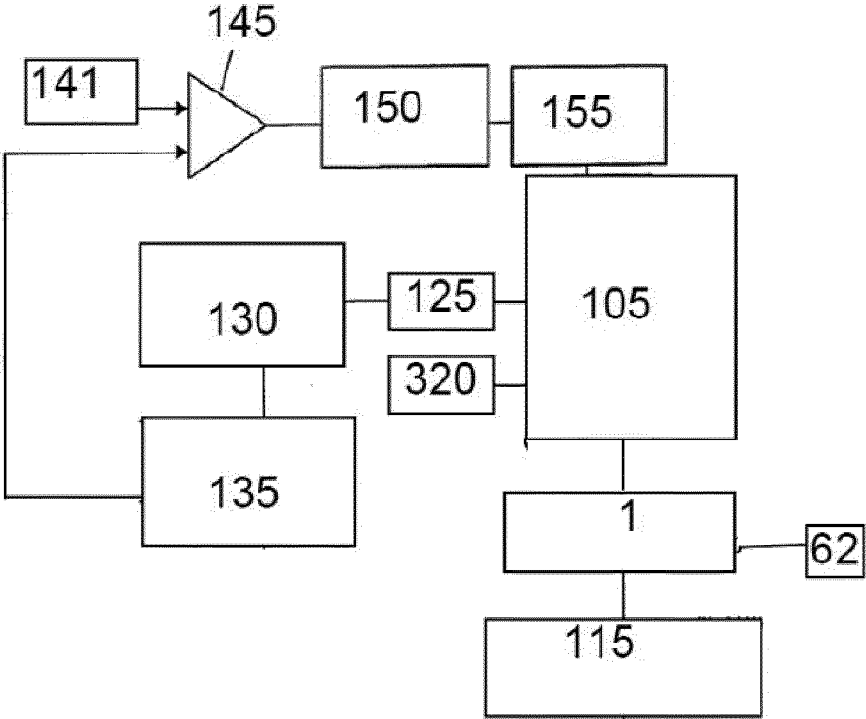


FIG.6

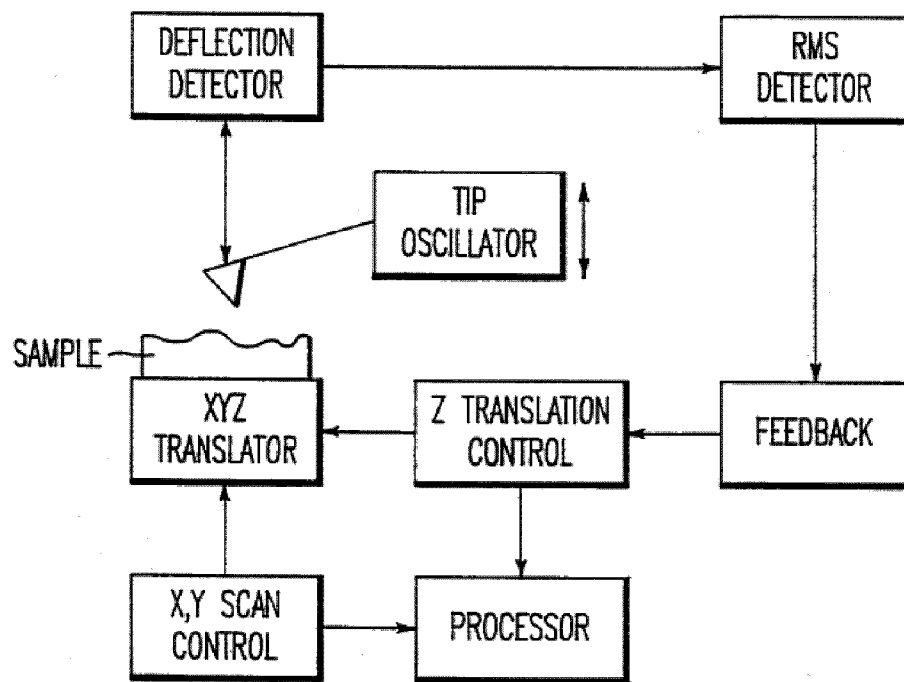


FIG.7
PRIOR ART

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/087287

A. CLASSIFICATION OF SUBJECT MATTER INV. G01Q10/04 G01Q30/14 G01Q60/32 G01Q60/38 G01Q70/14 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) G01Q		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/040873 A1 (UNIV MADRID POLITECNICA [ES]; IZPURA TORRES JOSE IGNACIO [ES] ET AL.) 15 April 2010 (2010-04-15) cited in the application	1-3, 6-9, 12-14
Y	figures 1,2	4, 5, 10, 11
A	page 2, line 26 - line 28 page 6, line 7 - page 8, line 27 ----- -/-	15
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 7 April 2022		Date of mailing of the international search report 21/04/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Polesello, Paolo

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2021/087287

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	AKIHIRO TAKAHASHI ET AL: "Quartz-crystal scanning probe microcantilevers with a silicon tip based on direct bonding of silicon and quartz", NANOTECHNOLOGY, INSTITUTE OF PHYSICS PUBLISHING, GB, vol. 21, no. 40, 8 October 2010 (2010-10-08), page 405502, XP020182079, ISSN: 0957-4484 cited in the application figures 1,2 paragraph [0002] -----	4, 5
Y	WO 2005/008679 A1 (UNIV BRISTOL [GB]; HUMPHRIS ANDREW DAVID LAVER [GB] ET AL.) 27 January 2005 (2005-01-27) cited in the application figure 6 page 19, line 17 - line 25 -----	10, 11
X	US 2010/306885 A1 (DEGERTEKIN FAHRETTIN L [US]) 2 December 2010 (2010-12-02) cited in the application figures 1-3 paragraph [0028] - paragraph [0031] -----	1-4, 6, 12, 15
A		5, 7-11, 13, 14

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2021/087287

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