Described is a device having an anti-reflection surface. The device comprises a silicon substrate with a plurality of silicon spikes formed on the substrate. A first metallic layer is formed on the silicon spikes to form the anti-reflection surface. The device further includes an aperture that extends through the substrate. A second metallic layer is formed on the substrate. The second metallic layer includes a hole that is aligned with the aperture. A spacer is attached with the silicon substrate to provide a gap between an attached sensor apparatus. Therefore, operating as a Micro-sun sensor, light entering the hole passes through the aperture to be sensed by the sensor apparatus. Additionally, light reflected from the sensor apparatus toward the first side of the silicon substrate is absorbed by the first metallic layer and silicon spikes and is thereby prevented from being reflected back toward the sensor apparatus.

6 Claims, 7 Drawing Sheets
OTHER PUBLICATIONS


* cited by examiner
FIG. 7

Relative Reflectance [%]

Wavelength [µm]

86.83 % @ 1 µm

27.17 % @ 1 µm

8.0 % at 1 µm

FIG. 7
The present invention relates to an anti-reflective device. The device comprises a silicon substrate having a first side and a second side. The first side includes a plurality of silicon spikes with nano-tips. A first metallic layer is formed on the silicon spikes, thereby forming an anti-reflection surface.

In another aspect, the silicon spikes are formed on the first side such that an aperture exists on the first side. The aperture extends from the first side to the second side and is surrounded by silicon spikes on the first side. Thus, light is capable of entering and exiting the substrate through the aperture.

In yet another aspect, the first metallic layer comprises a layer of chromium and a layer of gold.

In another aspect, the present invention further includes a second metallic layer formed on the second side of the silicon substrate. The second metallic layer includes a hole formed there through. The hole is formed to be aligned with the aperture. Additionally, a spacer is attached with the first side of the silicon substrate and a sensor apparatus is attached with the spacer such that a gap exists between the sensor apparatus and the silicon substrate. Therefore, light entering the hole passes through the aperture to be sensed by the sensor apparatus, and light reflected by the sensor apparatus toward the first side of the silicon substrate is absorbed by the silicon spikes and is thereby prevented from being reflected toward the sensor apparatus.

In yet another aspect, an array of apertures is formed on the first side of the substrate and a corresponding array of holes is formed in the second metallic layer.

Finally, the present invention also comprises a method for forming and using the device. The method for forming the device comprises a plurality of acts of forming and attaching the various parts as described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features and advantages of the present invention will be apparent from the following detailed descriptions of the various aspects of the invention in conjunction with reference to the following drawings, where:

FIG. 1 is an illustration of a device having an anti-reflection surface according to the present invention;

FIG. 2 is a graph illustrating results from an Energy-dispersive X-ray spectra, showing that micro-etch masks contain a high concentration of fluorine;

FIG. 3 is an enlarged-view illustration of exemplary high-density nano-tips;

FIG. 4A is an illustration of a fabrication step of a device having an anti-reflection surface, showing the formation of a photoresist and microetch mask on a substrate;

FIG. 4B is an illustration of a fabrication step of a device having an anti-reflection surface, showing the formation of silicon spikes and nano-tips;

FIG. 4C is an illustration of a fabrication step of a device having an anti-reflection surface, showing a first metallic layer being formed on the nano-tips;

FIG. 4D is an illustration of a fabrication step of a device having an anti-reflection surface, showing a second metallic layer being formed on the substrate and the photoresist being removed;

FIG. 5 is an exploded-view illustration of a device having an anti-reflection surface according to the present invention;
DETAILED DESCRIPTION

The present invention relates to an anti-reflective surface and, more particularly, to a device having a plurality of nano-tips to form the anti-reflective surface. The following description is presented to enable one of ordinary skill in the art to make and use the invention and to incorporate it in the context of particular applications. Various modifications, as well as a variety of uses in different applications will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to a wide range of embodiments. Thus, the present invention is not intended to be limited to the embodiments presented, but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

In the following detailed description, numerous specific details are set forth in order to provide a more thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without necessarily being limited to these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

The reader’s attention is directed to all papers and documents which are filed concurrently with this specification and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference. All the features disclosed in this specification, including any accompanying claims, abstract, and drawings (may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

Furthermore, any element in a claim that does not explicitly state “means for” performing a specified function, or “step for” performing a specific function, is not to be interpreted as a “means” or “step” clause as specified in 35 U.S.C. Section 112, Paragraph 6. In particular, the use of “step of” or “act of” in the claims herein is not intended to invoke the provisions of 35 U.S.C. 112, Paragraph 6.

(1) Introduction

The present invention relates to a device having an anti-reflective surface. The prior art describes many ways to make anti-reflective surfaces. For example, surface texturing to generate a surface having a low-aspect ratio is one technique for reducing reflection. However, techniques of the prior art are often expensive and result in easily damaged surfaces. Additionally, a surface with a high-aspect ratio would be more beneficial at reducing reflection than a surface with a low-aspect ratio. Manohara has reported a fabrication technique that uses a two-step dry etch process to produce high-aspect ratio silicon nano-tips. See, Manohara, H. NASA Tech Briefs 2004, 28 (11), 62.

The greatest advantage of the process described by Manohara is that it is inexpensive, simple, and that can be used on large area substrates. The process has the capability to be easily integrated with any monolithic silicon fabrication schemes. The present invention expands upon the work described by Manohara, adapting the technique of microfabricating high-aspect ratio nano-tips to create a highly efficient anti-reflective surface without using nanolithography. Described below are the anti-reflective surface fabrication technique and the optical characteristics of the nano-tips’ surface.

(2) Specific Aspects

(2.1) Basic Structure

As briefly described above, the present invention relates to a device having a high-aspect ratio, anti-reflective surface. As shown in FIG. 1, the device 100 comprises a silicon substrate 102 having a first side 104 and a second side 106. A plurality of silicon spikes 108 with nano-tips 110 are formed on the first side 104. The silicon spikes 108 are formed to have a high-aspect ratio 112 and thereby operate as an anti-reflective surface. Additionally, a first metallic layer 114 is formed on the silicon spikes 108. The first metallic layer 114 assists in absorbing light to further reduce reflection. The first metallic layer 114 is any suitable layer for blocking the transmission of light therethrough, a non-limiting example of which includes a Chromium/Gold layer. The Chromium is used as an adhesive to affix the Gold with the silicon.

(2.2) Nano-tip Formation

The basic principle of the fabrication technique is to grow micro-etch masks, which can then be etched away along with the substrate to make sharp nano-tips (for clarity, the first step will be referred to as the reactive ion etching (RIE) step and the second step will be referred to as the deep reactive ion etching (DRIE) step). In the RIE step, a cleaned silicon substrate, either with or without a pattern, is subjected to an RIE process with a carbon tetrafluoride and oxygen mixture of 95% to 8%, respectively, at a radio-frequency (rf) power of 200 watts (W), for a predetermined amount of time. This process causes the growth of a micro-etch mask (e.g., certain fluorine-based compound) on the substrate in randomly distributed sites. These growths look like short, approximately quadrilateral, cross sectional stumps with a concave top. These are familiarly known as “polymer RIE grass,” an unwanted byproduct of a dry-etching process. Depending on the process time, these growth sites may vary in their side dimension from 100 to 500 nanometers (nm) and grow as tall as a few hundred nanometers. The density of these sites decreases inversely with the process time. This is obvious as the neighboring sites merge due to growth as the process time is increased. To determine the compound creating the micro-etch masks, an Energy-dispersive X-ray spectra (EDX) is used. As shown in FIG. 2, the EDX revealed a fluorine peak 200 which indicates high concentration of fluorine in these growth sides. As shown, the relative intensities are high for fluorine, indicating a fluorine predominant compound.

In the next step, the substrate with the randomly distributed micro-etch masks is subjected to a process for forming high-aspect ratio silicon spikes with nano-tips. A non-limiting example of such a process is a deep reactive ion etching process (DRIE), which uses alternate cycles of etching and passivation. The etch gas is sulfur hexafluoride (SF$\text{}_6$), and the passivation gas is octafluorocyclobutane (C$\text{}_8$F$\text{}_{8}$). The gas flows of SF$\text{}_6$ and C$\text{}_8$F$\text{}_{8}$ are 130 and 85 standard cubic centimeters per minute (sccm), respectively. The coil power and platen power are 600 W and 140 W, respectively. The “polymer grass,” grown in the RIE step described above, acts as an etch mask in this step, slowing down the etch rate directly underneath the mask. After eight minutes of process time, this causes dramatic-looking, tall silicon, spike-like structures, with sharp nano-tips of 15-20 nm diameter. Because of the DRIE process, these tips exhibit scalloping along their height, which gives them a corkscrew-like appearance. Depending on the thickness of the micro-etch masks, these tips can be fabricated to heights in excess of 20 micrometers (µm). It...
should be noted that the final nano-tip density varies inversely as the micro-etch mask density from the RIE step. This is because an optimum thickness of the mask is required to successfully achieve sharp tips in the DRIE process (because the etch mask itself gets etched during DRIE, but at a much slower rate). FIG. 3 illustrates an exemplary, enlarged-view of high-density nano-tips 110 formed on the silicon substrate 102.

(2.3) Sun Sensor Mask Fabrication

As can be appreciated by one skilled in the art, the anti-reflection surface described herein can be incorporated into a wide array of devices. As a non-limiting example, the anti-reflection surface can be incorporated into a Micro-sun sensor utilizing a sun sensor mask. FIG. 4 illustrates a procedure for fabricating a sun sensor mask. As shown in FIG. 4A, photo-lithography is performed on the silicon substrate 402 to form a photoresist 400. The photoresist 400 defines an aperture array. Additionally, a micro-etch mask 404 (e.g., polymer “RIE grass”) is grown on the silicon substrate 402. As shown in FIG. 4B, the substrate 402 with these randomly distributed features is subjected to a DRIE process to create high-aspect-ratio silicon spikes 406 with sharp nano-tips 408. Next, as shown in FIG. 4C, a first metallic layer 409 is evaporated on the nano-tip 408 surface to absorb the infrared light, except at the apertures 410. The first metallic layer is any suitable metal, a non-limiting example of which includes Chromium (Cr)/Gold (Au).

As shown in FIGS. 4C and 4D, the photoresist 400 is removed to expose the aperture 410 below it. The photoresist 400 is removed through any suitable technique for removing a photoresist 400, a non-limiting example of which includes dipping the substrate 402 into acetone. Additionally, a second metallic layer 412 of a suitable material is evaporated on the backside of the substrate for the attenuation of sunlight. The second metallic layer 412 is any suitable material for attenuating the far-IR region (16–200 µm), because Aluminum (Al) has more absorbance than gold in the far-IR region. The 30-degree RIE times increase, the specular reflectance of the 40 min RIE silicon nanotips with Cr/Au at the target wavelength of 1 µm is about 0.9%. The same value for bare silicon is almost 35% at the same wavelength. The 30-degree specular reflectance of the 40 min RIE silicon nanotips with Cr/Au at the target wavelength of 1 µm is about 0.9%. The same value for bare silicon is almost 35% at the same wavelength. The 30-degree specular reflectance of the 40 min RIE silicon nanotips with Cr/Au at the target wavelength of 1 µm is about 0.9%. The same value for bare silicon is almost 35% at the same wavelength. In addition, as the RIE times increase, the specular reflectance decreases due to the higher density of the nano-tips. The reflectance of the substrate can be adjusted by changing the density of the nano-tips, which is determined by the “RIE-grass” growth process, as shown in FIG. 6A (the reflectance increases from a 40-min RIE surface 604 to a 5-min RIE surface 600 as 0.09% to 38.79%).

To assess the total reflectance from the nano-tip-covered surfaces, the hemispherical reflectance was measured from 0.3 to 2.5 µm wavelength range, which covers the wavelength of interest. FIG. 7 is a graph illustrating the total hemispherical reflectance of the samples with three different nano-tip densities that correspond to the RIE times illustrated in FIG. 6A (i.e., 5-minute RIE samples 700, 10-minute RIE samples 702, and 40-minute RIE samples 704). These measurements were done using the Cary 5000 UV-vis-NIR spectrometer with a Cary integrating sphere attachment. The samples were measured relative to a Spectralon (Teflon) reflectance standard from 0.3 to 2.5 µm. Once again, it can be seen that the 40-minute RIE 704 surface has the lowest hemispherical reflectance among the three measured, with ~8% at 1 µm.
wavelength. The reflectances for 10-minute 702 and 5-minute 700 surfaces are 27.17% and 86.83%, respectively.

(4) Conclusion

The present invention is a device having an anti-reflection surface with an extremely low reflectance using randomly distributed silicon nano-tips. The fabrication process of these nano-tips uses standard silicon fabrication methods and is conducive for integration with batch-fabricated silicon devices. When the RIE process times are changed, the density and aspect ratios of nano-tips can be varied and hence the reflectance can be varied. Without using nanolithography, nano-tip radii has been achieved that spans from 20 to 100 nm with an aspect ratio of 200. The specular and the total hemispherical reflectances from a dense 40-minute RIE nano-tip surface were measured to be 0.09% (relative to an aluminum surface) and ~8% (relative to a standard Spectralon surface), respectively, at a target wavelength of 1 µm. This reflectance is nearly 3 orders of magnitude lower than that of plain silicon. This process can be used in the Micro-sun sensors to remove ghost images that, otherwise, drastically decrease the accuracy of these sensors. The process developed here is reproducible from the performance point of view. That is, the nano-tip formation itself is a random process and, as a result, it is impossible to produce nanoips in the same identical location from sample to sample. However, qualitatively, the surface density of these tips is reproducible from sample to sample, which has been evident from the reflectance data of multiple samples. For example, among three different 40-minute samples tested, the measured 30 degree specular reflectance is in the range of 0.05% to 0.09%. Thus, reproduction has been verified.

As can be appreciated by one skilled in the art, although the above description utilized many specific measurements and parameters, the invention is not limited thereto and is to be afforded the widest scope possible. Additionally, although the device is described as being incorporated into a Micro-sun sensor, it is not intended to be limited to such an aspect and can be incorporated into a wide array of devices for a large variety of uses.

What is claimed is:

1. An anti-reflective device, comprising:
   a silicon substrate having a first side and a second side, the first side having plurality of silicon spikes with nano-tips;
   a first metallic layer formed on the silicon spikes, thereby forming an anti-reflection surface;
   wherein the silicon spikes are formed to have a high-aspect ratio;
   and
   wherein the silicon spikes are formed on the first side such that an aperture exists on the first side, the aperture extending from the first side to the second side and being surrounded by silicon spikes on the first side.

2. An anti-reflective device as set forth in claim 1, wherein the first metallic layer comprises a layer of chromium and a layer of gold.

3. An anti-reflective device as set forth in claim 2, further comprising:
   a second metallic layer formed on the second side of the silicon substrate, the second metallic layer having a hole formed there through, where the hole is formed to be aligned with the aperture;
   and
   a sensor apparatus attached with the spacer such that a gap exists between the sensor apparatus and the silicon substrate, thereby forming an anti-reflective device where light entering the hole passes through the aperture to be sensed by the sensor apparatus, and where light reflected by the sensor apparatus toward the first side of the silicon substrate is absorbed by the silicon spikes and is thereby prevented from being reflected toward the sensor apparatus.

4. An anti-reflective device, comprising:
   a silicon substrate having a first side and a second side, the first side having plurality of silicon spikes with nano-tips;
   a first metallic layer formed on the silicon spikes, thereby forming an anti-reflection surface;
   wherein the silicon spikes are formed on the first side such that an aperture exists on the first side, the aperture extending from the first side to the second side and being surrounded by silicon spikes on the first side.

5. An anti-reflective device as set forth in claim 4, further comprising:
   a second metallic layer formed on the second side of the silicon substrate, the second metallic layer having a hole formed there through, where the hole is formed to be aligned with the aperture;
   and
   a sensor apparatus attached with the spacer such that a gap exists between the sensor apparatus and the silicon substrate, thereby forming an anti-reflective device where light entering the hole passes through the aperture to be sensed by the sensor apparatus, and where light reflected by the sensor apparatus toward the first side of the silicon substrate is absorbed by the silicon spikes and is thereby prevented from being reflected from the first side toward the sensor apparatus.