3.46 PHOTONIC MATERIALS AND DEVICES

Design Review #1A

Ridge Waveguide

You just made a bet with someone that you couldn't design a waveguide for integrated optics that would have a lateral dimension larger than the wavelength of operation (λ = 1.55μm) and yet still be single mode. It turns out it was a stupid bet, because although you can do it, it was his job and now he's playing solitaire while you do all this work for a mere $50.

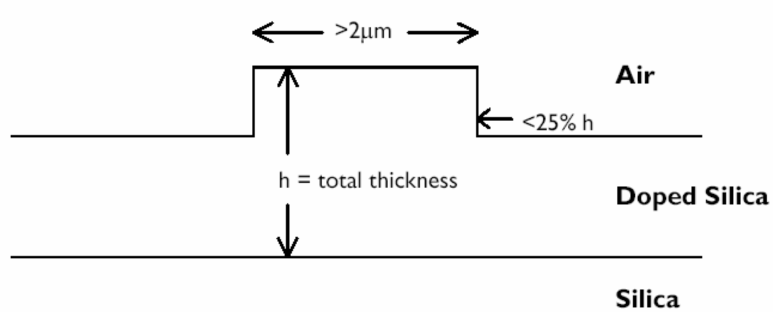
a) So here's the problem. You're starting with a pure undoped silica substrate and depositing germanium-doped silica on top to achieve a higher index of refraction. After the layer is deposited, you can use standard photolithography and chemical etching to achieve a profile shown in figure (1). The etching is a slow process, however, so you don't want to have to remove more than 25% of the thickness you just deposited. Also, although you can deposit a relatively thin layer, you are unable to pattern anything smaller than 2μm, so the waveguide will need to be at least that wide.

Specify the index of refraction of the waveguide layer and all of the dimensions to achieve a single-mode waveguide using this design. Then just try to get your $50.

A reference you may find useful is Lee, *Electromagnetic Principles of Integrated Optics*, Chapters 4 and 5.

b) This so-called friend of yours was fired for sexually harassing one of the human resources representatives and they hired you to replace him, because they liked your waveguide design from part (a) so well. They now inform you that the process they use for etching is not very uniform, and could vary by as much as ±25%. How does this affect your design? Show how you would need to vary the dimensions to account for this much etch variation. Assume that in the very least, the index of refraction is under control.

Now ask for a raise.



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Design Review #1B

High Reflectivity Dielectric Mirror

For your first assignment on the job, you've been given an old MBE reactor which can be used to grow layers of gallium arsenide, aluminum arsenide and their alloys. Your boss tells you that you need to design a dielectric stack mirror using alternating layers of AlAs and $Al_xGa_{1-x}As$. Your design will eventually be used as part of a surface emitting gallium arsenide laser operating at 850nm.

(a) If you need the reflectivity of this mirror to be 95%, what would the design be in the ideal case? This is the case where engineers are superfluous and MBE machines run perfectly, providing precisely the layer thicknesses and index of refraction as requested.

You can look up the index of refraction for GaAs and AlAs and assume a simple ratio for the alloys in between. A reference you may find useful for this and subsequent calculations is Kong, *Electromagnetic Wave Theory*, Chapter 3.3.

(b) Now lets be a little more realistic. Your predecessor, who designed and built the MBE machine, was not anticipating the tight tolerances required for these delicate applications. Nor did this individual leave adequate documentation to allow your technician to improve the tolerances. You've been running experiments for several months now and measuring the deviations in thickness and alloy concentration to see what you could expect from this machine. (I bet you were wondering when all that work would pay off!)

Unfortunately, you've found that across the wafer, and water-to-water, the best you can hope for is $\pm 10\%$. You find this appalling, and immediately complain to your boss, but he tells you that you'll just have to design the mirror that much better to account for it.

What you boss doesn't realize is that the marketing department has already informed you that they've given the customer a firm price for the laser and they've calculated that the cost of your mirror had better not exceed $2.50 per laser. You do a quick calculation based on wafer size, laser size, growth rate, etc and determine that the thickness you can afford to use is based on the answer you gave in part (a). (Those marketing guys never check with the engineers before giving a price.) Now you've got to figure how well you can specify the reflectivity, given the lousy tolerances of your system, so that the laser designer will know what she has to work with.

Fortunately, you're a whiz with Mathematica and you can get it to easily show how the mirror reflectance will vary with the layer thickness and the index of refraction.
So what are you waiting for?

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Design Review #1C

Single Mode Fiber

You are the low cost, commodity fiber design team. To be competitive, you must produce 10km fiber from a single preform.

You have three products of single mode fiber for transmission at

1) $\lambda = 1.3\mu m$
2) $\lambda = 1.5\mu m$
3) $\lambda = 1.3\mu m$ and $\lambda = 1.5\mu m$

Create design curves that relate the core diameter, d, to the fractional index change Δ.

A. Consider the fiber core to be silica (n = 1.46)
   a) design for a step index profile
   b) design for quadratic graded profile (p=2)
   c) show the variation in NA (numerical aperature) and Θ_{max} (acceptance angle) with your choices.

B. How thick must a 1m long preform be if the fiber outer diameter is $100\mu m$?

C. A reliability problem has occurred during use of these fibers. Losses in the $\lambda = 1.3 - 1.5\mu m$ range increase during undersea deployment. What is the likely cause of this problem? What is your recommended approach to develop a solution?

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Design Review #1D

Efficient Silicon Solar Cell

TeraTelecom has been founded to deploy communications hardware in remote regions that are not served by an electric power grid. The company has decided to supply power locally by photovoltaic energy conversion of sunlight. High conversion efficiency (electrical power/optical power) is the most important performance factor for the solar cells. You are the team assigned to provide solar electricity. The first challenge in your critical path is Project PC (Photon Control) with the goal of optimizing sunlight absorption by coupling light into the cell and controlling its path length in the silicon to maximize absorption.

Constraints

A. There is a worldwide shortage of silicon feedstock, and you must use thin wafers for your solar cells to keep costs down. Your manager has promised a 20% power conversion efficiency with a 100 μm thick wafer. He does not understand design, but he has confidence in your team.

B. Your team has delivered 100% quantum efficiency in conversion with no contact shadowing with a novel backside contact design.

C. The incident photon wavelength range is the solar AM-1.5 spectrum.

Plan and Design Actions

Develop a photon control design that uses the absorbed fraction of incident light as the Figure of Merit.

1. Determine the spectral convolution of AM 1.5 and the absorption spectrum of silicon; and decide what wavelength range is the subject of your design.
2. Optimize the coupling of the incident light into silicon.
3. Optimize the internal reflection of light in the silicon to increase path length.
4. Create design plots of reflectivity vs. design variables and efficiency vs. design variables.

Project PC Deliverables

1. A cross sectional view of your ‘photon control’ cell design with materials and layer thicknesses indicated.
2. A final design that minimizes the silicon cell thickness and delivers 20% power conversion efficiency.
3. Tell your manager that he “is very smart” or “needs some physics classes,” depending on your result.