Fabrication and Characterization of Integrated Optical Cavities for Enhanced Spin Measurements

Tadeas Liska, Ina Martin, Jesse Berezovsky
Physics Department, Case Western Reserve University

OBJECTIVES
1. Simulation of DBR microcavity using the MEEP framework
2. Fabrication of SiO$_2$ /TiO$_2$ distributed Bragg reflector (DBR) microcavity using electron beam physical vapor deposition and radio frequency magnetron sputtering
   2a. Embedding of CdSe/ZnS core-shell Quantum Dots
3. Characterization of DBR microcavity through spectroscopic ellipsometry and stylus profilometry
4. Testing of the integrated microcavity in the Berezovsky lab.

METHODS

MEEP SIMULATION ENVIRONMENT:
- Developed at MIT in the Scheme programming language for finite-difference evaluation of electromagnetic wave propagation in the time domain
- Scheme is an interpreted language that allows for low-level control of a large set of complicated structures
- Capable of extracting transmission spectra, gif simulations, and conducting harmonic analyses

ANGSTROM DEPOSITION SYSTEM:
- Quartz crystals allow deposition to be monitored within 1 nm
- Programmability allows for multiple processes to be used to deposit heterostructures
- Custom designed support reduces deposition time six-fold
- Deposited layers characterized by stylus profilometer and spectroscopic ellipsometry exhibit 5 nm accuracy

Inside of the Angstrom UHV chamber
E-Beam PVD pockets in center
Sputtering sources elevated on right
Thermal evaporation boats on left

PHOTONIC CRYSTALS:
- Resonance tuned based on layer thicknesses
  - Silica (SiO$_2$) 103 nm
  - Titania (TiO$_2$) 61 nm
- Constructed as a series of stacks of Bragg mirrors
- Without defect acts as stop band for wavelengths between 500-700 nm
- Cavity defect added in center silica layer as twice the ordinary thickness
  - Allows for a normal mode to occur at 600 nm

INTEGRATED QUANTUM DOTS:
- Cadmium Selenide core shell construction
- Display photoluminescence at 600 nm
- Couple with cavity normal mode according to the Jaynes-Cummings model resulting in a Purcell enhancement of excitation rate

RESULTS

SIMULATION:
- Modal analysis within MEEP confirms 600 nm resonance
- Quality factor monitored as a function of stacks with plateauing occurring after fourteen (Q$_0$ = 1500)
- Transmission spectrum obtained from transfer matrix calculations in MATLAB

0.2 0.4 0.6 0.8 1
900 800 700 600 500 400
Transmission Intensity
Wavelength (nm)

10 Layer Cavity 900-400 nm Frequency Response

FABRICATION & CHARACTERIZATION:
- E-Beam PVD of silica within 5% of desired thickness
  - Ellipsometry measured refractive index as 1.46
- RF magnetron sputtering of titania within 8% of desired thickness
  - Ellipsometry measured refractive index as 2.47

ACKNOWLEDGEMENTS
This project was made possible by the MORE center in collaboration with the Physics Department at Case Western Reserve University. All funding for materials was provided as part of the 2013 series of Physics Senior Undergraduate Projects.