Nano-optical devices consist of components whose optical properties are partially or entirely dependent on a nano-structured layer, usually a subwavelength-scale grating. The optical properties result from a combination of structural properties related to the shape and dimensions of the subwavelength structure and optical properties (usually index and absorption spectrum) of the materials. Effective design involves tradeoffs of structural and material properties to achieve the desired performance.

A generic nano-optic device consists of a nano-structured layer, a substrate, and a set of thin-film layers (see figure). The submicron-thick nano-structured layer, usually a grating, features a nano-structured material interleaved with another fill material. These can be dielectrics, metals, III-V materials, and others. The substrate, usually glass, can also be an optically functional material and may already be part of the overall system design. The set of thin-film interface layers generally consists of a back-side anti-reflection coating (ARC), an index-matching layer between the substrate and the nano-structured layer, and a top-side ARC.

The nano-structured layer is commonly a 1-D grating, but more complex structures can be used for more sophisticated designs. The dimension for the grating period is generally on the order of \( \lambda/5 \), typically from 100 to 300 nm. Additional nano-structured layers, interleaved with thin-film layers, can be stacked to create aggregate serial optical functions.

Nano-optical devices can be designed to function as retarders (wave plates), polarizers and polarization beamsplitters, narrowband and bandpass spectral filters, micro-lenses, and diffusive structures such as ARCs. Beyond the desired optical function, key application requirements include operational wavelength range, optical performance, physical dimensions, surface-quality and uniformity, storage and operating environments, handling, and reliability/life span.

Appropriate combinations of nano-structure design and materials choices can address each of these requirements. The optical function of the device is determined primarily by the shape and dimensions of the nano-structure: We use 1-D gratings to create retarders and polarizers; 2-D gratings for resonant-grating filters and diffusive structures; concentric rings for lenses; metal gratings, either aluminum or gold, for polarization structures; and dielectric materials for retarders and filters. Specific structural dimensions vary with the optical properties of the materials used.

The absorption properties of the materials determine the operational wavelength or wavelength range of the device. Materials selection also impacts environmental robustness and reliability. The grating fill material, if other than air, serves to improve the physical integrity of the device, especially with regard to cleaning and other handling.

Trading off materials choices with nano-structure physical design offers a means for improving manufacturability. This is done by selecting materials that are easier to deposit and etch with the accuracies required, coupled with design parameters that minimize the effect of manufacturing process variations on optical performance. The difference in index between the nano-structure grating material and the fill material, for example, can be selected to create very different effects: A large index contrast will create a larger birefringence suitable for quarter wave plates and the like; a small index contrast, using the same base structure, will result in fine-scale birefringence suitable for trim retarders.

The physical dimensions of a nano-optical device are not inherently dependent on the structure or materials, but they will influence the manufacturing process. Uniform wafer-scale monolithic structures, for instance, allow more efficient use of wafer real estate. Similarly, surface quality and uniformity requirements are primarily dependent on the uniformity of the substrate and the materials deposited in the construction of the nano-optical device.

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