Microprobe chip for detecting evanescent waves and method for making the same, probe provided with the microprobe chip and method for making the same, and evanescent wave detector, nearfield scanning optical microscope, and information regenerator provided with the microprobe chip

Mikrosonden-Chip zum Wahrnehmen von evaneszenten Wellen und Verfahren zu dessen Herstellung, Sonde mit diesem Mikrosonden-Chip und deren Herstellungsverfahren sowie evaneszente Wellensonde, optisches Nahfeld-Abtastmikroskop und Informationsregenerator mit dem Mikrosonden-Chip

Microsonde-puce pour détecter les ondes et procédé pour sa fabrication, capteur utilisant une telle microsonde-puce et procédé pour sa fabrication, ainsi que capteur d'ondes évanescentes et procédé pour sa fabrication, microscope de balayage optique de champs proche, et régénératrice d'informations pourvu d'une telle microsonde-puce.
Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a microprobe chip for detecting evanescent waves which is used in near-field scanning optical microscopes and a method for making the same, a probe including a thin film cantilever provided with the microprobe chip and a method for making the same, an evanescent wave detector, a near-field scanning optical microscope, and an information regenerator provided with the microprobe chip. In particular, the present invention relates to a microprobe chip having a tip with a small curvature, which is suitable for these apparatuses, and a method for making the same which is capable of producing the microprobe chip with high productivity.

Related Background Art

[0002] A scanning tunnel microscope (hereinafter referred to as a STM) was developed by G. Binning et al. in 1983 (Phys. Rev. Lett., 49, 57 (1983)). The STM can directly observe electronic structures of surface atoms on conductive materials, such as single crystals and amorphous materials and can obtain real space images with high resolution. Thus, various scanning probe microscopes (hereinafter referred to as SPMs) have been intensively investigated in microstructure analysis of materials.

[0003] Examples of SPMs include scanning tunnel microscopes (STMs), atomic force microscopes (AFMs), magnetic force microscopes (MFMs), and near-field scanning optical microscopes (NSOMs), which detect the surface structure of a material by means of changes in tunnel currents, atomic forces, magnetic forces, and light intensities, respectively. Such changes occur when scanning near the surface of the material with probes provided with microprobe chips.

[0004] Among these SPMs, NSOMs permit nondestructive measurement of fine patterns on tested materials with high resolution, that is, a positional resolution of less than \( \lambda / 2 \), which has not been achieved by conventional optical microscopes, by using evanescent light radiated from a fine pinhole. Further, NSOMs are applicable to various materials, which have not been observed by any conventional method, such as organisms and biological cells.

[0005] The evanescent waves are detected by the following three methods.

[0006] The first method was developed by E. Betzig, et al. ("Collection mode near-field scanning optical microscopy", Appl. Phys. Lett. 51(25), pp. 2088-2090 (1987)). Illuminating light is incident on the back surface of a test piece so as to satisfy the total reflection condition, and the evanescent waves occurring on the front surface of the test piece by the illuminating light are detected with a microprobe chip provided with a fine aperture. This method is capable of obtaining evanescent wave images with high resolution, and thus has been most intensively studied.

[0007] The microprobe chip is composed of a glass pipette or optical fiber of which the tip is pointed. It is therefore fabricated by mechanical polishing or the like with low productivity and high production costs. Further, the aperture is hardly ever formed with satisfactory reproducibility and high accuracy.


[0009] A typical microprobe chip used in the second method and a method for making the microprobe chip are disclosed in U. S. Patent No. 5,221,415, in which the microprobe chip is formed by anisotropic etching of single-crystal silicon in the crystal axes by means of a semiconductor production process. As shown in Figure 1, a pit 518 is formed on a silicon wafer 514 covered with silicon dioxide masks 510 and 512 by an anisotropic etching process, the silicon dioxide masks 510 and 512 are removed, and then the silicon wafer 514 is covered with silicon nitride layers 520 and 521. The silicon nitride layer 520 has a pyramidal pit 522 on the pit 518. After the silicon nitride layer 521 on the bottom surface is removed, a glass plate 530 provided with a sawcut 534 and a Cr layer 532 is joined to the silicon nitride layer 520. The silicon wafer 514 is removed by etching. As a result, a probe consisting of a microprobe chip and a cantilever which are composed of silicon nitride is replicated on a mounting block. When the probe is used in an optical lever-type AFM, a metal film 542 as a reflecting film is formed on the bottom surface. The probe can be produced with high productivity and reproducibility and has a pointed tip. The probe, however, forms a lower resolution NSOM image than that of the probe with an aperture produced by the first method.

[0010] In the first and second methods, the microprobe chip is used as an optical pickup and the scattered evanescent-wave light is amplified by a photomultiplier cell provided above the microprobe chip. On the other hand, the third method involves direct detection of scattered evanescent-wave light using a photodiode on a thin film cantilever (S. Akamine, et al., "Development of a microphotocantilever for near-field scanning optical microscopy", Proceedings IEEE Micro Electro Mechanical Systems Workshop 1995, pp. 145-150). Figure 2 is a cross-sectional view of a microprobe chip produced by the third method. The microprobe chip consists of a p-silicon thin film cantilever 601 of which one end is supported by a silicon substrate 600, a photodiode of pn junction 603 formed by providing an n layer 602, a silicon oxide film 604 provided thereon, and an aluminum wiring layer 605.
provided on the silicon oxide film 604 which extracts scattered light signals from the photodiode. The lower face of the thin film cantilever is provided with an etch stop layer 606 which is used for producing the cantilever.

[0011] It is possible for the photodiode optical detector provided on the free end of the cantilever to approach the test piece, hence the SN ratio and resolution can be improved. Further, the photodiode optical detector can simplify the system configuration. In the third method, however, the thin film cantilever as a microprobe chip is produced by a photolithographic process and an etching process with poor reproducibility, hence microprobe chips having the same shape cannot be produced in the same production lot.

[0012] DE-A 43 29 985 discloses a microprobe chip for detecting evanescent waves, comprising: a photoconductive material and a substrate for supporting said photoconductive material, which is part of a microprobe, said photoconductive material being connected to electrodes formed on said substrate. Further, said document discloses an apparatus for detecting evanescent waves comprising such a microprobe chip on a substrate provided with electrodes thereon, a means for applying a voltage to said microprobe chip through said electrodes; and a means for detecting photocurrent flows in said microprobe chip through said electrodes, wherein said evanescent waves are detected as said photocurrent flows.

SUMMARY OF THE INVENTION

[0013] It is an object of the present invention to solve the above-mentioned problems of the prior art technologies.

[0014] It is another object of the present invention to provide a microprobe chip for detecting evanescent waves having a high SN ratio and a high resolution and a method for making the same, a probe provided with the microprobe chip and a method for making the same, an evanescent wave detector, a near-field scanning optical microscope, and an information regenerator which are provided with the microprobe chip and which have simplified system configurations.

[0015] It is a further object of the present invention to provide a method for making with high reproducibility a microprobe chip having a pointed tip for detecting evanescent waves, and a method for making a probe provided with the microprobe chip.

[0016] It is still another object of the present invention to provide a method for making a microprobe chip for detecting evanescent waves which permits reuse of a female mold and high yield and low cost production, and a method for making a probe in which the microprobe chip is provided on a thin film cantilever. These objects are achieved by the microprobe chip according to claim 1, the probe provided with a microprobe chip according to claim 8, the apparatus for detecting evanescent optical waves according to claim 9, and the method of making a microprobe chip according to claim 12. The other claims relate to further developments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figures 1A to 1G are cross-sectional views of main steps of a method for making a prior art microprobe chip;

Figure 2 is a cross-sectional view of a prior art microprobe chip;

Figure 3A is an isometric view of an evanescent wave detecting apparatus in accordance with the present invention; Figure 3B is a block diagram of a near-field scanning optical microscope in accordance with the present invention;

Figures 4A to 4G are cross-sectional views of manufacturing steps of a microprobe chip in accordance with Embodiment 1 of the present invention;

Figures 5A to 5F are cross-sectional views of manufacturing steps of a microprobe chip in accordance with Embodiment 2 of the present invention;

Figures 6A to 6F are cross-sectional views of manufacturing steps of a microprobe chip in accordance with Embodiment 3 of the present invention;

Figures 7A and 7B are a top view and a side view, respectively, of a probe for detecting evanescent waves in accordance with the present invention;

Figures 8A to 8D are cross-sectional views of manufacturing steps of a microprobe chip in accordance with Embodiment 4 of the present invention; and Figure 9 is a block diagram of a near-field scanning optical microscope provided with the microprobe chip of the Embodiment 4 in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] In the present invention, the microprobe chip is formed of a photoconductive material, hence the microprobe chip functions as a photodetector with a high SN ratio and a high resolution. Further, the photoconductive layer formed on the peeling layer on the first substrate is transferred onto the junction layer on the second substrate. The microprobe chip can therefore be produced by the junction and transferring steps with great ease, high accuracy, and high productivity, without removing the first substrate by etching. Since the photoconductive layer, or the peeling layer and the photoconductive layer are formed after the transferring step, the first substrate as the female mold can be repeatedly used. The use of such a female mold enables the reduction in the production costs and an improvement in the reproducibility of the shapes of microprobe chips in the continuous production.

[0019] Preferably, the first substrate is composed of single-crystal silicon, and an indented section composed
of a plane (111) is formed on the first substrate by anisotropic crystal-axis etching. Since the material for the microprobe chip is deposited on the single-crystal substrate with the indented section, the tip of the microprobe chip is pointed. When a plurality of microprobe chips are formed using the same substrate, the pointed tips are regular in shape, and thus the microprobe chips are uniform in characteristics.

**[0020]** The curvature of the tip of the microprobe chip can be reduced by forming a silicon oxide (SiO₂) film by means of thermal oxidation of the silicon first substrate. The thickness of the silicon dioxide film depends on the shape of the silicon substrate. The curvature is therefore determined by controlling the thickness of the silicon oxide film formed by the thermal oxidation.

**[0021]** Materials suitable for the peeling layer must readily peel from the photoconductive layer and the first substrate, in other words, the materials must have little reactivity and contact characteristics with the photoconductive layer and the first substrate. Preferable materials may be selected from various metals, semiconductors, and insulators in view of a combination of the photoconductive layer and the first substrate. For example, when an amorphous inorganic semiconductor is used as the photoconductive material, it is preferable that the peeling layer be a noble metal, such as platinum or an alloy thereof, which is not reactive to and does not come into contact with the photoconductive layer. When a silicon substrate is used, a preferable material for the peeling layer is silver. Since silver having a high light reflectance, however, inhibits transmission of the evanescent waves into the photoconductive layer, the silver peeling layer on the photoconductive layer must be removed after removing the first substrate.

**[0022]** The peeling layer is formed on the indented section of the first substrate by a thin film deposition process so that the thickness of the peeling layer does not significantly change. The shape of the indented section can thereby be maintained. Examples of thin film deposition processes having high reproducibility of the film thickness include vacuum processes, such as resistance heating evaporation processes, electron beam evaporation processes, chemical vapor deposition (CVD) processes, and sputtering processes.

**[0023]** The photoconductive material absorbs the incident light and form an electric charge without a pn barrier or a depletion layer. A voltage is applied between the two ends of the photoconductive material, and the formed electric charge is detected as a photocurrent by a current detecting unit. In the present invention, using the photoconductive characteristics of the photoconductive material, the photoconductive layer of the microprobe chip absorbs the evanescent waves scattered from the surface of the test piece, and the photocurrent formed by the voltage applied to the photoconductive layer is detected. The information on the surface of the test piece is therefore detected as a change in the photocurrent.

**[0024]** Since the photoconductive layer is formed on the indented section provided on the first substrate, it is preferable that the photoconductive layer is formed by a thin film deposition process. Amorphous inorganic semiconductor materials, such as amorphous silicon and amorphous chalcogenide, are preferably used as materials for forming the photoconductive layers, since they can easily form the photoconductive layers at lower temperatures. Organic photoconductive materials are also preferable because they are superior to the amorphous inorganic semiconductor materials in mass-productivity, production costs, and safety.

**[0025]** The junction layer is formed on the substrate or the thin film cantilever, and preferably is composed of a metallic material, since electrodes provided for leading the formed photocurrent are generally used as the junction layers to simplify the production process. The photoconductive layer is preferably joined to the junction layer by a direct joining process. When using amorphous silicon as the photoconductive layer, for example, materials forming silicide are selected for the junction layer.

**[0026]** When using materials, such as organic materials, which are generally not reactive with metals, for forming the photoconductive layer, a metallic layer may be provided between the photoconductive layer and the junction layer to assist joining them.

**[0027]** The junction layer and the electrodes for leading the photocurrent may be formed by known thin film deposition processes, such as vacuum deposition processes, sputtering processes, CVD processes, plating processes, and coating processes, and may be patterned into a given pattern by photolithographic and etching processes.

**[0028]** In the present invention, a cantilever-type probe having a free end provided with a microprobe chip can be fabricated as follows. A thin film which will be used as a thin-film cantilever later is formed on the second substrate, and a patterned junction layer is formed on the thin film at the position which functions as the free end. After the photoconductive layer with the peeling layer is transferred by joining to the junction layer, the part of the second substrate which lies under the thin-film cantilever is removed so that one end of the thin-film cantilever is fixed to the second substrate. A cantilever-type probe having a free end provided with a microprobe chip is thereby obtained.

**[0029]** The indented shape on the first substrate is replicated to the microprobe chip with high reproducibility, and a gap is formed between the photoconductive layer and the junction layer. The microprobe chip provided at the free end of the thin film cantilever is lightweight, and thus the resonant frequency of the cantilever with the microprobe chip is not decreased.

**[0030]** Embodiments of the present invention will now be described in detail with reference to the attached drawings.
[Embodiment 1]

[0031] Figure 3A is an isometric view of an evanescent wave detector including a microprobe chip in accordance with the present invention, and Figure 3B is a block diagram of a near-field scanning optical microscope using the evanescent wave detector. As shown in Figure 3A, the evanescent wave detector includes a second substrate 12, a microprobe chip 20 composed of a pyramidal photoconductive material, electrodes 10 and 11 provided on both ends of the microprobe chip 20, an electric power source 14 which applies a bias voltage to the electrodes 10 and 11, and a current detector 15 which detects the evanescent waves absorbed in the microprobe chip as photocurrent flows.

[0032] The near-field scanning optical microscope provided with the evanescent wave detector includes, as shown in Figure 3B, a prism 153 which performs as a specimen table, a piezoelectric device 145 which drives the evanescent wave detector in the X, Y and Z directions, an XYZ driver 157 which controls driving of the piezoelectric device 145, and a signal processing circuit 155 which processes signals from the current detector 15 in Figure 3A and feeds the processed information to a display device 156. The specimen fixed on the prism 153 is irradiated by laser beams 150 for NSOM from the rear surface such that the incident laser beams are totally reflected on the surface, under the specimen, of the prism. Since the near-field scanning optical microscope in accordance with the present invention does not require a photoelectric converter, such as a photomultiplier, the system configuration is simplified.

[0033] Figures 4A to 4G are cross-sectional views of processes of a method for making the microprobe chip in this embodiment. As shown in Figure 4A, a silicon wafer with a <100> crystal orientation is prepared as a first substrate, wherein silicon dioxide films as protective layers 2 are previously formed on both surfaces of the first substrate 1 by thermal oxidation in an oxidative gas atmosphere. A photoresist layer is formed thereon as a mask by a photolithographic process, and a given place with a 3-μm by 3-μm area of the upper protective film 2 is removed by etching with an aqueous HF solution to expose the silicon film. The protective layer 2 is resistant to etching solutions, and protects the other regions of the surfaces of the silicon film when the first substrate 1 is subjected to anisotropic etching to form an indented section 3 which is used as a female mold of the microprobe chip. After the photoresist layer is removed, the first substrate is immersed into an aqueous 27% potassium hydroxide solution at 80 °C to form the indented section 3, which has a reverse pyramidal shape and consists of (111) crystal planes, by the anisotropic etching.

[0034] After removing the protective layers 2 by etching with an aqueous HF solution, a peeling layer 4 composed of a 50-angstrom Ti layer and a 700-angstrom Pt layer is formed on the entire upper surface including the indented section 3 of the first substrate 1 by a sputtering process using Ti and Pt targets, as shown in Figure 4B.

[0035] Next, as shown in Figure 4C, a photoconductive film 5 with a 1-μm thickness composed of amorphous silicon is deposited on the entire surface of the peeling layer 4 by a plasma CVD process using a silane gas. The photoconductive film 5 will be used as a microprobe chip later.

[0036] A resist pattern is formed thereon by a photolithographic process including applying, exposing and developing of a resist, the photoconductive film 5 is etched by a reactive ion etching process with gaseous CF₄ using the photoresist layer as a mask, and then the photoresist layer is removed. A patterned photoconductive layer 7 as shown in Figure 4D is thereby formed.

[0037] A Pyrex glass (trade name: #7059, made by Corning Incorporated) is prepared as a second substrate 12, a 50-angstrom Cr layer, and a 1,000-angstrom Au layer are separately deposited onto the second substrate by an electron beam evaporation process, and are patterned by photolithography and etching to form electrodes 10 and 11, as shown in Figure 4E. The electrodes function as junction layers between the substrate and the microprobe chip.

[0038] The photoconductive layer 7 provided on the first substrate 1 is put into contact with the electrodes 10 and 11 by inverting the first substrate 1, as shown in Figure 4F, and allowed to stand at 100 °C for 1 hour. Heating while pressing the first and second substrates helps formation of silicide by the reaction of Au with silicon at the interface between the photoconductive layer 7 and the electrodes 10 and 11. As a result, the photoconductive layer 7 is joined to the electrodes 10 and 11. Finally, the substrate 1 with the peeling layer is removed, as shown in Figure 4G. A microprobe chip is formed in such a manner. Since Au is highly reactive with silicon as compared with Pt, the interface between the Pt layer and the amorphous silicon layer will peel off when the first substrate is removed from the second substrate. Since glass is used as the second substrate in the present invention, the photoconductive layer 7 can be easily positioned.

[0039] The microprobe chip 20 in accordance with the present invention was observed with a scanning electron microscope (SEM). The tip had a replicated shape of the reverse-pyramid which was formed by anisotropic etching of crystal silicon, and it had a curvature radius of 0.03 μm. The sharpness of the tip was therefore satisfactorily replicated. The microprobe chip 20 has a space 20 as shown in Figure 4G.

[0040] As shown in Figure 3B, an NSOM image of a compact disc 144 made of polycarbonate was observed by a near-field scanning optical microscope using the microprobe chip 20 in accordance with this embodiment. The compact disc 144 was irradiated with HeNe laser beams as NSOM laser beams 150. An excellent NSOM image of the pits and gratings on the compact disc was observed with a high resolution of less than 40 nm.
Figures 5A to 5F are cross-sectional views of production steps of a microprobe chip composed of chalcogenide glass, i.e., Se. The indented section 23 on the first substrate is prepared as in Figure 4A. The first substrate 21 is composed of a silicon wafer having a <100> crystal orientation plane, and a silicon dioxide film as a protective layer is formed thereon by thermal oxidation in an oxidizing gas atmosphere. The silicon dioxide film is etched with an aqueous HF solution using a photoresist mask formed by a photolithographic process to expose a 3-μm by 3-μm area of the silicon wafer.

After the photoresist layer is removed, the first substrate is immersed into an aqueous 27% potassium hydroxide solution at 80 °C to form an indented section 23, which has a reverse-pyramidal shape and consists of (111) crystal planes, by anisotropic etching. After removing the silicon dioxide film by etching with an aqueous HF solution, a 700-angstrom peeling layer 24 composed of Ag is formed on the entire upper surface including the indented section 23 of the first substrate 21 by a resistant heating evaporation process, as shown in Figure 5A.

Next, as shown in Figure 5B, a 1-μm Se photoconductive film 25 is deposited thereon by a resistant heating evaporation process, and a 50-angstrom Cr layer and a 1,000-angstrom Au layer are separately deposited on the photoconductive film 25 by an electron beam deposition process. A third embodiment of a method for making a microprobe chip will now be described.

[Embodiment 3]

A resist pattern is formed on the metallic thin film 26 by a photolithographic process including applying, exposing, and developing a resist, the metallic thin film 26 with the resist mask is etched by an Ar ion milling process, and the photoresist is removed to form a metallic layer 28. The photoconductive film 25 is also patterned by a photolithographic process and an ion milling process to form a photoconductive layer 27, as shown in Figure 5C. The metallic layer 28 almost reaches the tip of the indented section of the photoconductive layer 27, as shown in Figure 5C. The metallic layer 28 which will be connected to electrodes later, permits a reduction of the voltage applied to the photoconductive layer 27 and an increase in the detection speed, since the travel distances of electric charges which are formed by absorption of evanescent waves are decreased by providing the metallic layer 28 near the tip of the indented section. Accordingly, the electrodes are provided on the back surface of the microprobe chip in accordance with the present invention, hence it can almost reach the tip of the microprobe chip.

Another embodiment of a method for making a microprobe chip in accordance with the present invention will now be described. Figures 5A to 5F are cross-sectional views of production steps of a microprobe chip composed of chalcogenide glass, i.e., Se. The indented section 23 on the first substrate 21 is formed as in Figure 4A. The first substrate 21 is composed of a silicon wafer having a <100> crystal orientation plane, and a silicon dioxide film as a protective layer is formed thereon by thermal oxidation in an oxidizing gas atmosphere. The silicon dioxide film is etched with an aqueous HF solution using a photoresist mask formed by a photolithographic process to expose a 3-μm by 3-μm area of the silicon wafer.

The metallic layer 28 which will be formed to form a photoconductive layer 27, as shown in Figure 5C. The metallic layer 28 is put into contact with the electrodes by pressing the first and second substrates 21 and 32. The first substrate 21 is removed from the second substrate 32 by peeling between the first substrate 21 and the Ag peeling layer 24. As a result, as shown in Figure 5C, a microprobe chip 40 composed of the photoconductive layer and the metallic layer is transferred onto the electrodes 30 and 31. The peeling layer 24 is removed by an Ar ion milling process to expose the photoconductive layer as shown in Figure 5F. A microprobe chip having a space 33 for detecting evanescent waves is formed in such a manner.

[Embodiment 2]

A second substrate 32 provided with electrodes 30 and 31 is prepared as in Figure 4E, the first substrate is inversely placed on the second substrate so that the metallic layer 28 is put into contact with the electrodes 30 and 31, as shown in Figure 5D. An Au-Au metallic bond is formed at the interface between the metallic layer and the electrodes by pressing the first and second substrates 21 and 32. The first substrate 21 is removed from the second substrate 32 by peeling between the first substrate 21 and the Ag peeling layer 24. As a result, as shown in Figure 5C, a microprobe chip 40 composed of the photoconductive layer and the metallic layer is transferred onto the electrodes 30 and 31. The peeling layer 24 is removed by an Ar ion milling process to expose the photoconductive layer as shown in Figure 5F. A microprobe chip having a space 33 for detecting evanescent waves is formed in such a manner.

[Embodiment 3]

A resist pattern is formed on the metallic thin film 26 by a photolithographic process including applying, exposing, and developing a resist, the metallic thin film 26 with the resist mask is etched by an Ar ion milling process, and the photoresist is removed to form a metallic layer 28. The photoconductive film 25 is also patterned by a photolithographic process and an ion milling process to form a photoconductive layer 27, as shown in Figure 5C. The metallic layer 28 almost reaches the tip of the indented section of the photoconductive layer 27, as shown in Figure 5C. The metallic layer 28 which will be connected to electrodes later, permits a reduction of the voltage applied to the photoconductive layer 27 and an increase in the detection speed, since the travel distances of electric charges which are formed by absorption of evanescent waves are decreased by providing the metallic layer 28 near the tip of the indented section. Accordingly, the electrodes are provided on the back surface of the microprobe chip in accordance with the present invention, hence it can almost reach the tip of the microprobe chip.
to expose a 3-µm by 3-µm area of the silicon wafer. After the photoresist layer is removed, the first substrate is immersed into an aqueous 27% potassium hydroxide solution at 80 °C to form an indented section 43, which has a reverse-pyramidal shape and consists of (111) crystal planes, by anisotropic etching.

[0052] After removing the protective film 42 by etching with an aqueous HF solution, a 5,000-angstrom peeling layer 44 composed of silicon dioxide is formed on the entire upper surface including the indented section 43 of the first substrate 41 by a thermal oxidation process in an oxidizing gas atmosphere, as shown in Figure 6B. The thickness of the silicon dioxide film formed by thermal oxidation depends on the shape of the silicon, and the curvature of the tip of the microprobe chip is determined by controlling the thickness of the silicon dioxide film. Accordingly, a microprobe chip with a tip having a smaller curvature radius can be produced by forming the silicon dioxide peeling layer 44.

[0053] As shown in Figure 6C, a 1-µm CuPc photoconductive film 45 is deposited on the peeling layer 44 by a resistive heating evaporation process, and then a 50-angstrom Cr layer and a 1,000-angstrom Au layer are separately deposited thereon by a vacuum evaporation process to form a metallic thin film 46.

[0054] A resist pattern is formed on the metallic thin film 46 by a photolithographic process including applying, exposing, and developing a resist, the metallic thin film 46 with the resist mask is patterned by an Ar ion milling process, and then the photoconductive layer 45 is patterned by a reactive ion etching process using gaseous oxygen to form a photoconductive layer 47. The photore sist layer on the metallic thin film is removed. The metallic thin film 46 on the photoconductive layer 47 is also patterned by a photolithographic process and an ion milling process to form a metallic layer 48, as shown in Figure 6D. The metallic layer 48 almost reaches the tip of the indented section of the photoconductive layer 47, as shown in Figure 6D. The metallic layer 48, which will be connected to electrodes later, permits a reduction of the voltage applied to the photoconductive layer 47 and an increase in the detection speed, since the travelling distances of electric charges which are formed by absorption of evanescent waves are decreased by providing the metallic layer 48 near the tip of the indented section.

[0055] A silicon wafer is prepared as a second substrate 52, and a 50-angstrom Ti layer and 1,000-angstrom Pt layer are deposited and electrodes 50 and 51 as Junction layers are formed by a photolithographic process and an Ar plasma etching process of the deposited layers. The first substrate shown in Figure 6D is inversely patterned by a photolithographic process and then the thin film cantilever 81 as shown in Figure 7A is patterned by a reactive ion etching process using CF₄. The silicon nitride film 82 and the silicon dioxide film 83 on the bottom surface of the second substrate 72 are anisotropically etched along the crystal axes. The upper silicon nitride film is patterned by a photolithographic process and then the thin film cantilever 81 and the lower silicon nitride film 82 is used as a mask when the back surface of the second substrate 72 is anisotropically etched. The upper silicon nitride film is used as the thin film cantilever 81 and the lower silicon nitride film 82 is used as a mask when the back surface of the second substrate 72 is anisotropically etched. The sharpness of the tip was therefore satisfactorily replicated.

[0057] An NSOM image of the compact disc 144 was observed by the near-field scanning optical microscope using the microprobe chip 60 in accordance with this embodiment, as shown in Figure 3B. An excellent NSOM image was observed.

[Embodiment 4]

[0058] This embodiment includes a method for making a probe for detecting evanescent waves, in which a microprobe chip composed of an amorphous silicon photoconductive layer is provided on a thin film cantilever.

[0059] Figures 7A and 7B are a top view and a side view, respectively of the probe. The probe includes a thin film cantilever 81, electrodes 70 and 71 which are used as junction layers and lead the photocurrent flows, a microprobe chip 80 composed of an amorphous silicon semiconductive layer, a silicon dioxide film 83, a silicon nitride film 82 which is used as a mask when etching the silicon wafer from the back surface, and a silicon block 84 which is formed by etching the silicon wafer and supports one end of the thin film cantilever 81. The electrodes 70 and 71 are connected to both ends of the bottom of the microprobe chip.

[0060] The production steps will now be described with reference to Figures 8A to 8D. A photoconductive layer is formed on the peeling layer by the steps shown in Figures 4A to 4D, and a 1-µm amorphous silicon layer as a photoconductive layer is deposited on the PtTi peeling layer.

[0061] A 0.5-µm silicon dioxide film 83 is deposited on a silicon wafer as a second substrate 72, and then 0.5-µm silicon nitride films are deposited on both surfaces of the second substrate 72 by a low pressure CVD process. The upper silicon nitride film is used as the thin film cantilever 81, and the lower silicon nitride film 82 is used as a mask when the back surface of the second substrate 72 is anisotropically etched along the crystal axes. The upper silicon nitride film is patterned by a photolithographic process and then the thin film cantilever 81 as shown in Figure 7A is patterned by a reactive ion etching process using CF₄. The silicon nitride film 82 and the silicon dioxide film 83 on the bottom surface of the second substrate are partially patterned as shown in Figure 7B by a photolithographic process and a reactive ion etching process. A 50-angstrom Cr layer and a 1,000-angstrom Au layer are separately deposited on the thin film canti-
Circuit 166 and the current detecting circuit 168 and signals from the XYZ driver 167, the displacement detecting circuit 166 detecting the displacement based on the change in the reflecting angle of light caused by the thin film cantilever, a position sensor 163 detecting a position in the X, Y and Z directions, and an XYZ driver 167 controlling the drive of the piezoelectric device 165 to simultaneously perform NSOM and AFM observation. An AFM image of pits and gratings was obtained by the displacement of the probe and an NSOM image with a high resolution of less than 40 nm was simultaneously obtained.

Using the microscope, the probe was moved close to the compact disc as the test piece 154, and the probe was scanned in the X and Y directions by the piezoelectric device 165 to simultaneously perform NSOM and AFM observation. An AFM image of pits and gratings was obtained by the displacement of the probe and an NSOM image with a high resolution of less than 40 nm was simultaneously obtained.

Since the bits on the compact disc are detected, the recorded information can be regenerated by decoding the detected bits by the signal processing circuit 168. Accordingly the system can be also used as an information regenerating apparatus.

While the present invention has been described with reference to what are presently considered to be the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, the invention is intended to cover various modifications and equivalent arrangements, as included within the scope of the appended claims.

Claims

1. A microprobe chip for detecting evanescent optical waves, comprising a substrate (12, 32, 52, 81), a photoconductive material (7, 27, 47, 67) shaped as a tip for detecting evanescent optical waves, and electrodes (10, 11, 30, 31, 50, 51, 70, 71) connected to said photoconductive material for conducting photocurrent, arranged on the substrate, characterized in that said photoconductive material is supported by portions of the electrodes, said portions being placed between the photoconductive material and the substrate and forming a junction layer joining the photoconductive material and the substrate.

2. The microprobe chip according to claim 1, wherein said photoconductive material is an amorphous semiconductive material.

3. The microprobe chip according to claim 2, wherein said amorphous semiconductive material comprises amorphous silicon or amorphous chalcogenide.

4. The microprobe chip according to claim 1,
wherein said photoconductive material comprises an organic photoconductive material.

5. The microprobe chip according to any one of claims 1 to 4, wherein said tip (20, 40, 60, 80) has a pyramidal shape.

6. The microprobe chip according to any one of claims 1 to 5, having a space (13, 33, 53, 73) between said substrate and said tip.

7. The microprobe chip according to claim 6, wherein said substrate comprises a thin film cantilever (81), and said tip is connected to said electrodes which are formed on the free end of said thin film cantilever (81).

8. A probe provided with the microprobe chip according to claim 7, wherein the end opposed to said free end of the thin film cantilever (81) is supported by a silicon block (84).

9. An apparatus for detecting evanescent optical waves, comprising:

- the microprobe chip according to claims 6 or 7,
- a means (14, 169) for applying a voltage to said microprobe chip through said electrodes; and
- a means (15, 168) for detecting photocurrent flows in said microprobe chip through said electrodes; wherein

said evanescent optical waves are detected as said photocurrent flows.

10. The apparatus according to claim 9, further comprising a means for radiating light onto a test piece (144, 164); wherein said evanescent optical waves occurring on said test piece by said means for radiating light are converted into photocurrent flows by said means for applying a voltage and said microprobe chip, and are detected as said photocurrent flows to detect the surface information of said test piece.

11. The apparatus according to claim 10, wherein said test piece is a recording medium and said surface information is the recording information on said recording medium.

12. A method for making the microprobe chip according to any one of claims 1 to 7, said method comprising the following steps of:

- forming a film (5, 25, 45), said film having the shape of the microprobe chip (20, 40, 60, 80) and comprising a photoconductive material on a peeling layer (4, 24, 44, 64) of a first substrate (1, 21, 41, 61), said first substrate having an indented section (3, 23, 43) which is replicated to the microprobe chip;
- transferring said film on said peeling layer onto an electrically conductive junction layer (10, 11; 30, 31; 50, 51; 70, 71) provided on a second substrate (12; 32; 52; 84);
- joining the junction layer with the side of the film opposed to the first substrate; and
- removing the first substrate.

13. The method according to claim 12, wherein said first substrate comprises single-crystal silicon, and said indented section is formed on the surface of said first substrate by anisotropic etching in the crystal axes.

14. The method according to claims 12 or 13, wherein said junction layer comprises a metal.

15. A method for making the probe according to claim 8, wherein the microprobe chip is manufactured according to any one of claims 12 to 14, and the probe is formed by processing said second substrate.

16. The method according to claim 15, wherein the probe forming step comprises the steps:

- forming a thin film cantilever (81) on said second substrate (84); and
- forming said junction layer (70, 71) on said thin film cantilever (81).

Patentansprüche

1. Mikrosondenchip zum Detektieren im Nahfeld abklingender (evanescent) optischer Wellen, umfassend:

- ein Substrat (12, 32, 52, 81),
- ein photoleitendes Material (7, 27, 47, 67), geformt als Spitz zu Detektieren im Nahfeld abklingender optischer Wellen, und
- Elektroden (10, 11; 30, 31; 50, 51; 70, 71), die auf dem Substrat angeordnet sind und an das photoleitende Material zum Leiten von Photostrom angeschlossen sind,


dadurch gekennzeichnet, dass das photoleitende Material gehalten wird durch Elektrodenabschnitte, welche sich zwischen dem leitenden Material und dem Substrat befinden und eine Übergangsschicht, die das photoleitende Material und das Substrat miteinander vereint, bilden.

2. Chip nach Anspruch 1, bei dem das photoleitende Material ein amorphes Halbleitermaterial ist.
3. Chip nach Anspruch 2, bei dem das amorphe Halbleitermaterial amorphen Silicium oder amorphen Chalcogenid ist.


5. Chip nach einem der Ansprüche 1 bis 4, bei dem die Spitze (20, 40, 60, 80) eine Pyramidenform hat.

6. Chip nach einem der Ansprüche 1 bis 5, mit einem Raum (13, 33, 53, 73) zwischen dem Substrat und der Spitze.

7. Chip nach Anspruch 6, bei dem das Substrat einen Dünnschicht-Freiträger (81) aufweist und die Spitze verbunden ist mit den Elektroden, die am freien Ende des Dünnschicht-Freiträgers (81) gebildet sind.


9. Vorrichtung zum Detektieren im Nahfeld abklingender optischer Wellen, umfassend:

den Mikrosondenchip nach Anspruch 6 oder 7, eine Einrichtung (14, 169) zum Anlegen einer Spannung an den Mikrosondenchip über die Elektroden; und eine Einrichtung (15, 168) zum Nachweisen von Photoströmen in dem Mikrosondenchip über die Elektroden; wobei die abklingenden optischen Wellen als die Photoströme nachgewiesen werden.

10. Vorrichtung nach Anspruch 9, weiterhin umfassend eine Einrichtung zum Aufstrahlen von Licht auf ein Teststück (144, 164); wobei die abklingenden optischen Wellen, die an dem Teststück durch das Beschneiden mit Licht auftreten, umgewandelt werden in Photostromflüsse durch die Einrichtung zum Anlegen einer Spannung und den Mikrosondenchip, und als diese Photoströme erfasst werden, um die Oberflächeninformation des Teststücks zu erhalten.

11. Vorrichtung nach Anspruch 10, bei der das Teststück ein Aufzeichnungssystem ist und die Oberflächeninformation die Aufzeichnungsinformation auf dem Aufzeichnungssystem ist.

12. Verfahren zum Fertigen des Mikrosondenchips nach einem der Ansprüche 1 bis 7, umfassend folgende Schritte:

Erzeugen eines Films (5, 25, 45), der die Form des Mikrosondenchips (20, 40, 60, 80) hat und ein photoleitendes Material auf einer Abschälfläche (4, 24, 44, 64) eines ersten Substrats (1, 21, 41, 61) besitzt, wobei letzteres einen eingekehrten Abschnitt (3, 23, 43), auf die Mikrosondenchip abgebildet wird, besitzt: Transferieren des auf der Abschälfläche gebildeten Films auf eine elektrisch leitende Übergangsschicht (10, 11, 30, 31, 50, 51, 70, 71), die auf einem zweiten Substrat (12; 32; 52; 84) vorhanden ist; Vereinen der Übergangsschicht mit der Seite des Films, die dem ersten Substrat gegenüberliegt; und Entfernen des ersten Substrats.


15. Verfahren zum Fertigen der Sonde nach Anspruch 8, bei dem der Mikrosondenchip nach einem der Ansprüche 12 bis 14 hergestellt wird, und die Sonde durch Bearbeiten des zweiten Substrats gebildet wird.

16. Verfahren nach Anspruch 15, bei dem der Sondenherstellungsschritt folgende Schritte beinhaltet:

Erzeugen eines Dünnschicht-Freiträgers (81) auf dem zweiten Substrat (84); und Bilden der Übergangsschicht (70, 71) an dem Dünnschicht-Freiträger (81).

Revendications

1. Puce de microsonde pour détecter des ondes optiques évanescentes, comprenant:

un substrat (12, 32, 52, 81), un matériau photoconducteur (7, 27, 47, 67) mis sous forme d’une pointe permettant de détecter des ondes optiques évanescentes, et des électrodes (10, 11 ; 30, 31 ; 50, 51 ; 70, 71) connectées audit matériau photoconducteur pour conduire un photocourant et agencées sur le substrat, caractérisée en ce que ledit matériau photoconducteur est supporté par des parties des électrodes, lesdites parties étant placées entre
le matériau photoconducteur et le substrat formant une couche de jonction joignant le matériau photoconducteur au substrat.

2. Puce de microsonde selon la revendication 1, dans laquelle ledit matériau photoconducteur est un matériau semiconductor amorphe.

3. Puce de microsonde selon la revendication 2, dans laquelle ledit matériau semiconductor amorphe comprend du silicium amorphe ou un chalcogénure amorphe.

4. Puce de microsonde selon la revendication 1, dans laquelle ledit matériau photoconducteur comprend un matériau semiconductor organique.

5. Puce de microsonde selon l'une quelconque des revendications 1 à 4, dans laquelle ledit matériau semiconductor a une forme pyramidale.

6. Puce de microsonde selon l'une quelconque des revendications 1 à 5, ayant un espace entre ledit substrat et ladite pointe.

7. Puce de microsonde selon la revendication 6, dans laquelle ledit substrat comprend un matériau semiconductor organique.

8. Sonde munie de la puce de microsonde selon la revendication 7, dans laquelle ladite extrémité opposée à ladite extrémité libre de l'élément en porte-à-faux à couche mince (81) est supportée par un bloc de silicium (84).

9. Appareil pour détecter des ondes optiques évanescentes, comprenant :

- la puce de microsonde selon la revendication 6 ou 7,
- un moyen (14, 169) pour appliquer une tension à ladite puce de microsonde par l'intermédiaire desdites électrodes ; et
- un moyen (15, 168) pour détecter des passages de photocourants dans ladite puce de microsonde à travers lesdites électrodes ; dans lequel lesdites ondes optiques évanescentes sont détectées sous la forme desdits passages de photocourants.

10. Appareil selon la revendication 9, comprenant en outre un moyen pour rayonner de la lumière vers une éprouvette (144, 164) ;

- dans lequel lesdites ondes optiques évanescentes se produisant sur ladite éprouvette du fait dudit moyen de rayonnement de lumière sont converties en des passages de photocourants par ledit moyen d'application d'une tension et ladite puce de microsonde, et sont détectées en tant que lesdits passages de photocourants pour détecter les informations de surface de ladite éprouvette.

11. Appareil selon la revendication 10, dans lequel ladite éprouvette est un support d'enregistrement et lesdites informations de surface sont les informations d'enregistrement sur ledit support d'enregistrement.

12. Procédé de fabrication d'une puce de microsonde selon l'une quelconque des revendications 1 à 7, ledit procédé comprenant les étapes consistant à :

- former un film (5, 25, 45), ledit film ayant la forme de ladite puce de microsonde (20, 40, 60, 80) et comprenant un matériau semiconductor sur une couche de décollement (4, 24, 44, 64) d'un premier substrat (1, 21, 41, 61), ledit premier substrat ayant une section gaufrée (3, 23, 43) qui est reproduite sur la puce de microsonde ;
- transférer ledit film de ladite couche de décollement sur une couche de jonction électriquement conductrice (10, 11 ; 30, 31 ; 50, 51 ; 70, 71) prévue sur un deuxième substrat (12 ; 32 ; 52 ; 84) ;
- joindre la couche de jonction à la face du film qui est opposée au premier substrat ; et
- enlever le premier substrat.

13. Procédé selon la revendication 12, dans lequel ledit premier substrat comprend un silicium monocristallin et ladite section gaufrée est formée sur la surface dudit premier substrat par attaque anisotope suivant les axes cristallins.

14. Procédé selon la revendication 12 ou 13, dans lequel ladite couche de jonction comprend un métal.

15. Procédé de fabrication d'une sonde selon la revendication 8, dans lequel la puce de microsonde est fabriquée conformément à l'une quelconque des revendications 12 à 14, et la sonde est formée en traitant ledit deuxième substrat.

16. Procédé selon la revendication 15, dans lequel l'étape de formation d'une sonde comprend les étapes consistant à :

- former un élément en porte-à-faux à couche mince (81) sur ledit deuxième substrat (84) ; et
- former ladite couche de jonction (70, 71) sur ledit élément en porte-à-faux à couche mince (81).
FIG. 2
PRIOR ART
REFERENCES CITED IN THE DESCRIPTION

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