Picture Paints a Thousand Words: Optical Interference and Langmuir Blodgett Thin Films

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AR. Anti-reflection nanocoatings were discussed as early as 1938. Coating with 102.8 nm thickness was applied to *both sides* of glass by an associate of Nobel Laureate Irving Langmuir of General Electric. The associate was Katherine B. Blodgett. She used this *Nano coating* to make glass form being visible (Washington Post 12-27-1938). Pure glass is found to transmit 92% of light. 99% of light was transmitted after Ms. K. B. Blodgett coated the glass. The coated pane could only be viewed using the edges per the news clip 'Woman Scientist Discovers Coating to Make Glass Invisible'. Clocks dial faces and showcase glasses and window panes cease to be visible. Light is not reflected from any angle. This can be used in eyeglasses to keep wearers to be bothered by light reflection or stray beams from side or behind. Camera lens with 8% less reflection can be prepared. Some cameras with 3-4 of these lenses can be used to achieve a 25-35% light transmission. The chemical formula of the coating is not yet made public and the process was not on the market for commercial sale.

Thin films devices based on constructive interference principles can be used in order to make dielectric mirrors, interference filters, color TV cameras, heat reflectors and oil slick imaging.

Coatings that can be found during the *iridescence* of butterfly, soap bubbles and sea shells was touched upon under 'How Nature Stages Her Most Colorful Light Show', in Washington Postdated 06-14-1995. According to the Merriam-Webster dictionary, iridescence is defined as a lustrous rainbow like play of color caused by differential refraction of light waves that tends to change with changes in angle of view. The word 'iris' comes from the Greek goddess of rainbow.

The iridescence of butterfly wings, soap bubbles can be explained using optical interference principles. *Vibrating blue* color of wings of butterfly can be seen from low flying airplane windows. Why does Japanese beetle's wings' color change from gold to green? The blue glow of neton tetra in a tropical fish tank, pearly pinks and blues of an abalone shell, deep purple of a raven's back, red of a ruby throated hummingbird, rainbow of an oil slick can be explained using light interference principles. The nature of the *reflecting surface* is important. The surfaces can be *smooth* or rough. Optical paths from the smooth surface and *corrugated* surfaces can lead up for different changes in light color patterns in the eye.

Light travels as *waves*. The incident light rays get *refracted* and *reflected* from the surfaces of the butterfly wings. When two rays get superposed, during *constructive interference* they become stronger and the color is striking. The amplitude of the resulting wave is greater than the amplitude of the reflected rays. When the resulting amplitude is smaller, destructive interference is said to occur. *Destructive interference* can lead to cancellation of color as seen from Figure 1. The smoothness of the surface the rays get reflected from is a salient consideration. When the surface is rough the light rays may diffract. *Diffraction* is associated with bending of light waves or sound waves as the case may be. Sound from the class rooms heard by the principal as he walks past classrooms is an example of sound diffraction. The Huygens-Fresnel principle states that light wave incident on two slits will spread out and exhibit a pattern. This pattern is called *diffraction pattern*.

Sir Isaac Newton recognized 6 colors. Orange is the 7th color. Each color light has a different wavelength and frequency. The speed of light can be calculated by multiplying the wavelength with the frequency. Violet has the shortest wavelength and red has the longest wavelength. When an object appears a certain color it is due to the absorption of all colors but the one the eyes see. Objects that are found to iridescence tend to quell some colors and intensify some colors and the eye sees the result of *optical transformations*. Newton observed that the cause of the colors of peacock feathers was more than shear pigmentation. It can be because of interaction of light waves and *interference*. The arrival of the SEM, *scanning electron microscope* and better understanding of the wave nature of light took several years after the discourses of Sir Isaac Newton. Helen Giradella a biologist at the State University of New York at Albany has studied butterfly colors and moth scales using scanning microscopy and other characterization tools. The light patterns seen from iridescence are physical colors. They can be distinguished from colors from pigmented or painted surface. The color from pigmented surfaces is from chemicals. In the case of butterfly, yellow and rusts of the monarch come from chemicals. Ghiradella's SEM image of the wing of butterfly reveals that it is covered with overlapping rows of scales. The scale thickness falls in the micron range. *Ridges, lamellar, microribs* and other microstructural features of the wings of butterflies can be seen as a result of what is called in introduction to physical science class as '*thin film interference*'. Incident light rays penetrate layered materials and get reflected from each layer. The thickness of the layers plays a significant role in reflection of light. The light colors that get reflected, intensified or cancelled depend on the surface smoothness and layer thicknesses.

In X-ray diffraction analysis the 14 Bravais lattice structures are identified using reinforced light waves. Microribs were found perpendicular to the lamellae stacks. This is called *rococo architecture*. Other microstructures found were rolled-up layers seen in *bristle* scales of *astraptesazul* butterfly. The distance between the rolled-up layers is ~ 1/4th the wave length of green light (100 nm). This is a plausible reason for iridescent green seen from this butterfly. Honeycomb like diffraction lattice structure was seen in the butterflies from Peru. The intercavity distance of the insect is 260 nm. This leads up for green color seen from these butterflies. Bristle morphology is analogous to 'quarter wave interference mirrors" used in solid-state lasers. Constructive and destructive interference optical transmission can be the causative factor in dimmer of light seen from astraptes.

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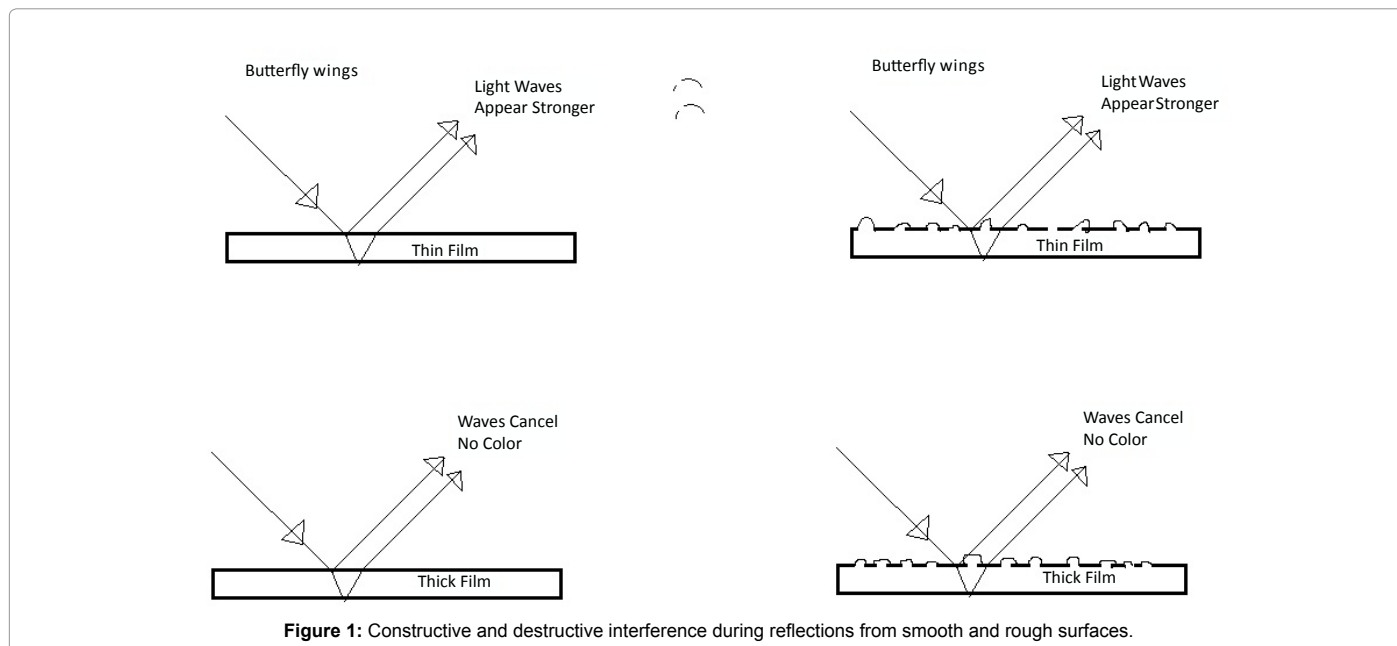
Figure 1: Constructive and destructive interference during reflections from smooth and rough surfaces.

Cells from the human dermis after lysis form a *protective coating*.

Butterfly epidermal cells also form a coating upon cell death. According to H. Ghiradella "…scales are highly structures, scale formation is a virtuoso exercise in biological pattern formation at the cellular level". The scales change during the metamorphosis from caterpillar into a butterfly. Carbohydrate based polymer such as chitin is secreted from epidermal cells as a covering. Upon lysis the cuticle buckles and curls. This is caused by the forces of contraction. The final morphology is after the mechanical transformations including some fracture. Metallic green of tiger beetles, multicolored sheens of pigeon feathers, polished brass look of scarab beetles, luster of June beetles and iridescence of blue fruit flies – *Elaeocarpus Angustifolius.*

Danainae is a tropical butterfly subfamily. The pupa stage of this butterfly looked like lima bean shaped polished gold hanging from the undersides of leaves. Their optical properties were examined by two German researchers. The exterior had a shining golden luster but for a few spots of pigments. The pupa surface was found to comprise of 520 alternating layers of chitin-based cuticle and water with the distances between succeeding layers changes continuously. This makes them broad-band interference reflectors. Color changes come about as the surface dries out. Prof. G. W. Kattawar of Texas A&M University, College Station, TX explained the polished brass look of scarab beetle species.

Anti-reflection coating can be used in solar cells for the purpose of increasing the *light to electricity conversion efficiency* [1]. Gaze Nanotech Corp., Saratov, Russia has obtained a patent [2] for a solar cell device that comprises of a photovoltaic cell and an efficiency improving antireflective nanocoating film. The thickness range of the coating falls between 100-100 μm. Dielectric material with metal nanoparticles with diameters of 4.5-10 nm is dispersed in the coating solution. The nanoparticles cluster formation at the *mesocopic level* can be the attributable cause for the increase in transmission of light. Polymer solution with well dispersed nanoparticles of gold, silver and another diamagnetic metal is used. The thin film coating is formed by *heat treatment* and *drying* at certain temperatures and times. There are two approaches to increasing the solar cell efficiency: (i) one is

by developing novel photovoltaic materials and other nanoelectronic structures and the other is by; (ii) secondary methods such as increasing the transmittance of light into the cell and minimizing the radiation losses from the bottom surface. The first generation of solar cell devices boasted a light to electricity conversion efficiency of about 6-9% and was made of amorphous silicon. Breakthrough research has led to solar cell devices that can operate with 30% light to electricity conversion efficiency. Losses stem from reflection of light from the cell and radiation losses from the bottom of the cell.

Over 10% increase in transmittance can be observed upon use of nanostructured coating on *both sides* of a glass slide [3] compared with uncoated glass. Nanostructured silica is used as antireflection coating. For angle of incidences less than 70° the transmittance of nanostructured coated glass was found to be *about 99%,* up from 92% for broadband transmittance between 350-1800 nm. Oblique angle SiO_2 nanowires and nanorods can be used to prepare advanced nanostructured antireflection coatings. These can be used in next generation sensors and optical windows. In this approach the reflection losses are minimized. AR coatings are critical to the development of EO/IR electro-optical/infra-red sensors and photo voltaic, PV sources. AR coatings can be designed using a GA, genetic *algorithm* and fabricated using *oblique angle deposition* [2]. They have developed an analytical model that can be used to predict the porosity and deposition rate of nanoporous films grown by oblique-angle deposition. One fitting parameter is used to account for *geometrical* factors and *surface diffusion* phenomena. The *porosity* and deposition rate were obtained from the measured refractive index and thicknesses of SiO_2 and ITO, indium tin oxide nanoporous films as a function of various incident angle of deposition. Model can be used for predictive control of refractive index, porosity and deposition rate for a wide range of deposition angles and materials.

Refractive index of the coating is an *important parameter* in the design of solar cells and other optical devices where the coating is applied. Materials with n, refractive index in the range of 1-1.4 are limited. Aerogels may foot the bill but the control of its thickness is difficult. Prof. F. Schubert's research group [3] deposit silica nanorods

by evoporation. They obtain good control of refractive index by varying the angle of incidence. They obtain a material with refractive index of 1.1 for an incident angle of 80°, material with n=1.07 at an incident angle of 85°. A *world record* for material with low n=1.05 was obtained at an incident angle of 87°. They conduct research in development of *graded-index AR*, anti-reflection coatings for a new class of optical materials. Standard AR coating is 0.25λ thick and zero reflectivity is seen at one wavelength. This can be used in some applications. The electromagnetic spectrum from the sun is broader in scope, ranging from uv, ultraviolet and IR, infrared.

The principle of total internal reflection is used to obtain *zero transmission losses*. When optical ray travels from a denser to rare medium the angle of refraction will be greater than the angle of incidence. At some higher angle of incidence the angle of refraction would be greater than 90°. This would mean the ray that was to be refracted has been totally internally reflected. They deposit five layers of decreasing refractive indices. The difference in refractive index between two adjacent layers is small. The output efficiency of LEDs can be improved by use of AR coating. Another application is in the area of *super luminescent* diodes. High reflectance mirrors and Bragg reflectors can use AR coating.

Fresnel reflection can be eliminated from an interface of AIN/air, aluminum nitride. *E-beam evaporation* was used [3] in order to grow porous nanostructured materials by use of oblique angle deposition technique. Directional vapor flux is used to create a variety of optical structures. Surface diffusion, self-shadowing phenomena may have significant effect in the deposition process. A shadow region is created from random growth fluctuations on the substrate where the incident vapor flux did not arrive. Shined regions are where upon the incident light is found to deposit in a directional manner. An oriented structure such as nanorod is formed. High porosity is a feature of this method. Self-organization is evident and only some materials possess this capacity. GA, genetic algorithm is used to optimize the AR coating performance. Multi-layer coatings with co-sputtered and porous nanostructures can be designed. 90% porosity at an=1.05 was achieved.

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