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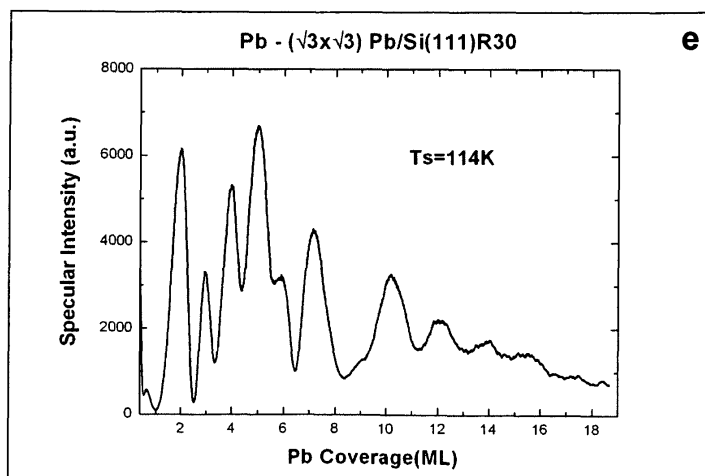
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(57) The present invention relates to a device for coherently reflecting a beam of atoms or molecules, said device comprising a crystalline substrate with a high-quality surface on which a metal surface structure is deposited such that the specular reflectivity of the beam is

about 20 % or higher and a method for producing the same. It further relates to an atom-optical apparatus containing said device and its use in high vacuum or ultra-high vacuum systems, and a method for reflecting a beam of atoms or molecules by using said device.

Fig. 2



Description

[0001] The present invention relates to a device for reflecting beams of atoms or molecules, in particular He atoms or H₂ molecules, a method for producing said device and a system, in particular a microscope or lithography device, comprising said device. The present invention also relates to a method for reflecting atoms or molecules.

[0002] Helium (He) atom scattering is a powerful, well-established technique for investigating the structural and dynamical properties of surfaces, as it is described e.g. in "E. Hulpke (Ed.) 1992, Helium Atom Scattering from Surfaces, Springer Series in Surface Sciences Vol. 27, Springer (Berlin)" and "D. Farias and K.H. Rieder, Rep. Prog. Phys. 61, 1575 (1998)". Because of the low energies used (10-100 meV), neutral He atoms probe the topmost surface layer of any material in an inert, completely nondestructive manner. This means that a Scanning Helium Atom Microscope (SHeM), where a focused beam of neutral He atoms is used as an imaging probe, would be a unique tool for reflection or transmission microscopy, with a potential resolution of 20-50 nanometers. It could be used to investigate glass surfaces, biological materials and fragile samples which are difficult to examine by other methods, mainly due to the appearance of sample charging or electron excitation effects.

[0003] The physical realisation of such a microscope requires the development of a device (hereinafter also referred to as "mirror") able to focus a beam of low energy neutral He atoms into a small spot on the sample to be examined.

[0004] Electrostatic bending of a hydrogen passivated Si(111) crystal to focus a 2 mm He beam to a final spot diameter of 210 microns is demonstrated in "B. Holst and W. Allison, Nature (London) 390, 244 (1997)". However, the most serious limitation for improving the resolution is given by the low intensity obtained in the focused peak, which is a consequence of the poor reflectivity of such surfaces (~ 2%).

[0005] It is also known in the art to use the combination of microskimmers with Fresnel zone plates to focus a He beam down to 1.5 micron as described in "R.B. Doak, R.E. Grisenti, S. Rehbein, G. Schmahl, J.P. Toennies and Ch. Wöll, Phys. Rev. Lett 83, 4229 (1999)". However, again the very low intensity in the focused central peak poses a serious limitation for use in a microscope. In fact, as compared to mirror focusing, the use of Fresnel zone plates implicates significant disadvantages: the focused intensity is much smaller, it does not offer true white light focusing and it suffers from chromatic aberrations.

[0006] US 2004/0238733 A1 discloses an atomic reflection optical element for an atomic wave designed to increase the (coherent) reflectance of the atomic wave by using a porous surface structure, a structure supporting a very thin film or a structure in which the insular portion (reflection surface) of a reflection-diffraction grating is narrowed. The materials used for those structures

are silicon, silicon carbide or silicon nitride.

[0007] In the development of a device suitable to focus a beam of low energy atoms, such as neutral He atoms, the problem of using a surface for atom optics must be considered at both the macroscopic level, where classical mechanics is applicable, and the microscopic level, where quantum effects dominate.

[0008] At the macroscopic scale, the device must be bent to a Cartesian reflector surface to avoid aberrations. Recent results have shown that Si(111)-wafers with appropriate properties can be produced by improved current crystal cutting and polishing technologies.

[0009] The most serious problem arises at the microscopic scale, as a consequence of the large cross section for defects characteristic of He atom scattering, as described in "B. Poelsema and G. Comsa, 1989, Scattering of Thermal Energy Atoms from Disordered Surfaces, Springer Tracts in Modern Physics vol. 115, Springer (Berlin)". This requires surfaces of outstanding crystalline perfection, homogeneous over large scale lateral distances (10s of nanometers or more). Furthermore, the surface must be inert, since the mirror surface must be held atomically clean for long periods.

[0010] Semiconductor surfaces can be produced with smaller density of steps and point defects than metal surfaces. However, the large charge corrugation at semiconductor surfaces results in a large loss of intensity from the specular beam into several diffracted beams.

[0011] Metals, on the contrary, reflect He atoms mostly into the specular beam, the diffracted ones being many order of magnitude smaller. Unfortunately, metal crystals as such are not suitable as mirrors. First, their surfaces usually show a higher step/defect density. Furthermore, most metals are highly reactive, it is difficult to produce very thin metal crystals and the mechanical properties are less desirable, in particular the crystals are prone to display mosaic structures. Thus, a combination of a semiconductor substrate covered by a layer of a suitable metal may provide a solution to the above problem. However, such composite structures are difficult to prepare since many metals show a persistent tendency to grow in a three-dimensional (3D) mode, i.e. by forming 3D islands, on most semiconducting surfaces.

[0012] It is therefore a first object of the present invention to provide a device for (coherently) reflecting a beam of atoms or molecules without the disadvantageous properties as discussed above. It is a further object of the present invention to provide a process for producing the device in a reproducible and controlled manner. The device should have high specular reflectivity so that the focused beam can be used in the operation of a microscope or a lithography device or other atom-optical components.

[0013] According to the present invention, the first object is solved by a device for (coherently) reflecting a beam of atoms or molecules, said device comprising a crystalline substrate with a high-quality surface, e.g. a (100) or (111) surface, on which a metal surface structure

is deposited such that the specular reflectivity of the beam is about 20 % or higher. Preferably, the crystalline substrate is based on a semiconductor.

[0014] The present invention also relates to a method for producing a device as defined in any of the preceding claims, said method comprising the steps of:

a) providing under high vacuum or ultra-high vacuum conditions a crystalline substrate with a high-quality surface (clean or passivated);

b) depositing on top of the high-quality surface of the crystalline substrate a metal to form a metal surface structure such that it covers uniformly the crystalline substrate on the atomic scale.

[0015] Furthermore, the present invention relates to a microscope, in particular a scanning helium atom microscope (SHeM), or a lithography device or another atom-optical component using the device of the present invention, and to a high vacuum or ultra-high vacuum system comprising said device, microscope or component.

[0016] Finally, the present invention relates to a method for reflecting, in particular focusing, a beam of atoms or molecules by using a device as defined above, and to a method for operating a microscope or a lithography device using the scattering of atoms or H₂ molecules, under high vacuum or ultra-high vacuum conditions, comprising providing a beam of atoms or molecules, reflecting the beam by using a device as defined above and detecting the diffraction or transmission intensities of the beam after interaction with a material to be examined.

[0017] As used herein, the terms "atoms" or "molecules" also relate to those species which carry a charge, i.e. ions of atoms and molecules, and which may be manipulated (reflected, focused) by using the devices and methods of the present invention.

[0018] Preferred embodiments of the present invention are described in the dependent claims.

Brief Description of the Figures

[0019]

Figure 1 shows at the top and in the middle angular scans of He scattered from the clean Si(111)7x7 surface. At the bottom, evolution of the He specular intensity during the deposition of Pb on top of this surface at 140 K is shown.

Figure 2 shows a series of 100 nm × 100 nm STM images recorded during the deposition of Pb on the ($\sqrt{3}\times\sqrt{3}$)Pb/Si(III)R30 surface at 158 K. The ($\sqrt{3}\times\sqrt{3}$)Pb/Si(III)R30 structure is prepared by depositing 1 ML of Pb on the clean Si(111)-(7x7) surface at 158 K, followed by a 5 minute anneal to 700 K to desorb the excess Pb. The result of this preparation is the

ordered ($\sqrt{3}\times\sqrt{3}$)Pb/Si(III)R30 structure, with a total Pb coverage of 1/3 ML. This coverage is defined with respect to the unreconstructed, bulk terminated Si(111) surface, i.e. there is one Pb atom for 3 Si atoms. The images have been taken with a sample bias of 3 V and correspond to 0.7 (1 min), 1.3 (2min), 2.0 (3min) and 6.6 ML (10min) of additional Pb. Figure 2e shows the evolution of the specularly reflected He beam intensity during the deposition of Pb on top of a ($\sqrt{3}\times\sqrt{3}$)Pb/Si(III) R30 surface at 114 K.

Figure 3 shows a series of 500 nm x 500 nm STM images of a 6.6 ML-thick Pb film deposited at 158 K and heated to different temperatures.

Figure 4 shows at the top a 500 nm x 500 nm STM image of 7.1 ML-thick Pb film deposited at 98 K and heated to 260 K. Most (94 per cent) of the surface is covered with 7 ML Pb. Not a single step is visible in the image. At the bottom, a He diffraction spectrum corresponding to a surface covered with 4 ML Pb at 120 K is shown.

Figure 5 shows 2 μm x 2 μm (top) and 50 nm x 50 nm (bottom) STM images of the Si(111)/Pb-($\sqrt{3}\times\sqrt{3}$)R30 structure according to the present invention.

Detailed Description of the Invention

[0020] As summarized above, the present invention is based on a device for coherently reflecting a beam of atoms or molecules comprising a crystalline substrate with a high-quality surface on which a metal surface structure is deposited such that the specular reflectivity of the beam is about 20% or higher, preferably higher than 50%, more preferably higher than 70%, for example 75% or 85%.

[0021] In this context, the term "high-quality surface" as used herein means a surface which is cleaned and treated by methods known in the art to provide a surface which is atomically flat over lateral scales of the order of one micron, for example 0.8 to 1.2 microns. Preferably, the surface is atomically flat over a lateral scale of more than one micron, for example, 1.2 or 1.5 microns, or more preferably more than 2 microns, e.g. 5 microns or more, or even 10 microns or more than 10 microns.

[0022] The preferred substrate surfaces are (100) and (111) surfaces, in particular those of semiconductor substrates like Si or Ge cut along the (111) plane. In particular, a high-quality semiconductor substrate surface is a Si(111) surface treated under vacuum conditions, i.e. high vacuum conditions characterized by very low pressures of 10⁻¹⁰ to 10⁻¹¹ mbar, to result in a Si(111)-(7x7) surface. One process for preparing such a surface is to outgas the Si(111) sample at 900 K for a prolonged period of time (6-24 hours, depending on sample quality). The oxide layer that covers the surface is then removed by flashing the substrate to 1450 K for 15 seconds watch-

ing that the pressure does not exceed 1×10^{-9} mbar. The sample temperature is then decreased slowly to room temperature at a rate of about 1 K per second. Such a procedure leads to the appearance of excellent helium diffraction patterns from the 7×7 surface reconstruction of Si(111), as shown in Figure 1 in the angular scans of helium scattered from that surface. Another well-known process for preparing such a surface is via anisotropic etching reactions conducted outside the vacuum chamber, as detailed in D. Baredo et al., Surf. Scie. 601 (2007) 24-29. For example, Si wafers having a Si(111)(7×7) surface may be used. These wafers may have a thickness in the range up to 1000 microns, in particular 5 to 500 or 300 to 500 microns, e.g. about 500 microns. However, depending on the mechanical requirements and the design of the system in which the substrate is to be used other thicknesses may be used. For example, a thickness in the range from 5 to 100 microns such as 50 microns may be preferred.

[0023] The metal surface structure deposited on the high-quality semiconductor substrate surface, in particular a Si(111)-(7×7) surface, can be (and preferably is) prepared according to the following procedure.

[0024] In general, a suitable metal, in particular a metal selected from the group consisting of Pb, Sn, Ag, Au, Al and Pb or mixtures thereof, in particular Pb, is deposited under high vacuum or ultra-high vacuum conditions at temperatures at about room temperature, i.e. at about 300 K. The metal may also be deposited at temperatures below room temperature, for example, at temperatures in the range from 90 to 200 K, for example, 90 to 150 K. It will be understood by the person skilled in the art that those temperatures may vary depending on the chemical nature of the metal.

[0025] The metal is generally deposited on the surface by physical vapor deposition, i.e. by evaporation from a suitable source of metal, e.g. a Knudsen cell, at rates of 0.1 to 2.0 ML/min, more preferably 0.1 to 1.0 ML/min, in particular 0.1 to 0.7 ML/min, for example 0.5 ML/min.

[0026] In this context, the term monolayer (ML) means three times the coverage in the well-ordered ($\sqrt{3} \times \sqrt{3}$) Pb/Si(III)R30 structure (see above).

[0027] After deposition of a desired amount of metal, for example 1 ML or more, for example 2, 3, 4, 5, 6, 7, 9, 10, 11, 12 or 13 ML, the metal surface structure thus formed may be subjected to an annealing (heating) procedure to modify and to improve the structure of the metal/semi-conductor composite material to enhance the specular reflectivity of a beam of atoms or molecules scattered from such surface.

[0028] In general, the annealing step may be conducted at temperatures from room temperature to about 800 K, for example in a temperature range from 300 to 700 K, in particular 500 to 700 K, preferably at about 700 K. During the annealing step (hereinafter also referred to as heating step), the temperature may be raised at a rate of 1 K/sec. The end temperature may be held constant for time periods of several minutes, e.g. 1 to 10 minutes,

in particular 1 to 5 such as 3 minutes.

[0029] Heating the metal films, in particular a Pb film, will produce an atomic rearrangement which further increases the helium intensity specularly reflected as larger areas of the film may become atomically flat, in particular defect free. Also, excess metal may be removed from the surface.

[0030] According to a preferred embodiment of the present invention, after depositing a first amount of metal, and subsequent heating of the metal surface structure thus formed, a second amount of metal may be deposited. Again, after deposition of the second amount of metal, heating may be applied.

[0031] According to the present invention, it has been found that metal films having a layer thickness of 1, 3, 5, 7, 9, 11, 13 MLs (after heating to the temperature range in which each of them are stable) show good stability and reflectivity properties. Without being bound to a theory, it is believed that those thicknesses are stabilized by discrete Quantum Well States.

[0032] A preferred structure produced by the procedures of the present invention described above is a Si(111)/Pb-($\sqrt{3} \times \sqrt{3}$)R30 structure with a total Pb coverage of about $1/3$ ML, which is obtained after depositing 1 ML of lead on top of Si(111) 7×7 high-quality surface and subsequent annealing to about 700 K for 3 minutes. STM images of this preferred structure are shown in Figure 5. The high helium specular reflectivity of this surface is shown in the bottom spectrum of Figure 4. Other preferred structures are selected from the group consisting of (2×1), (2×2), (2×4), c(8×4) and c(4×4) Pb structures on Si(100).

Examples

[0033] The following examples further illustrate the invention.

[0034] The experiments are carried out in two different UHV (=Ultra-High Vacuum) chambers with base pressures in the low 10^{-11} Torr. In this context, it is noted that the terms "High Vacuum" and "Ultra-High Vacuum" are known to the person skilled in the art. Throughout this specification, they have the meaning commonly used in the art. The first one contains a variable temperature Scanning Tunneling Microscope (STM), whereas the second chamber is a high-resolution He scattering apparatus with a time-of-flight arm and a fixed angle of 106.8° between incident and outgoing beam [12]. Both chambers offer the capability to evaporate in-situ, a rear view Low Energy Electron Diffraction (LEED) optics that is also used for Auger Electron Spectroscopy (AES), ion gun and mass spectrometer. High-quality Si(111) wafers, 0.5 mm thick, cleaned by standard methods prior to insertion in the UHV chambers, are used as substrates. Inside the vacuum the samples are in general cleaned by heating to 1400 K while keeping the base pressure in the 10^{-10} Torr regime, which leads to the appearance of excellent He diffraction patterns from the 7×7 surface re-

construction of Si(111), as shown in Fig. 1. STM examination of the clean surfaces shows atomically resolved terraces larger than 2 microns, confirming the very low misalignment of the wafers. Pb is evaporated from Knudsen cells at slow rates of 0.1-0.7 ML/min, while the samples are either in the microscope or in the He diffractometer at 90-150 K.

Example 1

Deposition of Pb on a Si(111)7x7 surface

[0035] The bottom graph of Fig. 1 shows the specular intensity of He measured during the deposition of Pb on Si(111)7x7 at 140 K. The initial specular intensity from Si(111)7x7 is fairly small (10^5 counts/sec) as most of the intensity goes into the numerous diffracted beams (see Fig. 1). Apart from a first weak maximum upon completion of the wetting layer (i.e. the layer formed after depositing about 2/3 ML of Pb), the reflected intensity is negligible for the first 4 ML of Pb. It reaches a maximum 18 times more intense than on the starting surface for a 4 ML-thick Pb film, which corresponds to the completion of the magic islands that are the first stage of the growth. From that moment on, the intensity oscillates as new layers are added, basically in a layer by layer fashion.

Example 2

Deposition of Pb on a $(\sqrt{3}\times\sqrt{3})\text{Pb}/\text{Si(III)}$ surface structure

[0036] Growing directly on the Si(111) 7x7 substrate never results in films of enough lateral perfection. If the surface is prepared, however, to present the $(\sqrt{3}\times\sqrt{3})\text{Pb}/\text{Si(111)}\text{R30}$ structure, subsequent deposition of Pb leads to films of much higher perfection. The $(\sqrt{3}\times\sqrt{3})\text{Pb}/\text{Si(111)}\text{R30}$ structure is prepared as described above. The resulting surface was examined by STM. Fig. 2b shows the specular intensity recorded during deposition of Pb on $(\sqrt{3}\times\sqrt{3})\text{Pb}/\text{Si(III)}\text{R30}$ at 114K. Well defined oscillations are detected in a wide temperature range (100-160 K). There is a hint of a first maximum at 1/3 of a ML, followed by clear maxima which are separated by the time needed to deposit a single monolayer from 2 to 7 ML. Then, maxima in the specular intensity are observed every 2 MLs.

[0037] The diffraction spectrum corresponding to 4 ML, recorded along the [110] azimuth, is shown in the middle of Fig. 1. Only specular diffraction is observed in the angular distribution, as expected from a close-packed metal surface. A similar spectrum is obtained along the [121] azimuth (not shown). The specular intensity amounts to 20% of the incoming He beam intensity, which represents an improvement of more than one order of magnitude with respect to the results obtained from hydrogen passivated Si(111) surfaces (as reported in D. Barredo et al., Surf. Sci. 601, 24 (2007)).

[0038] Fig. 2 shows a series of STM images recorded for increasing Pb coverages during deposition on the $(\sqrt{3}\times\sqrt{3})\text{Pb}/\text{Si(111)}$ surface at 158 K which are characteristic of the surface morphology in the 100-150 K range.

[0039] Fig. 2a shows the surface covered with 0.7 ML of Pb and illustrates the presence of a dense array of small features 2 Å high that cover uniformly the substrate. This coverage corresponds to the wetting layer. All film thicknesses are given here above the wetting layer, which corresponds, as indicated, to 2/3 of ML of Pb. For 1.3 and 2.0 MLs of Pb (see. Fig. 2b and 2c, respectively), the surface consists of small islands with a size that increases with the coverage, but that remains smaller than the coherence length of the incoming He beam. The large density of island boundaries and defects is consistent with the small reflected intensity of He before the maximum at 2 ML. Fig. 2d shows that, by the time the specular intensity displays clear oscillations, the surface contains islands, typically 250 Å wide. The difference in height across the image is 1 ML. The Pb islands show an atomically flat top, (111)-oriented, as demonstrated by atomic resolution images (not shown). Each island is a (111)-oriented Pb nanocrystallite, where electrons from the sp band of Pb are efficiently confined between the vacuum barrier and the Si band gap around the Fermi energy. Each Pb crystallite, then behaves as a 1D quantum well. The confinement discretizes the s-p band of Pb and the corresponding Quantum Well States (QWS) can be detected by local tunnelling spectroscopy performed on top of islands of different heights or by Angular Resolved Photoelectron Spectroscopy.

[0040] Observation with STM reveals that the films deposited at low temperature are continuous, but "atomically rough", i.e. they usually contain significant fractions of (at least) three adjacent atomic layers, i.e. a 8 ML-thick film deposited at 136 K contains 25.4 percent of 9 ML, 39 percent of 8 ML and 36.5 percent of 7 ML (always above the wetting layer).

[0041] STM performed in situ at variable temperature is used to follow the evolution of the morphology of the films during a quasistatic annealing with a temperature ramp of 1K per minute. Heating the Pb films produces an atomic rearrangement and a further increase in the He intensity specularly reflected, as larger areas of the film becomes atomically flat. The maximum reflected intensity is approximately the same (7×10^6 c/s) for thicknesses of 1, 3, 5, 7, 9, 11, 13 MLs upon heating to the temperature range in which each of them are stable. Without being bound to a theory, it is believed that those thicknesses are stabilized by discrete Quantum Well States.

[0042] Fig. 3 shows the snapshots from an STM movie recorded during the heating of a 6.6 ML Pb film. The film shows a flat granular structure with no change up to 180 K. Above 200 K, the dominant height start to decompose and pits that reach the wetting layer appear. The image at 268 K illustrates the decomposition of the film in 9, 11 and 13 ML-high regions, i.e some of the magic heights.

The dark areas correspond to the wetting layer.

[0043] Figure 4 shows the surface morphology of a 7.1 ML thick film of Pb deposited at 114 K and annealed to 260 K. The film is atomically flat and most of the surface (94 per cent) is 7 ML-thick. Only 5 per cent of the surface is occupied by 9 ML-thick regions (bright areas) and a 1 per cent for 5 ML-thick regions imaged as dark small islands. Notice that not a single step is visible in the image. Very large scale STM images indicate that the film at 260 K is atomically flat over lateral scales larger than 10 microns. In these conditions, the total reflectivity for He atoms is 20 percent of the incident He beam (at 21 meV), that is, 20 times higher than for Si(III)-H(IxI) passivated surfaces under similar scattering conditions (as reported in D. Barredo et al., Surf. Sci. 601, 24 (2007)).

[0044] The above results show that Quantum Size Effects can be used to stabilize close to room temperature atomically flat films of Pb grown on Si(111), with the same degree of perfection as the substrate. A He specular reflectivity of 50% can be obtained from these Pb/Si(III) surfaces working at $\theta_i = 53.4^\circ$ and $E_i = 21$ meV. At a larger angle of incidence ($\theta_i \sim 70^\circ$) and an incidence energy close to $E_i \sim 10$ meV, specular reflectivity values as large as $\sim 70\%$ can be obtained. This means that a Scanning Helium Atom Microscope designed to work under this conditions and using a mirror based on a crystalline substrate, in particular a semiconductor/metal system as described above will have a signal more than one order of magnitude larger than in current prototypes, which will result in greatly enhanced resolution.

[0045] The device of the present invention can advantageously be used in an atom-optical apparatus. Non-limiting examples of apparatuses are a microscope, a scanning helium atom microscope, a lithography device, a holography device, an interferometer or a cooling device for atomic beams, or indemagnifying mirrors or other atom-optical apparatuses. In particular, it can be used as a means for focusing a beam of atoms or molecules.

[0046] The following documents, of which some have been explicitly referred to above, have been considered in the context of the present invention.

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Claims

1. Device for coherently reflecting a beam of atoms or molecules comprising a crystalline substrate with a high-quality surface on which a metal surface structure is deposited such that the specular reflectivity of the beam is about 20 % or higher.
2. Device according to claim 1, wherein the crystalline substrate is a semiconductor.
3. Device according to claim 1 or claim 2, wherein the atoms or molecules are selected from the group consisting of He atoms, Ne atoms, H₂ molecules or O₂ molecules.
4. Device according to any one of the preceding claims, wherein the crystalline substrate is based on silicon or germanium.
5. Device according to any one of the preceding claims, wherein the crystalline substrate is a silicon wafer.
6. Device according to any one of the preceding claims, wherein the metal is selected from the group consisting of lead, tin, silver, gold, copper and aluminium or mixtures thereof.
7. Device according to any one of the preceding claims, wherein the crystalline substrate is a silicon wafer having a Si(111)(7x7)-surface which is atomically flat over lateral scales of the order of 1 micron.
8. Device according to any one of the preceding claims, wherein the substrate with the metal surface structure is selected from the group consisting of (2x1), (2x2), (2x4), c(8x4) and c(4x4) Pb structures on Si(100) and a ($\sqrt{3}\times\sqrt{3}$)Pb/Si(100)R30 structure.
9. Device according to any one of the preceding claims, wherein the metal structure has a height of 2, 3, 4, 5, 6, 7, 8, 9, 20 or more layers.

10. Method for producing a device as defined in any of the preceding claims, said method comprising the following steps:

- a) providing under high vacuum or ultra-high vacuum conditions a crystalline substrate with a high-quality surface;
- b) depositing on top of the high-quality surface of the crystalline substrate a metal to form a metal surface structure.

11. Method according to claim 9, further comprising a heating step after step (b) to improve the surface structure and/or to desorb a certain amount of the metal deposited in step (b).

12. Method according to claim 10, wherein subsequently to the heating step further metal is deposited and potentially subjected to a further heating step.

13. Method according to claim 10 or claim 11, wherein the heating step is conducted in the temperature range of 650 to 750 K, in particular at about 700 K.

14. Atom-optical apparatus, containing a device as defined in any of claims 1 to 9 or as prepared according to any of claims 10 to 13.

15. Atom-optical apparatus according to claim 14, wherein the atom-optical apparatus is selected from the group consisting of a microscope, a scanning helium atom microscope (SHeM), a lithography device, a holography device, an interferometer or a beam-cooling device.

16. High vacuum or ultra-high vacuum system comprising a device as defined in any of claims 1 to 9 or as prepared according to any of claims 10 to 13, or an atom-optical apparatus according to claim 14 or 15.

17. Method for focusing a beam of atoms or molecules by using a device as defined in any of claims 1 to 9 or as prepared according to any of claims 10 to 13.

18. Method for operating an atom-optical apparatus as defined in any of claims 14 and 15 using the scattering of atoms or molecules, under high vacuum or ultra-high vacuum conditions, comprising providing a beam of atoms or molecules, reflecting the beam by using a device as defined in any of claims 1 to 9 or as prepared according to any of claims 10 to 13, and detecting the diffraction or transmission intensities of the beam after interaction with a material to be examined.

19. Method according to claim 18, wherein the beam is focused.

Fig. 1

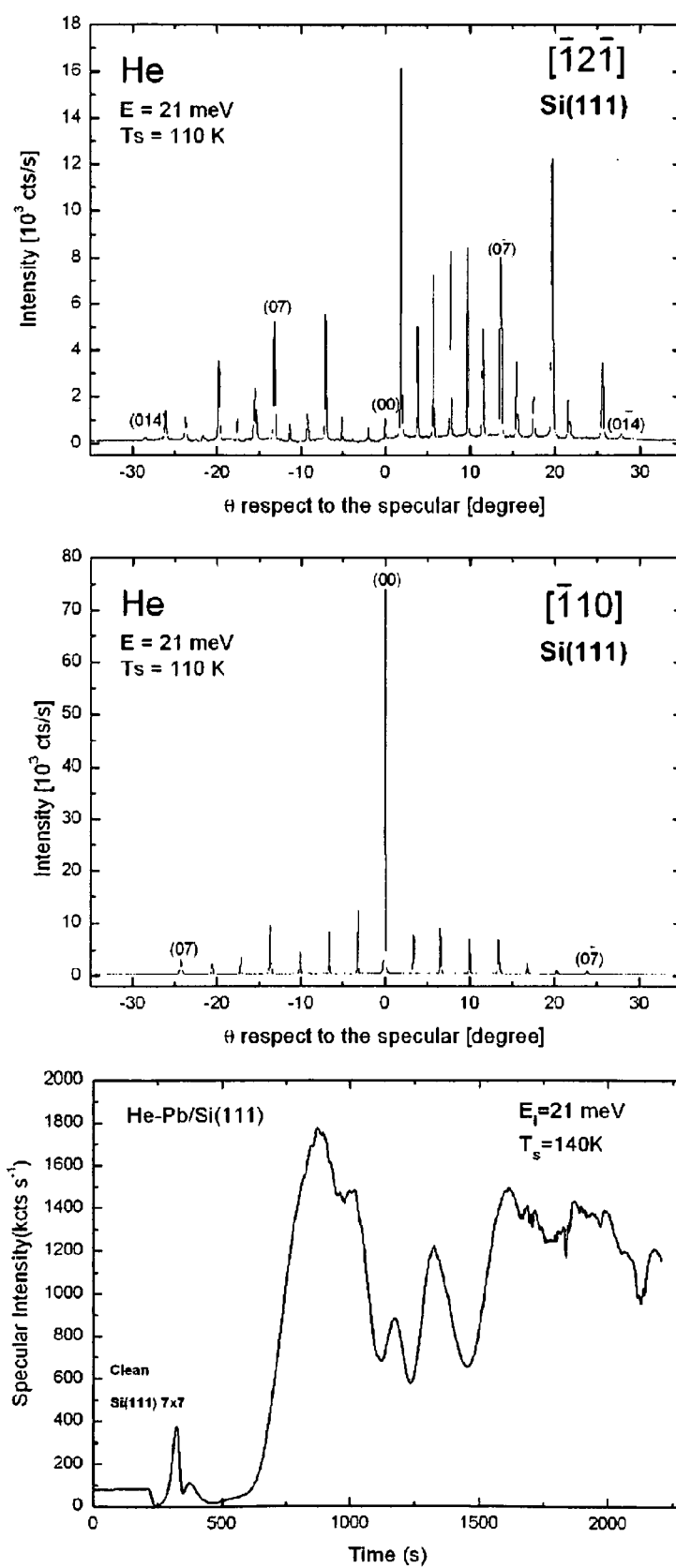


Fig. 2

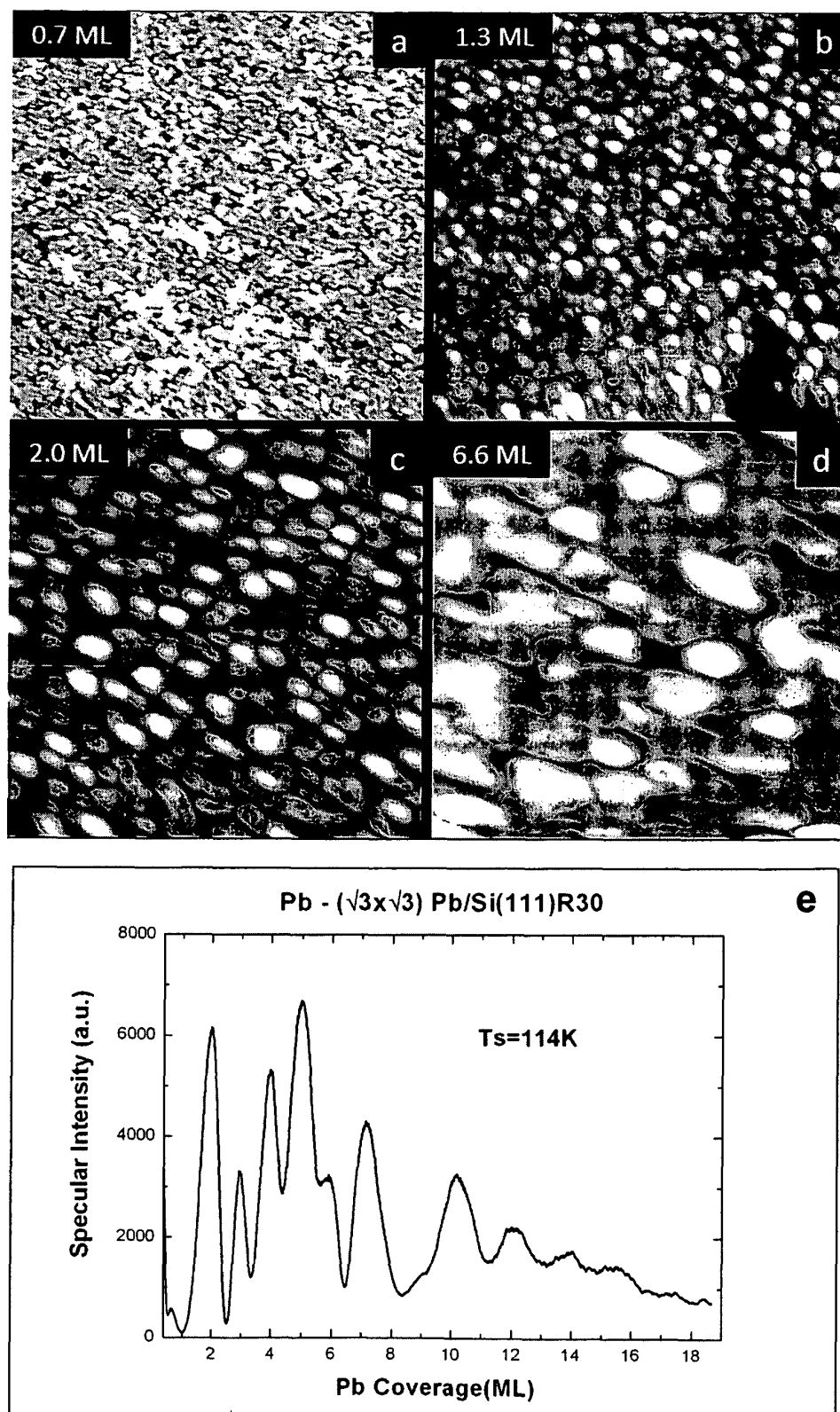


Fig. 3

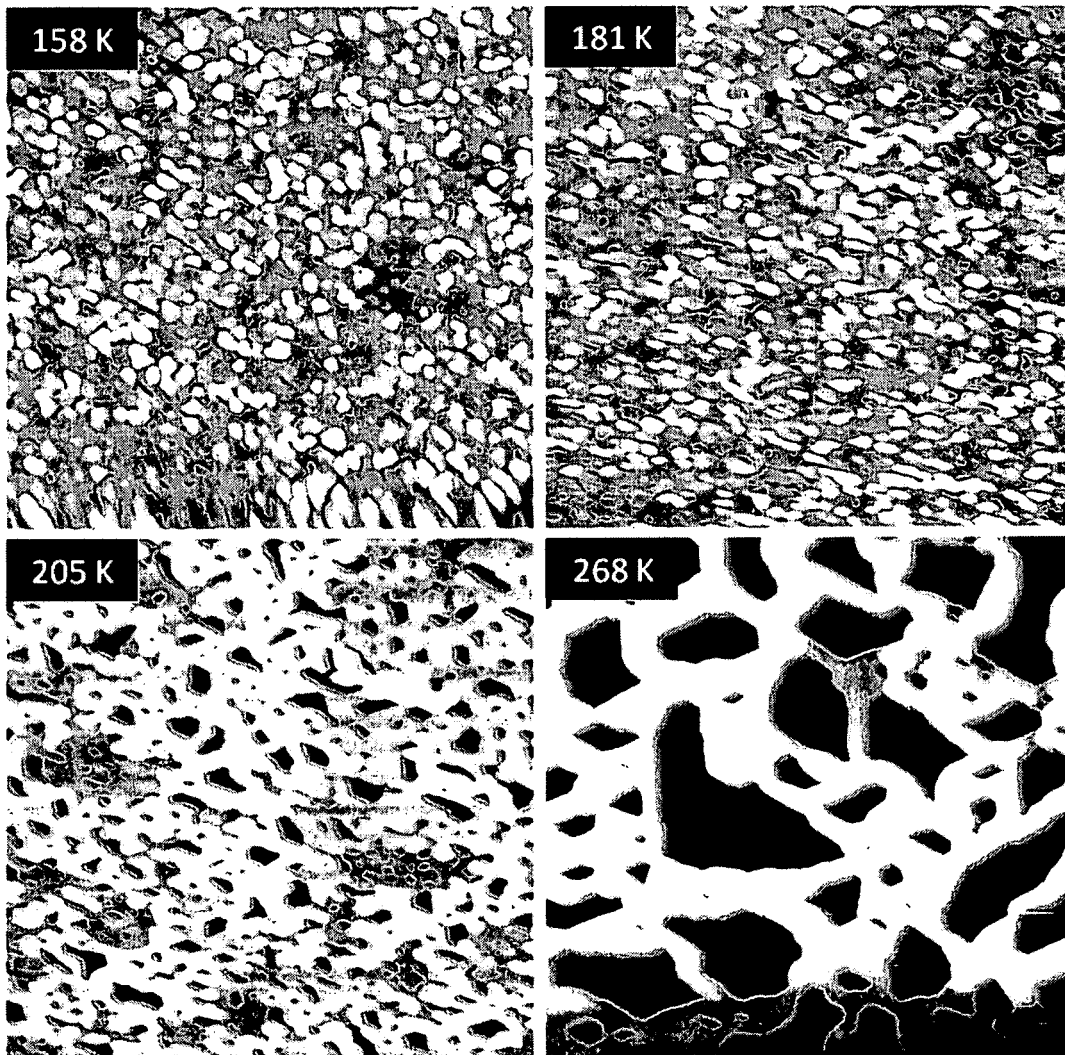


Fig. 4

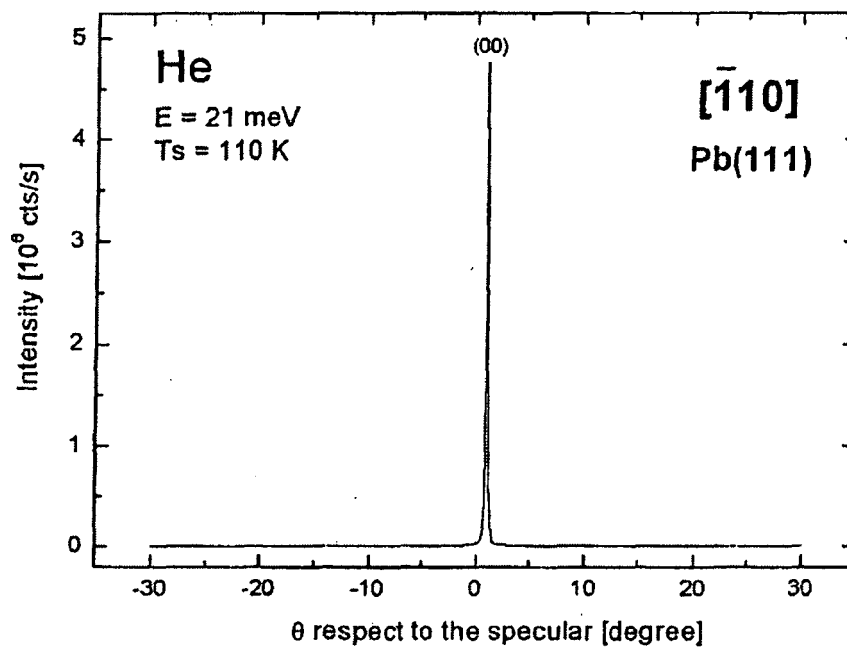
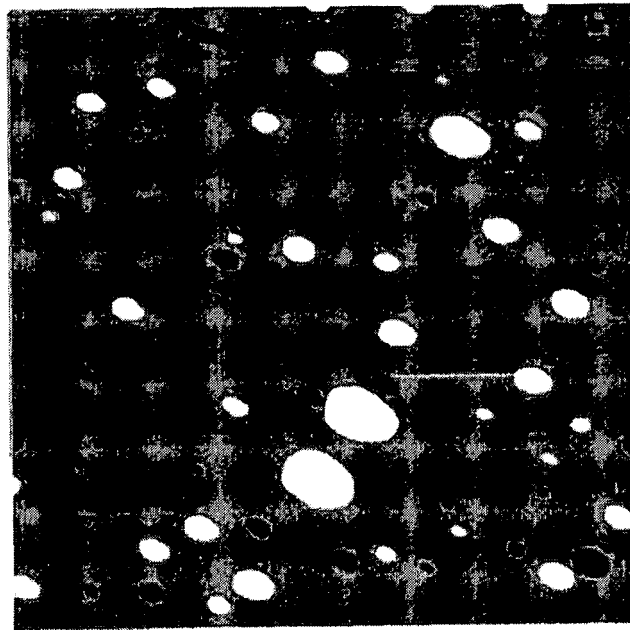
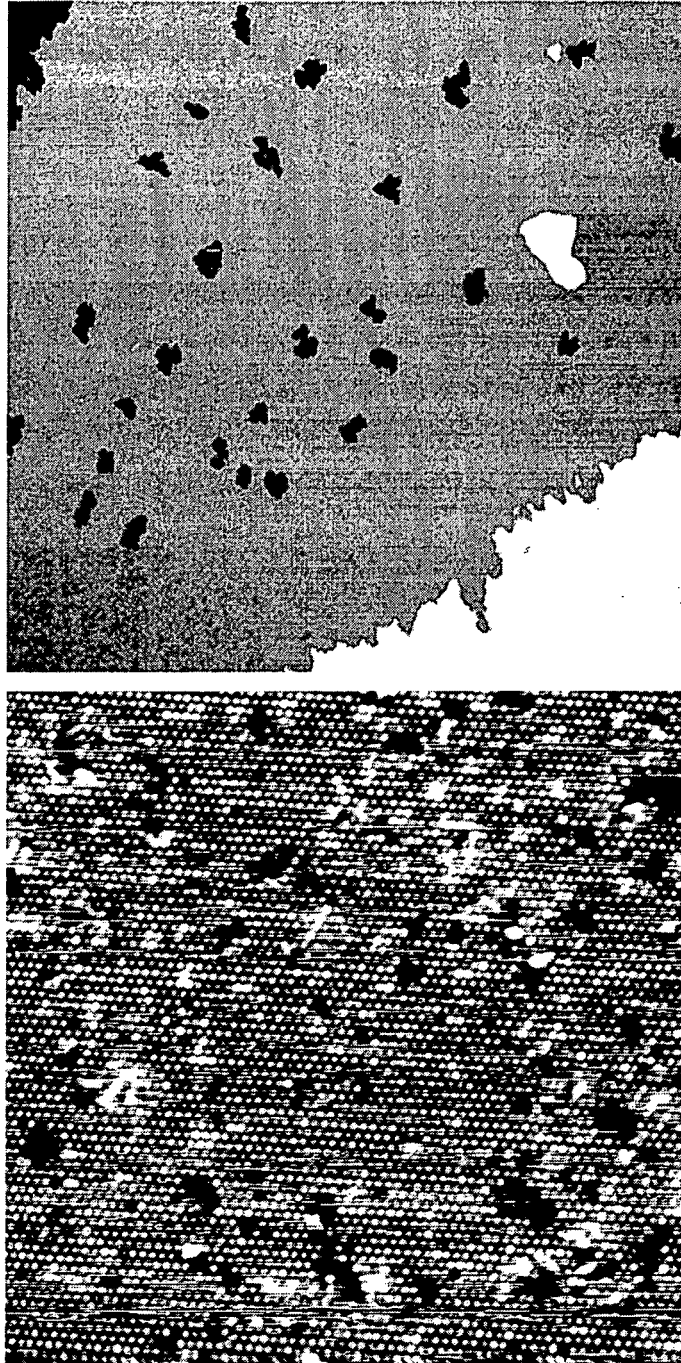


Fig. 5





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EUROPEAN SEARCH REPORT

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EPO FORM 1503 03.82 (P04C01)



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