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Antireflective light-blocking layers using a liquid top matte coating

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Abstract

Methods exist for the creation of antireflective thin film layers; however, many of these methods depend on the use of high temperatures, harsh chemical etches, or are made with difficult pattern materials, rendering them unusable for many applications. In addition, most methods of light blocking are specifically designed to increase light coupling and absorption in the substrate, making them incompatible with some applications that also require blocking transmission of light. A method of forming a simple, patternable light-blocking layer that drastically reduces both transmission and reflection of light without dependence on processes that could damage underlying structures using a light scattering matte coating over a partially antireflective thin film light-blocking layer is presented.

Keywords

Optics; antireflective; light blocking

1 Introduction

Antireflective layers are important in a wide variety of optical applications, for example, in displays and LEDs, where black layers improve the contrast.^{1,2} Black layers are also important in applications, such as radiometers and pyroelectric detectors, where these layers improve detection efficiency.^{3,4} One of the most common purposes of antireflective layers is in solar cell applications, and many of the existing methods for creating antireflective layers are targeted at this application.⁵ What these applications have in common is the need to avoid reflection not only of a single wavelength but across a broad spectrum.

Some optical applications additionally require transmission through a layer to be blocked as well as the reduction of reflection. An example is an optical sensor, which could use light-blocking antireflective layers to allow light to illuminate portions of the device but be blocked from others, preventing false signal readings from the input.⁵ Additionally, these devices are often complicated and fragile, which result in a large variety of constraints on

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the mechanical strain, temperature, and chemical processes that can be used in the application of an antireflective layer.

Because of their importance, the fabrication of broadband antireflective layers is already widely documented, but these methods often depend on processes that are not compatible with applications that need light blocking and are sensitive to temperature, chemical, mechanical, and patterning constraints. These methods can be classified into two main categories: interference based and surface structure based. Interference-based antireflective coatings work using multiple layers of thin films deposited using either vacuum deposition, sol-gel processes or nanoparticle solutions.⁵⁻⁷ These processes can be very effective, but in addition to requiring extreme layer precision, are most often used to increase transmission of light to the substrate and increase energy absorption in the device. Because of this, these processes can be difficult to use in applications where light also needs to be blocked off from the underlying devices, as index matching is difficult with layers such as metal that can be used to block light. Structure-based antireflective layers include surface etched materials, such as black silicon.⁸ However, many of these methods depend on the material of the substrate, such as the crystal structure, making them incompatible with underlying device layers. Other methods get around this by texturing layers that can be deposited include etching amorphous silicon through gold or silver nano-island masks, laser pulse etching of metal, or thin metal film deposition on roughened surfaces to create the correct surface structures.⁹⁻¹² Another method is the deposition of carbon nanotubes.¹³ These methods are good for many applications but depend upon harsh chemical etches or high temperatures in the feature creation or patterning process, which renders them unusable in some applications. Additionally, some of these layers need to be thicker to allow for opacity and complete absorption required for light blocking, which causes additional mechanical strain and renders them unusable for fragile applications.

These difficulties render many traditional methods of antireflective layers unusable, or at least highly impractical, in some applications involving optical sensors. For such devices, an effective layer needs to be tolerant to a wide variety of temperature, chemical, mechanical, and patterning restraints.

One method of reducing the complexity of the antireflective layer is to allow light scattering. Many applications avoid this because the purpose of the antireflective layer is to allow increased transmission or absorption in the device, but for applications where light needs to additionally be blocked, this is not a problem as long as the amount of light reflected in any given direction is drastically reduced enough to avoid the risk of false signal at an optical detector. Such a layer would be unusable for applications such as solar cells that depend on transmission of light, but for the devices in which transmission is unneeded or unwanted, a much simpler layer could be created as a practical and cheap solution.

This paper presents a method for creating a broad spectrum, patternable light-blocking, and antireflective layer that avoids the need for high temperatures, harsh chemical etching, rigorous patterning constraints, and precise index matching. This is done using a particle-based matte coating, such as used in nail polish, to create a broadband light absorbing and scattering layer on top of a simple, easily deposited and patterned light-blocking layer.

2 Method

Our designed structure is based on a stack of thin film materials, with the goal being to completely block all incoming light and reduce reflections across the entire visible spectrum.

2.1 Transmission Blocking Layer

The first layer of the stack is 300 nm of aluminum. This layer was selected because aluminum is easy to deposit through thermal or electron beam evaporation, can be easily patterned, and is sufficiently thick to block effectively all light transmission across the visible spectrum from reaching underlying layers.

2.2 Antireflection Layer

The first part of the antireflective layer is created using 50 nm of chrome with either 80 nm of silicon dioxide or 50 nm of silicon nitride. The purpose of these layers is to lower the overall reflectance of the base layer so that the top matte layer can be deposited on an already darkened layer. These layers were selected based on their ease of deposition with a variety of low-temperature methods and ease of patterning with lift-off or etching methods. For our tests, the silicon dioxide and silicon nitride layers were deposited using chemical vapor deposition but can also be deposited using methods, such as electron beam evaporation or sputtering. A reflectance calculator created by Filmetrics Corporation was used to optimize the thicknesses for these layers to reduce the reflectance.¹⁴ The simulated reflectance of these stacks is shown in Fig. 1.

2.3 Matte Layer

The top layer used is a particle suspension using a matte layer specifically developed to be applied over nail polish. This matte layer is readily commercially available from a large number of sources (for example OneDor)¹⁵ and by selecting a gel-based UV curable polish and can be spun on and patterned using the same process as for standard photoresist lithography. The layer contains various micron-scale silica particles in a gel-based solution. This layer is critical, because it allows the creation of a light-blocking layer on top of a layer that is only partially light blocking by itself.

Since gel-based nail polish is designed to last for multiple weeks on a fingernail, it is extremely durable for regular device usage. It can withstand a rinse with water or isopropyl alcohol for cleaning or can be removed with several minutes of soaking in acetone.

This layer is generally several microns thick, depending on the speed at which it is spun. The thickness as a function of spin speed is shown in Fig. 2. This test was done by spinning the matte coating on at different speeds and measuring the thickness from the substrate to the top of the matte layer using a Tencor Alpha 200 profilometer.¹⁶

The reflectance of the matte layer can be reduced by subjecting it to high temperatures. The matte layer designed to coat nail polish has the helpful property that it carbonized at relatively low temperatures, allowing a darkening effect such as that achieved by heating photoresist, but at a much lower temperature, allowing darkening for more temperature sensitive devices. The matte layer continues to darken as temperature increases, and if the

underlying layer is able to withstand higher temperatures, the overall reflectance can be further reduced. This improvement is reported in Sec. 3.

The overall stack for the layers created here is shown in Fig. 3.

3 Results and Discussion

The specular reflectance as a function of wavelength for the layers both with and without the matte layer is shown in Fig. 4. The matte layer was baked at 250°C. The test was done using a Filmetrics F20 film measurement system.¹⁷ The F20 series is reported to be able to measure reflectance accurately enough to predict the thickness of oxide layers to within 0.4%.

As shown in Fig. 4, the reflectance of the layers with the top matte coating after a 250°C bake is very low. It is noted that in comparison to Fig. 1, although the result for Si_3N_4 is comparable to the simulated results, the SiO_2 is significantly different, suggesting that the oxide deposited by our test resulted in a different refractive index. It is additionally noted that the Filmetrics F20 is not optimized for measuring rough scattering surfaces; although this shows that the reflectance is very low and is usable for determining relative reflectance, the exact reflectance cannot be accurately determined using the F20 alone. Furthermore, testing is shown later in this section. As shown in Fig. 4, the reflectance across the entire spectrum can be reduced without dependence upon precise refractive index matching. The matte layer drops the reflectance sufficiently that even a partially darkened layer can be used to create an effective antireflective layer.

The improvement of the layer with temperature for different thicknesses across the visible spectrum is shown in Fig. 5.

Since the matte layer causes scattering, additional testing was needed to determine the diffuse reflection as well. A test was done using a Newport integrating sphere using a red laser at 633 nm to find the total specular and diffuse reflection.¹⁸ The results are shown in Table 1. As shown in the table, the specular reflection is low at 633 nm, but using silicon nitride instead of silicon oxide drastically reduces the diffuse reflections by absorbing more light.

An SEM showing the structure of the matte layer is shown in Fig. 6. As shown in the figure, the matte layer contains micron-scale silica particles of varying size from $\sim 10\text{ }\mu\text{m}$ down to 100 nm. Because of these particles, some of the light incident on the matte layer is absorbed, but most of it is scattered, dramatically reducing the intensity of the reflection at any given point.

This layer is not only easily patternable but has a lower spectral reflectance than many of the other existing methods for creating black light-blocking layers. A comparison of overall reflectance is shown in Table 2. As shown in Table 2, the layer is comparable to or better than low-temperature methods as reported in the literature.

4 Conclusion

This paper presents a method for depositing a light-blocking layer that effectively reduces the reflection and transmission of light. Because of its simplicity, this layer can be easily deposited and patterned and can be created using a wide variety of methods, including low-temperature options, which makes it useable with a larger variety of light-blocking applications than other methods.

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Biography

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Aaron Hawkins received his BS degree in applied physics from Caltech 1994 and his PhD in electrical and computer engineering from the University of California, Santa Barbara in 1998. He was a cofounder of Terabit Technology and later worked at CIENA and Intel developing optical communications components. Currently, he is a professor in the electrical and computer engineering department at Brigham Young University, Provo, Utah. He has authored or coauthored over 350 technical publications.

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Fig. 1. Simulated reflectance of 300-nm Al, 50-nm Cr with 80-nm SiO₂, and 300-nm Al, 50-nm Cr with 50-nm Si₃N₄. Data generated by online reflectance calculator provided by Filmetrics Corporation.

Fig. 2.
Thickness in microns of the matte coating as a function of spin speed.

Fig. 3. Layer stacks showing the overall structure of with (a) 80 nm of oxide and (b) 50 nm of nitride.

Fig. 4. Overall measured reflectivity of stacks with matte layer using Filmetrics reflectivity measurement.

Fig. 5.
Average reflectance across the visible spectrum of the matte layer with bake temperature at 1500 and 2500 rpm.

Fig. 6.
SEM image of matte layer.

Table 1

Specular and diffuse reflectance for completed layers.

Layer	Specular reflectance (%)	Diffuse reflectance (%)
Si ₃ N ₄ + matte	0.9	5.56
SiO ₂ + matte	1.2	10.9

Table 2

Average reflectance for a variety of different antireflective layers.

Method	Average specular reflectance (%)
Matte layer nail polish with nitride	1
Black silicon ⁸	5
Nano-island-etched silicon ⁹	5
Laser-etched platinum ¹¹	5
Dielectric layer stacks ⁵	0.2
Carbon nanotubes ¹⁹	0.01
Sol-gel ⁷	1
Index alternated nanoparticles ²⁰	0.03