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Light Source for WDM Microphotonics
Design Review 2—April 24, 2006

VCSEL Light Source

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Two Agilent VCSEL packages.

You have just founded a start-up called LightConnect. Your first customer is DigiHouse, Inc. with an order for a low cost Digital Video Interface cable that is capable of 1 Gbps data rates over a 100 ft link of plastic optical fiber. The fiber loss figure at the desired wavelength of operation, 850 nm, is 100 dB/km. Your company has committed to supplying the VCSEL laser. Your assets consist of a computer, an MOCVD deposition system and a relationship with a GaAs foundry. Of course, the superior design capability of your team is the asset that won the contract.

Design a VCSEL to deliver $50 \ \mu W$ of coupled power to a silicon photodetector at 1 GBps with $\lambda = 850$ nm. Your materials design work that led to the proposal has defined the following materials selection criteria:

Quantum Wells: Emission wavelength; Lattice constant; Materials Quality

DBR: Index of refraction; Bandgap; Doping capability; Thermal conductivity; Process Compatibility

Create a device design and a process flow for the VCSEL product. In doing so, develop design plots that relate the design variables to a selected set of the following device characteristics: Wavelength/Spectral Width; Threshold Current; Slope Efficiency; Maximum Power; Turn on Voltage; Series Resistance; Capacitance; 3 dB Bandwidth; Rise and Fall Time; Eye Diagram; High and Low Temperature Performance; Reliability.

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Table of Relevant Materials Properties for VCSEL Design

Substrate	Binary	Ternary	Quaternary	Composition	Thermal Conductivity (W/m-k)	Bandgap Wavelength (nm)	Refractive Index
GaAs	AlAs				80	< 600	2.91
		AlGaAs		90% Al	15	< 600	2.96
		AlGaAs		20% Al	25	730	3.31
	GaAs				46	870	3.41
InP	InP				68	915	3.2
			InGaAsP	50 % P	< 4	1210	3.43
			InGaAsP	30 % P	< 4	1365	3.62
		InGaAS		53 % In	4.8	1650	3.59

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Tunable Light Source

Design a laser to the following specifications:

- 1 mW of light coupled into single-mode fiber

- < 1 GHz bandwidth

- tunable over the entire CWDM spectral range 1260 - 1610 nm

- drive current less than 200 mA

- drive voltage less than 5 V

Keep in mind that your tuning range is much greater than kT at room temperature so you may need to engineer an inhomogeneously-broadened gain medium in your design.

Include at least three relevant design space explorations showing the parameter spaces and use these to show the optimality, as well as the robustness, of your approach. If, for example, you decided upon a design based on widely polydispersed quantum dots (to provide a large inhomogeneously-broadened gain bandwidth) within a mechanically-tuned microcavity resonator, you might include among your design spaces explored:

- {gain bandwidth} vs. {quantum dot size distribution} for a variety of injected current densities

- {outcoupled optical power} vs. {operating current} for a variety of mirror reflectances and cavity/active layer thicknesses.

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Broadband Planar Light Source

It's a black Monday morning at Planar Photonics in Sunnyvale, CA. You're holding your cup of wake-up brew, staring at a sky full of dark gray clouds through 2 x 4 class 10 sealed windows. In walks the Division Head:

"What's up, chief?" you say.
Your boss looks at you, "The ceiling. I need a light source design by Friday."
You set down your cup, "Okay. I'm your man. What're the specifications?"
"1-10 Gbit/s transmission rate. Si Microphotonics. Your resonant cavity will be a ring resonator."
You look at him, "Can ya' give me some more details, boss?"

Here they are:

Design a laser based on an Er dopant light emitter in the 1.55 μm wavelength region, using an Er-doped ring resonator which evanescently couples to a single undoped waveguide. The waveguide and ring should be made of core material that is either silicon nitride (Si_3N_4), with refractive index 2.0 or silicon oxynitride (SiON), with refractive index 1.6. This laser should be designed for planar Si Microphotonics, which means that the planar structures must be grown on a silicon (Si) substrate. Since the refractive index of Si is much higher than SiON or Si_3N_4, an isolating layer of silicon oxide (SiO_2), refractive index 1.46, must exist between waveguide structures and the Si substrate. Use SiO_2 as your cladding material, assume it completely covers the waveguide and ring—i.e., this is a symmetric waveguide problem. Your task is to calculate the net gain achievable by Er stimulated emission, in the presence of radiative turning loss and scattering transmission loss, inside the ring. Use the attached Property Map to determine your loss values: for a given refractive index difference between waveguide core and cladding, the right axis tells you waveguide scattering loss. The left axis tells you, at this index difference, what the ring radius should be in order to have a radiative turning loss of 0.05 dB/cm.

The Er light emitter is a three-level system, optically pumped from ground state (level 1) to second excited state (level 3) by a 980 nm wavelength optical pump (pump absorption cross-section: $\sigma_{13} = 2 \times 10^{-21}$ cm^2). The Er atom immediately relaxes to the first excited state (level 2), from which it de-excites to the ground state (level 1) either by spontaneous emission (radiative lifetime $\tau_r = 10$ ms, non-radiative lifetime $\tau_{nr} = 10$ ms) or stimulated emission (signal stimulated emission and absorption cross sections $\sigma_{21} = \sigma_{21} = 6 \times 10^{-21}$ cm^2). The Er dopant concentration is $[Er] = 4 \times 10^{20}$ cm^{-3}.

Compute the required optical pump power in the ring in order to reach lasing threshold as a function of ring total quality factor Q (for the lasing signal). This is your first Design Plot: use it to determine if a Si_3N_4 or SiON waveguide core is more practical for this laser. Invent two additional Design Plots.

Specify the Free Spectral Range and line-width of your ring laser. Will this be a single Fabry-Perot mode or multi-mode laser? Using your final waveguide core choice, compute the required ring radii in

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order to have multiple laser wavelength light sources, covering the emission bandwidth of Er, spaced roughly 100 GHz apart.

Taking your final design, compute an LI-curve: a plot of signal laser power versus pump power inside the ring. Relate it to the external signal laser power that evanescently couples out to the waveguide. Determine quantum efficiency and lasing threshold power from this external LI-curve.

We suggest you do your lasing threshold and LI-curve calculation in Matlab or a favored programming language of your choice. Come see us for more theoretical background on modeling this three-level system.

    "Sure," you nod, "I can do this by Friday."
    The chief looks at you, "Don't let me down."
    You smile at your boss, "Trust me."
    Now you get to work.
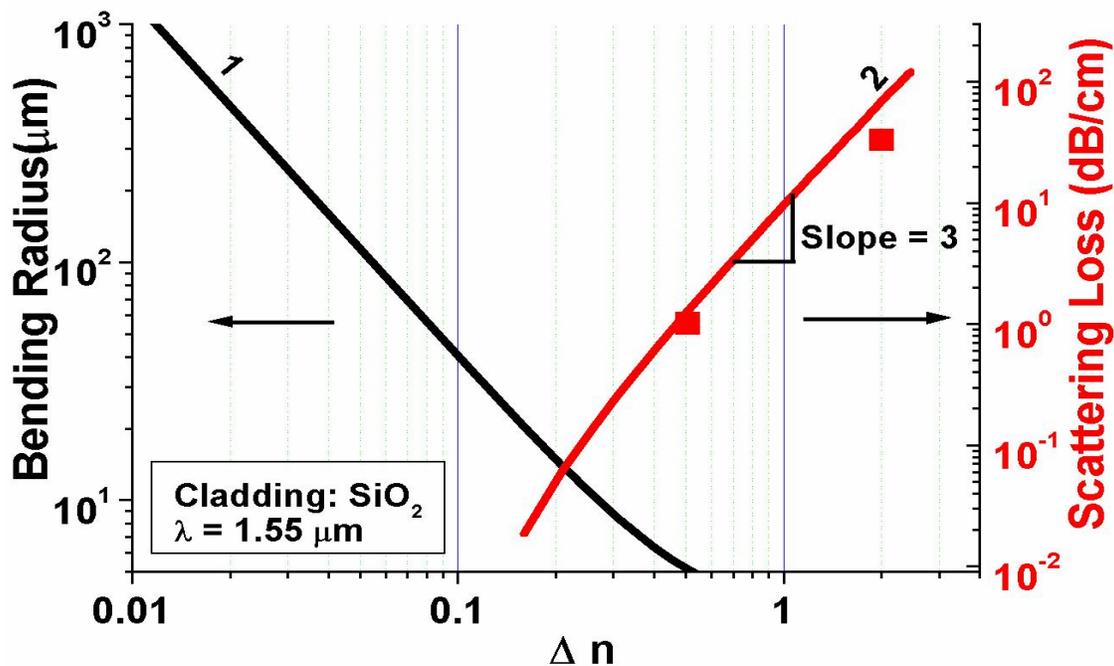
Property Map (Courtesy of K. K. Lee & L. C. Kimerling)

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