Photonics Solutions for the Design Engineer

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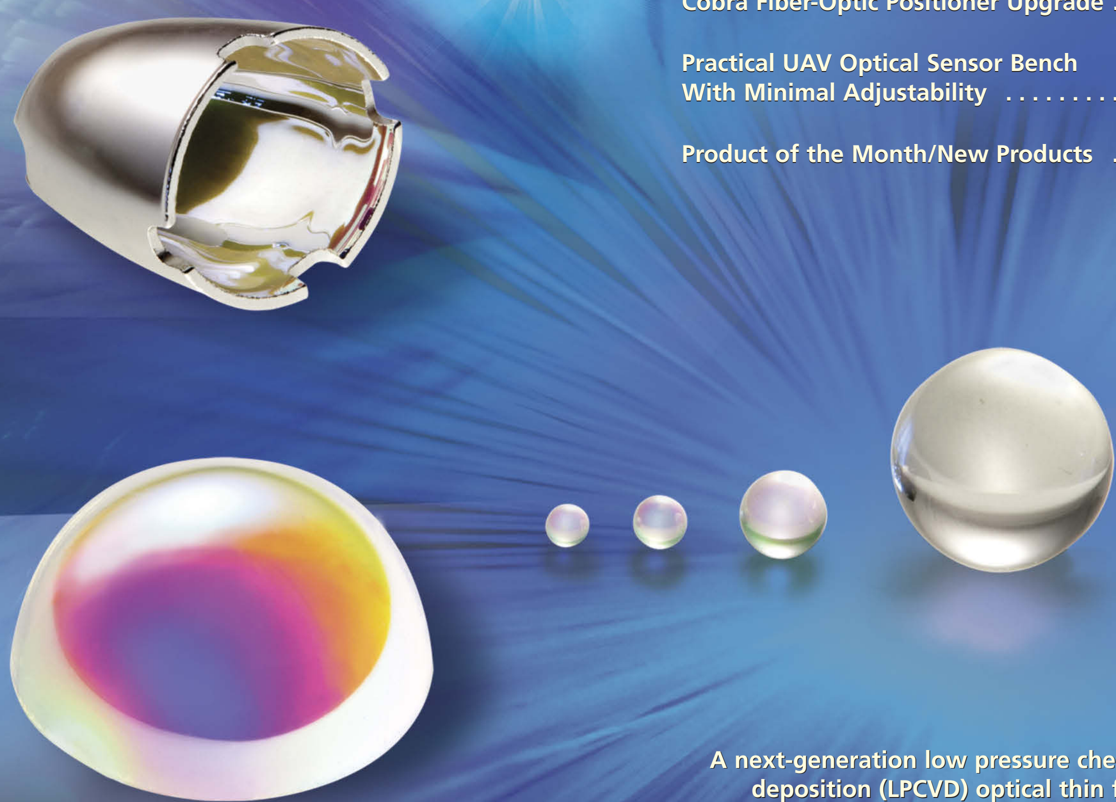
# PTB™

## Photonics Tech Briefs





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*(Image courtesy of Deposition Sciences, Inc.)*

Supplement to *NASA Tech Briefs*

# Optical Thin Films on Complex Substrate Geometries

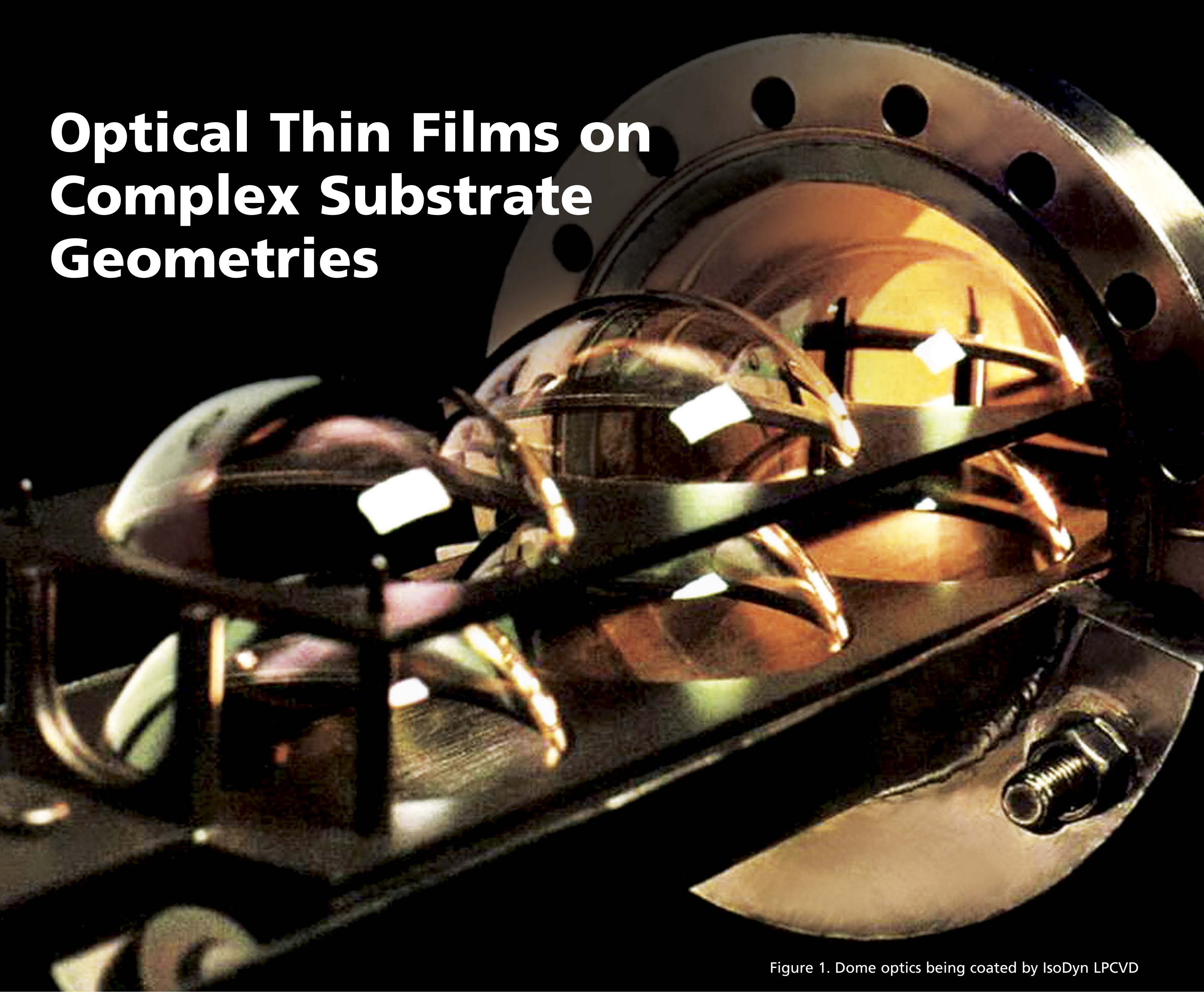

Figure 1. Dome optics being coated by IsoDyn LPCVD

A next-generation low pressure chemical vapor deposition (LPCVD) optical thin film coating process is permitting the manufacture of interference filter coatings, such as single wavelength, dual band and broadband AR, cold mirror, dichroic, and conductive. The enhanced thin film IsoDyn™ process, designed by Deposition Sciences, Inc. (DSI) is now being used to produce conformal coatings on complex substrate geometries. This capability allows for a myriad of new applications that may require uniform, multilayer coatings on complex shapes, ranging from simple ball lenses to almost any imaginable optical shape.

With broad wavelength coverage from 300nm to 5µm, the new LPCVD thin film technology opens the door for novel optic designs. Such designs may not have been considered in the past due to the limitations of more common deposition methods such as evaporation or sputtering. While excellent for some applications, these deposition methods cannot match the conformal coverage and coating uniformity that LPCVD offers for non-planar and asymmetrical optical components (Figure 1).

## LPCVD Process

The IsoDyn low pressure chemical vapor deposition process is similar to technology commonly used in the semiconductor industry. It has been optimized to produce pinhole-free, low particulate, high-quality optical coatings with excellent surface quality. Scratch/dig quality of a substrate surface is not degraded by deposition and films of low surface roughness (i.e. < 5nm) can be obtained.

LPCVD is essentially a thermal process used to deposit thin films from gas-phase precursors at subatmospheric pressures. Deposition occurs by diffusion of reactants onto a heated substrate surface, where an irreversible surface reaction takes place. The chemical reaction at the surface could be one of a number of possible mechanisms including thermal decomposition (pyrolysis), reduction, hydrolysis, oxidation, carburization, and nitridation. The hot substrate, commonly in excess of 400°C, provides the energy for the reaction to occur.

LPCVD differs from other deposition processes like evaporation, sputtering, and even atmospheric chemical vapor deposition (CVD) in a number of important and advantageous ways. Physical vapor deposition (PVD) techniques, such as evaporation and sputtering, are limited to line-of-sight geometries, and cannot be used to coat deeply recessed shapes. LPCVD, on the other hand, can easily provide uniform coatings on all substrate shapes including deeply recessed shapes and even tubes, due to its small mean free path. The mean free path, the average distance between molecular collisions, is many orders of magnitude smaller for LPCVD than for PVD. This means that there are many more collisions between atoms and molecules in the gas phase prior to encountering the substrate. While a "billiard ball" model is often used to describe PVD processes, CVD is more comparable to fluid flowing through a pipe. Put simply, with LPCVD all exposed surfaces are going to get "wet". Furthermore, LPCVD does not require the high vacuum (very low pressures) that is needed for PVD.

When compared with atmospheric CVD, LPCVD enables more uniform conformal coatings. Due to the reduced pressure and elevated deposition temperatures used in LPCVD, thermal diffusivity is large, thus facilitating an even distribution of reactants within a given cross-section of the deposition chamber. Proper consideration of the flow conditions is one of the keys to the successful development of CVD processes (Figure 2). LPCVD is characterized by continuum flow conditions operating within the laminar regime. Reactor geometry is a critical factor to be considered in LPCVD process setup and optimization.

These fundamental properties of LPCVD enable deposition processes to be developed that provide uniform coverage on all surfaces of the substrate. This attribute has led to the wide use of LPCVD within the semiconductor industry since excellent step coverage of micron and submicron features can be similarly obtained. In contrast, the large mean free path and molecular gas behavior that characterize PVD processing provide for mainly line-of-sight deposition.

## Materials

Unlike sputter or evaporative processes which use solid targets as source materials, CVD processes utilize a wide variety of chemical compounds typically referred to as precursors. There are 3 major classifications of precursors within the CVD world: metal hydrides, metal halides, and metal-organics. Within the realm of metal-organic CVD (MOCVD), there exist a large number of potential precursor materials. In fact, there are over 100 metal-organic compounds available just for tin. Selection of an appropriate precursor material is a key aspect of LPCVD deposition. Important considerations in the selection of a source precursor material include the reaction temperature, purity requirements, reaction pathways, and the ability to suitably vaporize the material and deliver it to the substrate surface.

Proper handling of precursor source materials and by-products is an important aspect of CVD, as some materials can be hazardous to people, animals, and the environment. Abatement is often achieved through the reaction of by-products at very high temperatures, followed by chemical scrubbing, absorption, and/or condensation techniques to separate by-products from the effluent stream.

A wide range of materials have been deposited using CVD techniques. These include metal oxides, transparent conductive oxides, nitrides, carbides, semiconductors, pure metals, and synthetic diamond. Accordingly, the number of potential applications is immense. Coatings produced by CVD can be used in the aforementioned multi-layer interference stacks as protective coatings for diffusion, corrosion, and wear resistance, and in a variety of photovoltaic, semiconductor, and fiber-optic-based systems.

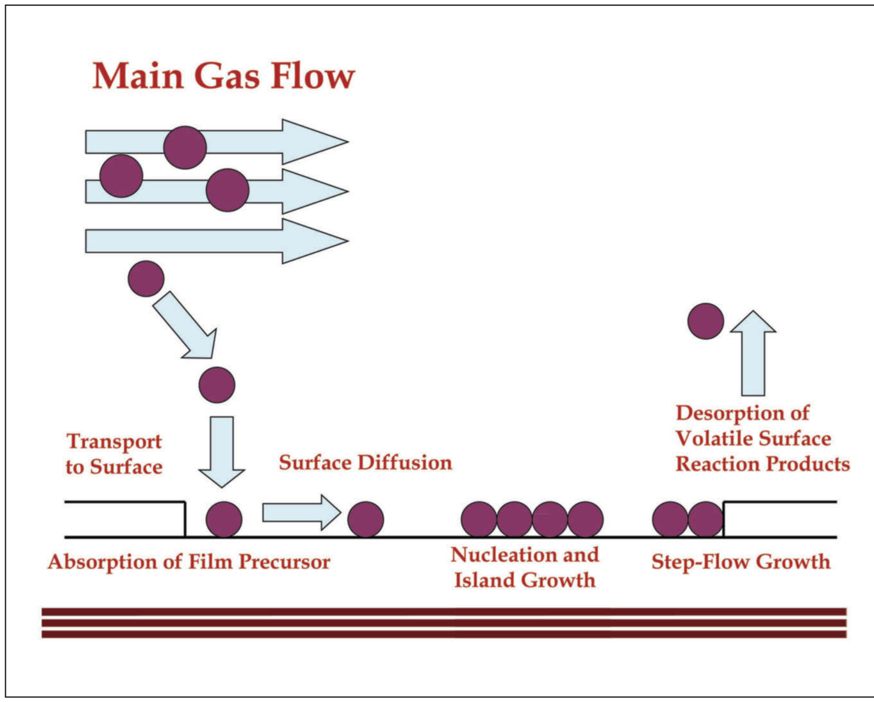


Figure 2. Schematic of film growth mechanism by CVD.

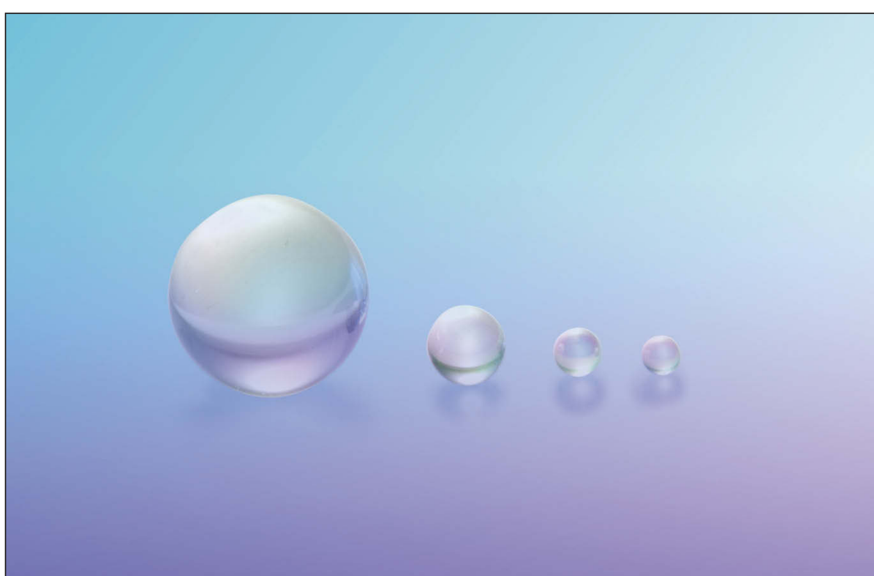

Figure 3. Ball lenses used in fiber-optic coupling systems with AR coating.

## Transparent Conductive Optical Coatings

A wide array of transparent conductive oxides (TCOs) have been deposited via CVD including fluorine-doped tin oxide (SnO:F), aluminum-doped zinc oxide (ZnO:Al), antimony tin oxide (SnO:Sb), and indium tin oxide (ITO), to name a few of the more common materials. TCOs are characterized by excellent transmission in the visible range, while possessing significant electrical conductivity. Due to the abundance of free carrier electrons, these materials can be highly reflective at infrared and longer wavelengths when sheet resistance is suitably low. Applications include electrodes, antistatic coatings, energy efficient low-E glass, and RF-blocking coatings for security applications. The use of such materials on substrates of complex shape may be an area for future growth, providing new options for system design.

Figure 4. Example of cold mirror reflectors coated by IsoDyn LPCVD process.

## Applications

DSI's IsoDyn LPCVD process has been successfully employed to coat a wide variety of different surfaces including parabolic concentrators, dome optics, ball lenses, optical fibers, tubes, and other non-planar substrates. DSI has considerable experience in the telecom/datacom industry with high quality, conformal AR coatings on ball lenses (Figure 3). The AR coatings produced by the LPCVD process provide 100% coverage on each ball lens, eliminating any orientation considerations. This, in turn, provides for a reduction in the manufacturing costs associated with the assembly of optical fiber couplers/collimators — typically operating in the wavelength range between 1.30μm to 1.57μm.

Today, ball lenses are finding use in new fields beyond fiber coupling. One area of increasing interest is in the field of concentrated photovoltaic (CPV) power generation. Placed at the center of an array of mirrors, a large-diameter ball lens can be used to focus solar energy onto a high-efficiency solar cell. This system takes advantage of the optical properties of ball lenses to collimate diffuse light into a tightly focused beam. The application of an antireflective coating can be used to improve system efficiency by up to 6.5% through minimization of reflectance losses. The IsoDyn LPCVD process is capable of coating ball lenses ranging in size from 200μm to 200mm with single, dual band, and broadband AR coatings, as well as more complex optical filter designs.

The LPCVD process has also been employed by DSI in a variety of reflector applications covering a wide range of component geometries. The coatings deposited on reflectors range from broadband visible cold mirror designs, shortwave pass, longwave pass, and dichroic filters. The capability exists to handle part sizes up to 8" × 12".

The new capability to produce coatings covering the spectral band range from 300nm to 5μm, encompasses a wide range of optical thin film designs. In the visible range, broadband AR, shortwave pass, longwave pass, cold mirror (Figure 4), and dichroic filter designs have been successfully employed. Single, dual, and broadband AR coatings are also available for telecom wavelengths of 1310nm/1550nm on substrates ranging in index from BK7 to sapphire and cubic zirconia. Furthermore, broadband solar (400nm to 1700nm) AR coatings as well as hot mirror may be applied to a variety of substrates. In some cases, it may be possible to achieve performance over multiple spectral regions, such as an AR coating for both VIS and midwave infrared (MWIR) spectral bands.

Thin film optical coatings produced with the proprietary LPCVD process can be used in extremely harsh operating environments. The coatings produced by this process are thermally stable and chemically inert in most operating environments, with demonstrated service temperatures up to 850°C. Mechanical durability and adhesion are excellent, a result of the strong covalent bonds with the substrate and at layer interfaces. The IsoDyn process is useful for coating almost all optical glasses, crystalline materials, ceramics, and metals.

## Summary

The advanced IsoDyn coating process utilizes the fundamental advantages of LPCVD deposition in order to provide conformal, low defect thin film coatings on non-planar and asymmetrical optical components. The benefits of LPCVD processing have long been exploited in the semiconductor industry, and now provide new opportunities for novel optical system designs. New interference filter coatings for single wavelength, dual band and broadband AR, cold mirror, hot mirror, long/shortwave pass, dichroic, conductive are available. The coatings deposited using the IsoDyn process are extremely robust and capable of performing in the most demanding operating environments.

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