Optical Dielectric Thin Film Design in Hollow Glass Waveguides (HGWs) for Infrared Laser Delivery & Spectroscopy Applications

Carlos M. Bledt and James A. Harrington

Department of Materials Science & Engineering
Rutgers, the State University of New Jersey, Piscataway, NJ 08854, USA

Research Objectives

- To explore the theory of and deposit optically functional dielectric thin films in Hollow Glass Waveguides (HGWs) for low-loss delivery of infrared radiation at ranges from 1.8 - 14 µm
- To create a model correlating the dependency of the optical response of dielectric coated HGWs on the chemical kinetics behind the relevant thin film deposition processes
- To optimize processing of dielectric thin film designs in HGWs for maximum transmission at desired wavelength(s) by altering dielectric thin film thickness as determined necessary

Optical Thin Films & High Reflection Coatings

- Functional optical dielectric (non-conducting) thin films below 1 µm in thickness have been widely used in optical systems and devices for enhancing or preventing reflectivity as desired for a given application
- High reflection coatings (HR) consisting of one or multiple dielectric thin films on an appropriate substrate allow for enhancement of reflective properties at desired incident wavelengths by essentially creating dielectric mirrors
- The functionality of dielectric mirrors is based on thin film interference effects where the incident light upon the dielectric mirror reflects from the interfaces and exists the system in phase, resulting in constructive interference
- Thin film materials for HR coatings must be highly transparent at target wavelengths and have a mismatch in refractive index (n) between adjacent layers
- Suitable transparent materials for HR thin films include highly transparent materials such as silver iodide (AgI), cadmium sulfide (CdS), lead sulfide (PbS), zinc sulfide (ZnSe), and zinc selenide (ZnSe)

Functional dielectric thin films are deposited via Dynamic Liquid Phase Deposition (DLPD) techniques involving deposition of desired materials from precursor species containing aqueous solutions
- Low surface roughness, highly reflective thin silver films are deposited via reduction of silver-diamine complexes to metallic silver by organic reducing agents in solution
- Dielectric thin films are then deposited on the reflective silver layer thin film substrate through different reactions/mechanisms via DLPD techniques at different flow rates
- The choice of dielectric thin film to be used is determined by the desired optical response as well as factors such as deposition ability and durability of the material

- Understanding of chemical deposition processes is necessary for success
- Correct optimal thin film thickness, good uniformity of deposited films, and low film surface roughness are essential for exceptional HDG functionality at any wavelength

- Present study involved 1,000 µm ID HGW samples with flow rates of 11.8 (AgI), 22.6 (CdS), and 16.8 (PbS) mls/min

Spectral Characterization of Deposited Thin Films

- Successful and reproducible optically functional dielectric thin films of AgI, CdS, and PbS have thus far been deposited in HGWs for both consistent spectroscopic analysis and IR radiation propagation properties
- Spectral analysis of HGW samples involved Fourier-Transform (Infrared) spectroscopy utilizing a Thermo Nicolet 460 FTIR spectrometer in conjunction with cryogenic TycoLink InSb and MCT/IR detectors

- Silver Iodide (AgI) Thin Films
  - Iodine solution: 39.40 mM in cyclohexane
  - Silver Iodide (AgI) dielectric thin films are produced through the subtractive iodination (conversion) of pre-deposited Ag metal layers in HGWs
- As a result, formation kinetics of AgI dielectric thin films on Ag substrate are mass transport limited
- AgI HGWs were manufactured at iodination times from 60 to 240 seconds in 30 second intervals

- Cadmium Sulfide (CdS) Thin Films
  - CdS(NO3)2 Sol: 0.32 mM / Cd(NH3)2 Sol: 41.82 mM
  - Cadmium Sulfide (CdS) dielectric thin films are produced through the additive chemical deposition of CdS from solutions in compatible substrate

  - Kinetics of CdS film growth limited by homogeneous and heterogeneous nucleation and growth
  - Ag/PbS HGWs were manufactured at deposition times from 450 to 720 minutes in 45 minute intervals

- Lead Sulfide (PbS) Thin Films
  - PbS(NO3)2 Sol: 3.02 mM / Pb(NH3)2 Sol: 19.70 mM
  - Lead Sulfide (PbS) dielectric thin films are produced through the additive chemical deposition of PbS from solutions in compatible substrate

  - Kinetics of PbS film growth limited by homogeneous and heterogeneous nucleation and growth
  - Ag/PbS HGWs were manufactured at deposition times from 60 to 135 minutes in 15 minute intervals

- Analysis of spectral response for deposition of thin films as a function of deposition time yielded thin film growth kinetics in HGWs via DLPD processes and allowed for optimization of dielectric thin films for use at λ = 10.6 µm

Deposition Kinetics-Optical Response Model

- Analysis of resulting spectra allows for determination of film thickness as function of deposition procedure time
- Thin film thickness can be calculated from wavelength corresponding to first interference peak position (λ) and refractive index (n) by using Minsky’s formula
- Thin film thicknesses for all deposited thin films as derived from spectral analysis were plotted as a function of deposition time to determine film growth kinetics

HGW Thickness as a Function of Deposition Time for Ag/CdS, Ag/CdS, and Ag/PbS-HGWs

Film growth rates determined to be; 2.03 nm/sec for AgI, 9.19 mm/min CdS, and 3.78 mm/min for PbS

Optical Attenuation in HGWs

- Attenuation measurements and spatial profiles were taken using a Laser Engineering Carbon Dioxide laser 50 Watt maximum output power laser as an IR source emitted at a wavelength of λ = 10.6 µm
- Cutback methodology was utilized for all attenuation measurements to prevent possibility of error due to coupling inefficiencies
- Dielectric thin films seem to greatly reduce attenuation in HGWs

Novel Dielectric Film Designs for Use in HGWs

- Current research involves the successful thin film deposition of highly lucrative HR films for use in HGWs including highly IR transmitting ZnSe and ZnS as well as low index polymer thin film materials such as polystyrene
- Incorporating multiple dielectric layers of appropriate thickness consisting of materials of alternating low (nL) and high (nH) refractive indices will allow for enhancement of reflection coefficient and thus higher transmission
- ZnSe and ZnS thin films would allow for highly transparent thin films with medium-low refractive indices having excellent properties as single films or in along with high index films such as PbS in multi-layer designs
- To date, multi-layer designs including CdS/PbS, CdS/PS, and PbS/PS alternating layers have been successfully produced and continue to be thoroughly researched for optimal functionality in desired applications

Applications of HGWs & Conclusion

- HGWs are used in a variety of applications involving transmission of light at infrared wavelengths including high power laser delivery for surgical applications and remote chemical sensing involving spectroscopy
- HGWs effectively incorporate dielectric thin film designs for low-loss transmission of infrared radiation
- HGWs can be easily and inexpensively tailored for maximum transmission at desired wavelength(s)

References

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The image contains text that discusses various aspects of optical thin film design and deposition in hollow glass waveguides (HGWs) for infrared laser delivery and spectroscopy applications. It covers topics such as dielectric thin film deposition processes, spectral characterization of deposited thin films, and the optimization of thin film thickness for specific wavelengths. The text also includes references and acknowledgments for the research project.