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SCRATCH-RESISTANT ANTIREFLECTION COATING

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Abstract
A scratch resistant, antireflection coating can include a plurality of layers of alternating high and low refractive index materials. In some cases, a ratio of the total thickness of the high refractive index materials to the total thickness of the low refractive index materials can be greater than 3.0, and the nano hardness of the antireflection coating is greater than 15 GPa. In some cases, hard materials can be used for both the high and low refractive index material layers, and the nano hardness of the antireflection coating is greater than 15 GPa.

Many optical elements, including lenses, windows, emissive displays, etc. include an antireflection coating to reduce reflection and glare from the element. Displays of electronic devices, for example, consumer electronics devices, can include antireflection coatings to reduce glare and reflection of light from a surface of the display, so as to improve the contrast of information rendered on the display and to improve the readability of information during high ambient light conditions. Such consumer electronics devices can include, for example, laptops, tablets, mobile phones, wearable devices (e.g., wristwatches, fitness, and health monitors, etc.), and the like.

Antireflection coatings on a surface can include a stack of layers of materials having different optical properties (e.g., a refractive index of the material), so that destructive interference of light reflected from the interfaces of the different layers results in a smaller amount of light reflected from the coated surface as compared with the amount of light that would be reflected from the surface without the coating. For example, an antireflection coating can include multiple alternating multiple layers of high refractive index material (e.g., niobium pentoxide (Nb_2O_5)) and low refractive index material (e.g., silicon dioxide (SiO_2)). In some implementations, the coating can include fewer than 10 low refractive index layers and can have a total thickness of less than 500 nm. However, many antireflection coatings are relatively soft in comparison with the glass substrate that they coat, and they can be easily scratched. For example, many coatings can have an estimated nano hardness of less than 5 GPa. Some antireflection coatings can include high refractive index materials (e.g., silicon nitride (SiN or Si_3N_4) that increase the hardness and the scratch resistance of the coating, but even with such materials, the estimated nano hardness of the coating generally is less than 10 GPa, and such coatings may not prevent scratches and damage to the coating into an underlying class substrate of the display to a desired degree.

However, antireflection coatings that also are hard enough to prevent scratches and physical damage to the coating and to the surface of the display can be created by including a sufficient amount of hard material in the layers of the coating. For example, the high refractive index layer material, in many cases, can have a higher hardness than the low refractive index layer material, and by using a sufficiently high ratio (e.g., greater than 2.5, greater than 3.0, greater than 4.0) of high refractive index material to low refractive index material in the layers of the coating, the hardness of the coating can be sufficiently high (e.g., greater than 15 GPa) to prevent scratches and damage to the coating and to the underlying surface. For example, high refractive index layers can include hard material, such as, for example, silicon nitride and/or aluminum oxide (Al_2O_3), and low refractive index layers can include aluminum oxide and/or silicon dioxide.

The layer composition of one example antireflection coating that coats a glass surface is shown in Table 1. The high refractive index layers of the coating include silicon nitride and the low refractive index layers include silicon dioxide. An outermost layer of the coating, which interfaces with air, includes a silicon dioxide layer that is less than 150 nm thick (e.g., 84.88 nm), and the total thickness of the coating is 2309.51 nm. The coating includes one silicon nitride layer that is the first layer beneath the outermost low refractive index layer and that has a thickness of 1486.66 nm. In addition, the total thickness of all the silicon nitride layers is about 1775 nm, and the total thickness of all the silicon dioxide layers is about 534 nm, such that the ratio of the total thickness of the high refractive index layers to the total thickness of the low refractive index layers is greater than 3.3, and the ratio of the thickness of the thickest high refractive index to the total thickness of the coating is greater than 0.4, and is greater than 0.5, and is greater than 0.6. Because of the high ratio of the high refractive index material to low refractive index material, and because of the thick high refractive index material layer closest to the outermost layer, the estimated nano hardness of the coating is greater than 15 GPa, and the scratch-resistance of the coating is enhanced.

Glass	
SiN	11.62
SiO2	66.25
SiN	16.64
SiO2	102.82
SiN	15.37
SiO2	51.87
SiN	143.62
SiO2	30.5
SiN	14.11
SiO2	59.78
SiN	12.46
SiO2	75.58
SiN	28.04
SiO2	46.04
SiN	44.55
SiO2	18.72
SiN	1486.66
SiO2	84.88
Total (nm)	2309.51

Table 1

A graph showing a calculated reflectance (in percent of incoming light that is reflected) of the layer (on the y-axis) vs. a wavelength of incoming light for the coating of Table 1 is shown in Figure 1. As seen from Figure 1, the coating reduces the reflectance of the surface over all visible wavelengths below the typical value of 4.0 percent for an uncoated glass/air interface.

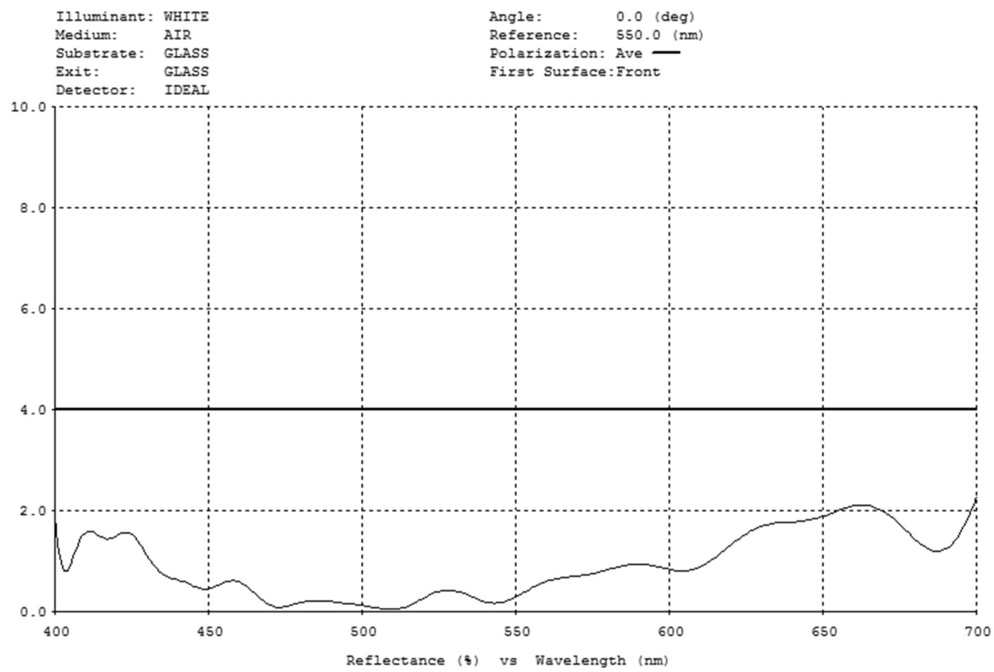

Figure 1

In another example, an antireflection coating can include two thick (e.g., 400 nm to 1500 nm) high refractive index material layers among a plurality of 10 or more layers, with an outermost low refractive index layer. In another example, an antireflection coating can include three thick e.g., 250 nm to 1000 nm) high refractive index material layers among a plurality of 10 or more layers, with an outermost low refractive index layer. The ratio of the total thickness of the high refractive index layers to the total thickness of the low refractive index layers can be greater than 3.0.

The layer composition of another example antireflection coating that coats a glass surface is shown in Table 2, in which the high refractive index layers include silicon nitride and the low refractive index layers include aluminum oxide, with one 88.05 nm thick silicon layer layer as the outermost layer that interfaces with air. The total thickness of the coating is 1553.55 nm. In this example, the coating includes only one relatively thin layer of low hardness material in the outermost silicon dioxide layer, while the remaining layers of silicon nitride in aluminum oxide have relatively high hardnesses. Thus, both the high refractive index layer material and the low refractive index layer material have relatively high harnesses and the total estimated nano hardness of the coating is greater than 15 GPa.

Glass	
Al2O3	84.28
SIN	31.52
Al2O3	30.44
SIN	19.7
Al2O3	155.69
SIN	10.47
Al2O3	12.67
SIN	8.69
Al2O3	166.87
SIN	69.66
Al2O3	20.72
SIN	28.52
Al2O3	83.2
SIN	128.12
Al2O3	81.6
SIN	31.98
Al2O3	17.81
SIN	72.16
Al2O3	82.71
SIN	22.79
Al2O3	28.72
SIN	70.5
Al2O3	85.86
SIN	14.24
Al2O3	41.23
SIN	65.35
SiO2	88.05
Total (nm)	1553.55

Table 2

A graph showing a calculated reflectance (in percent of incoming light that is reflected) of the layer (on the y-axis) vs. a wavelength of incoming light for the coating of Table 2 is shown in Figure 2. As seen from Figure 2, the coating reduces the reflectance of the surface over all visible wavelengths significantly below the typical value of 4.0 percent for an uncoated glass/air interface.

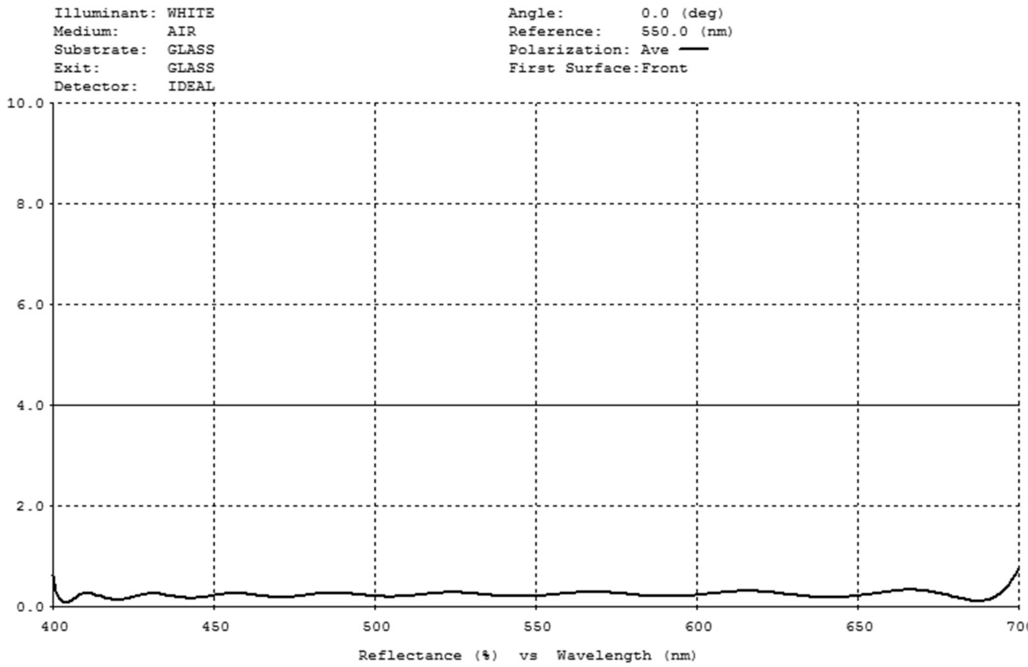

Figure 2

While certain high and low refractive index materials have been mentioned above, other materials also can be used. For example, ZrO_2, TiO_2 and Ta_2O_5 can be used as high refractive index materials in a coating layer stack, and SiO_2, Al_2O_3 or MgF_2 can be used as low refractive index materials in a coating layer stack. It is noted that aluminum oxide is disclosed as a possible high refractive index material when used in combination with other materials (e.g., silicon dioxide) having a lower refractive index, and is disclosed as a possible low refractive index material when used in combination with other materials e.g., silicon nitride having a higher refractive index. Thus, whether a particular material is characterized as a high or low refractive index material depends on the context in which it is used in an antireflective layer stack. However, the materials selected for the coatings and their thicknesses in the coatings result in a nano hardness of greater than 15 GPa.