Deposition of Multicomponent Glasses for Planar Optical Waveguide Applications

Glen R. Kowach

The City College of the City University of New York
Bell Laboratories, Lucent Technologies

kowach@sci.ccny.cuny.edu
Collaborators

Materials Synthesis
John MacChesney
Ed Chandross
Tom Stockert

Modeling
Chris White

Convection
Mark Hodes

Colloidal Films
Deok-Yang Kim
Suhas Bhandarkar
David Johnson
Henry Du
Reach versus Bandwidth

Note: Assuming 1 bit/Hz

Courtesy of Marcus Weldon and Ibo Matthews
Control of Index of Refraction of SiO₂

Typical glass for planar optical waveguides is based on LPCVD which limits the possible glass compositions.
Comparison of Deposition Techniques

1. Films from Colloidal Suspension
   Details in talk by Doug Kim.

2. Particulate Films
   - Sedimentation
   - Electrophoresis
SEM of Dried and Sintered Pure SiO₂ Film

- Relatively low temp. sintering @ 1300 °C (40% shrinkage)
- Refractive index by reflectometer → 1.4577
- 180 MPa in compression due to thermal stress
Particulate Films
-Sedimentation

**Advantage of Multicomponent Glasses:**
Start with bulk glass with tailored properties
- CTE match
- index control
- other unique properties

**Method of Deposition:**
Mill bulk glass into powder with diameters of 5 microns and smaller
Allow suspended powder to settle onto wafer
Dry
Consolidate by viscous sintering

**Advantage:**
Conforms to surface features

This work was started by Suhas Bhandarkar and John MacChesney in 1993.
Glass Compositions

Optimization of “Phase Diagrams”

Pyrex composition (Corning 7740) (mol %): 81% SiO$_2$, 13% B$_2$O$_3$, 2% Al$_2$O$_3$, 4% Na$_2$O

Corning 7070 (mol %): 71% SiO$_2$, 26% B$_2$O$_3$, 1% Al$_2$O$_3$, 0.5% Na$_2$O, 0.5% Li$_2$O, 0.5% K$_2$O

Variables: Softening temperature (viscous flow), onset of crystallization (for reasonable quench rates), onset of bubbling (O$_2$ partial pressure), index of refraction, propagation loss, CTE
When glass goes bad!

Peeling of dried film due to thickness above critical thickness of cracking.

Black colored glass due to incomplete burnout of organics.

Bubbles in glass due to lack of oxygen during sintering.
Study of Bulk Glass

Due to bubble formation in films, prepared bulk samples to optimize sintering conditions.

Corning 7070, -200 mesh, pressed pellets

900 °C, O₂

900 °C, He

SEM image (900 °C, O₂) cross-section

Dark colored glass due to incomplete decomposition of organics.
When glass is good!

Sample B3F3

SEM image

Optical micrograph

Cleaved surface
Film thickness = 75 microns
Particulate Films
-Electrophoresis

Deposition on metal plate

- substrate Pt/TiN/Ti/Si
- Corning 7052 glass milled in n-butanol
- voltage = 50 V
- current at start = 8 mA
- current at end = 5 mA
- thickness after 4 min green body = ~500 microns

Important variables include the following:
- voltage (determines deposition rate)
  interesting to map out electric field at electrodes
- water content in alcohol and on glass particulates
  (partly determines charge on particulates)
- reaction of alcohol with glass surface
  (determines drying and sintering behavior)
Waveguide Structures

Patterned

Annealed (ink-jet)

Diffused (metal or metal oxide)
Immediate Application

Thick upper cladding which can be planarized for further deposition of waveguiding layers.

Requirements of upper clad:
- index of refraction must be close to pure SiO$_2$ (1.458 at 1550 nm)
  - incorporate F into glass
- CTE matched to Si
- moderate softening temperature
- thick deposition (~80 microns)

Planarize using CMP (chemical mechanical polishing)

Deposit an additional PLC layer
State-of-the-art ink jet technology for paper printing can precisely place a 2 picoliter dot with submicron accuracy.

This would allow for rapid prototyping by avoiding mask fabrication, and enables integration of waveguides with electro-optics, optical amplifiers, and photonic crystals.
Summary

Films from Colloidal Suspension
- Deposited via spin-coating
- Doped to increase the index of refraction
- Patterned into waveguides

Particulate Films
- Thick films of 50-200 microns have been deposited using Pyrex-like compositions.
- Sedimentation
  - Initial experiments show dense films conforming to substrate features can be sintered.
- Electrophoresis
  - Critical parameters have been identified indicating good control over depositions conditions.

Further work of this promising glass matrix will continue.