JWA049

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Wide Dynamic Range of Ring Resonator Channel-Dropping Filters with Integrated SOAs

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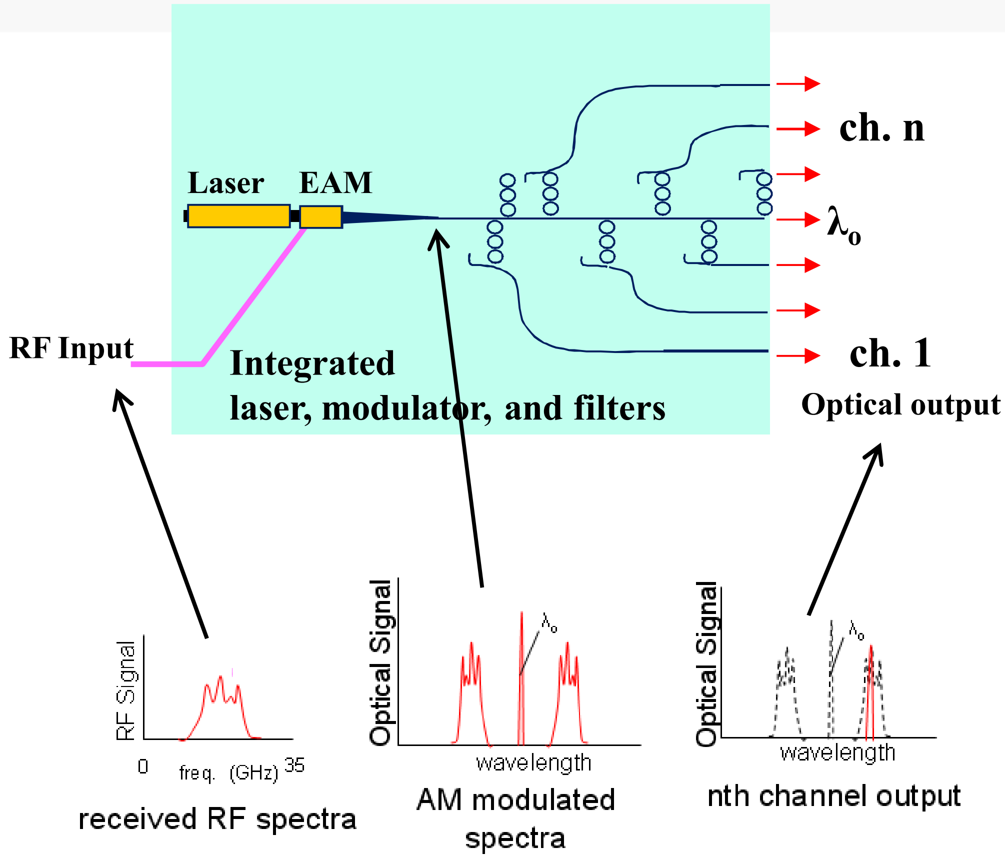
Channel-Dropping Filters



- Analyze an RF signal for frequency content
  - Filter outputs are spectral power density integrated over the filter bandwidth
- Monolithic integration with active components such as lasers and modulators enables compact, highly functional photonic integrated circuits (PICs)

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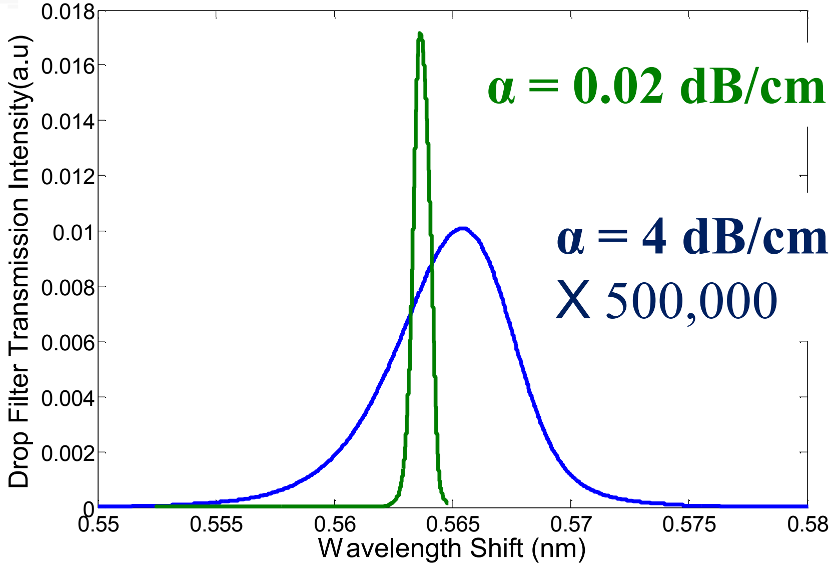
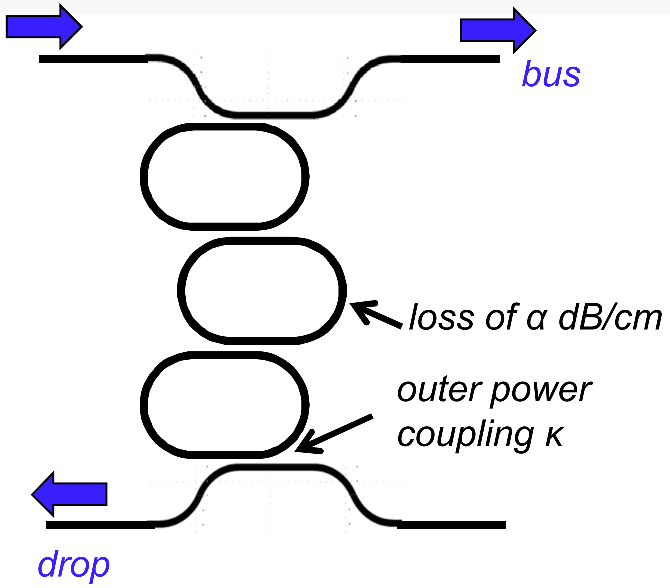
Monolithic Integration and Loss-Limited Filter Response





- Optical waveguide losses dominate the filter performance
- Useful passive ring resonant filters are typically made of glasses or undoped semiconductors with very low optical loss.
- Ring Filters with losses commonly seen in doped InGaAsP waveguides for active PICs have too little optical transmission to be useful as GHz-class filters

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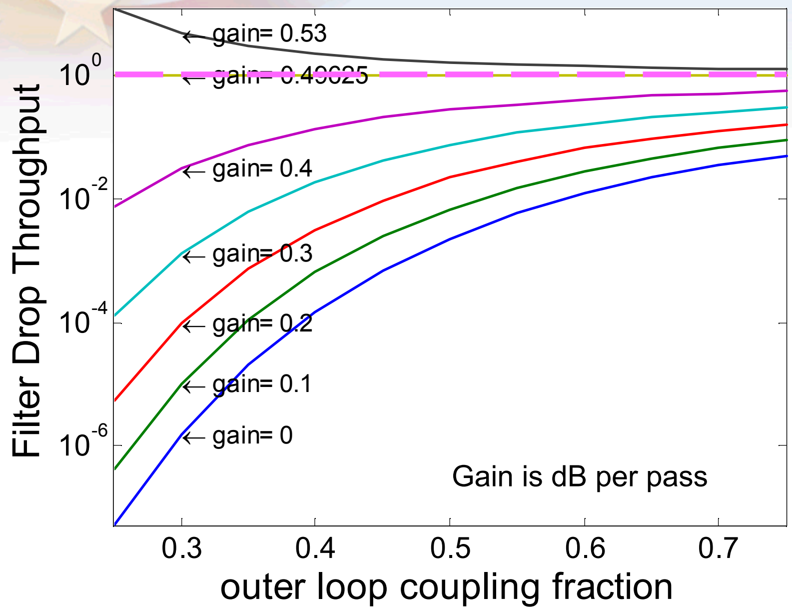
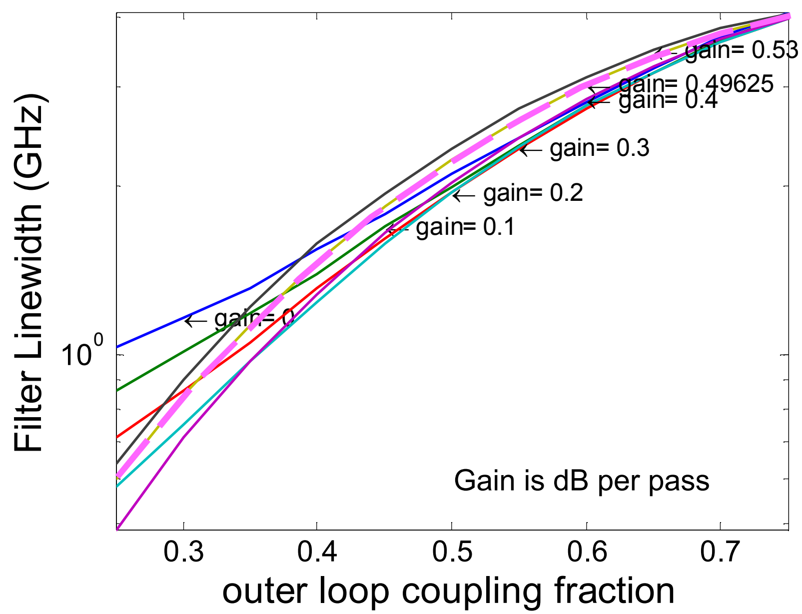
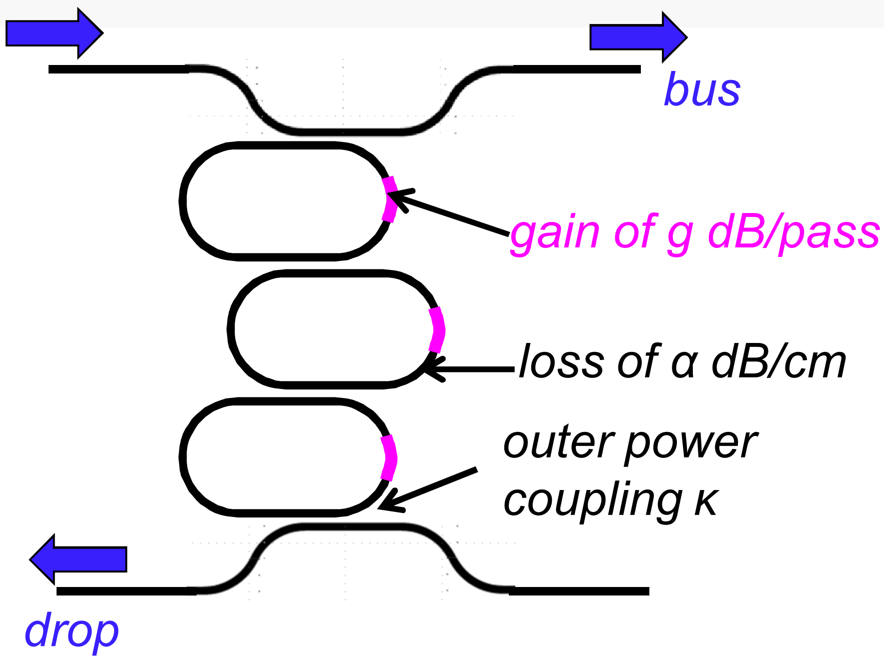
A Small Amount of Gain Offsets Losses







- SOAs enable monolithic integration
- Introduce an ideal loop gain to each filter
  - No noise in model, yet
- Ring waveguide loss
  - 4 dB/cm
- Loss-less filter achieved
  - 0.5 dB/pass gain element

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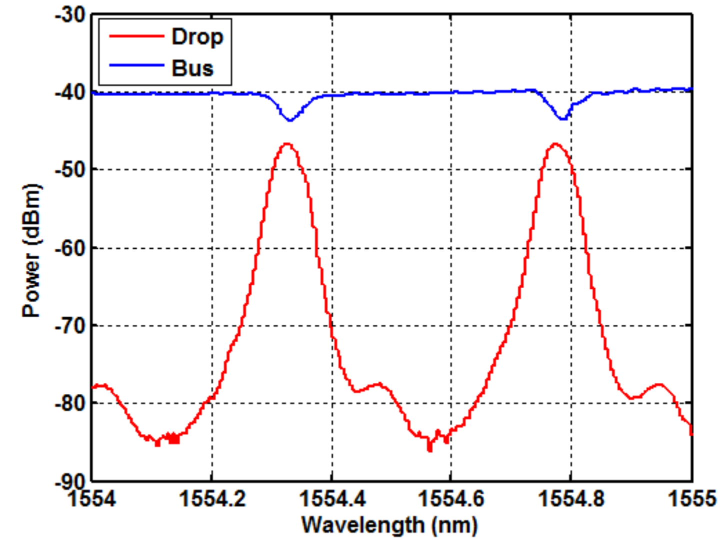
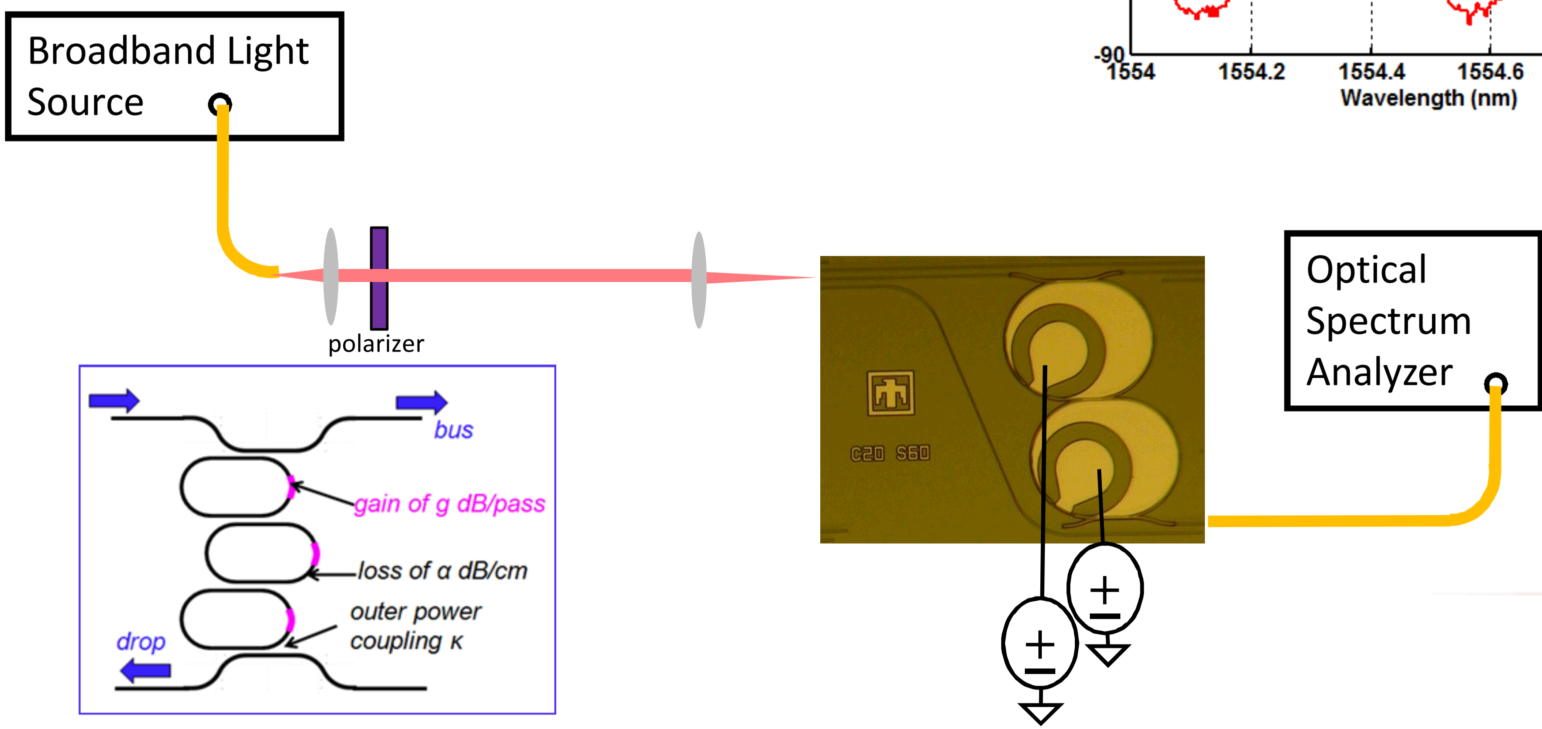
Active Rings : Experimental

See paper OThW2
Thur. @ 4 pm

- Dual-ring filters
  - > 30 dB extinction ratio
  - 2.5 GHz linewidth
  - $I_{SOA1} = I_{SOA2} = 1$ mA
  - Extinction ratio of >30 dB
  - Filter loss of 1.7 dB
    - Loss defined as total power on resonance compared to total power off resonance
- OSA measurement
  - Broadband light source





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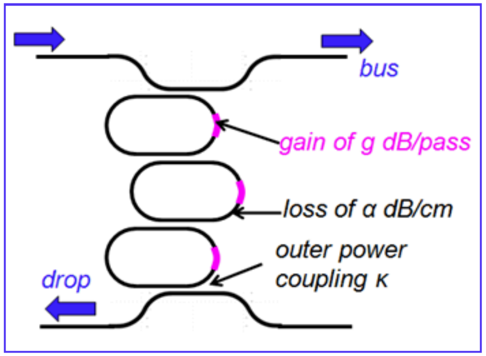
Active filter modeling



- Time domain travelling wave model of single and multi-ring filters
- Semiconductor Optical Amplifier (SOA) embedded in each ring
- Local gain and spontaneous emission modeled as functions of injection current and optical power
  - Time-dependent rate-equation approach
- Complete power spectra computed at each time step

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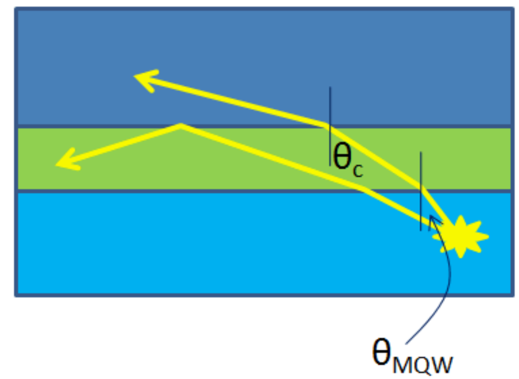
Fraction of SOA spontaneous emission coupled into waveguide mode

- Amplified spontaneous emission (ASE) noise from SOAs creates a noise floor on filter spectra
- ASE noise computation in two steps
  - Spontaneous emission recombination event
  - Coupling of spontaneous emission into guided mode of ring
- The spontaneous emission factor influences the noise floor due to ASE



- Indexes
  - InP, n= 3.168
  - Q13, n = 3.3877
  - MQW, n = 3.427
- Included angle of captured light
  - 44.8 deg
- Area of spherical cap
  - $A_{cap}=2\pi rh$
  - $H = r(1-\cos\theta)$
- Area of sphere
  - $A_{total} = 4\pi r^2$
- Fractional area
  - $A_{cap}/A_{total} = (1-\cos\theta)/2$
  - θ=22.4 deg
  - Fractional area = 0.0378
- Fraction of light capture by guided mode
  - Multiply fractional area by overlap integral with guided mode
  - Γ (fractional area) = 0.06989x0.0378 = 0.00264
- SponBetaNA = 0.00264

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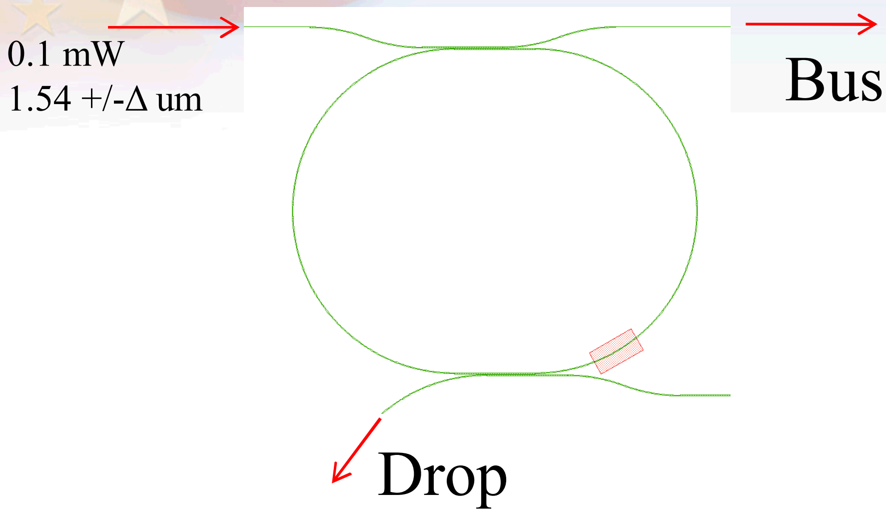
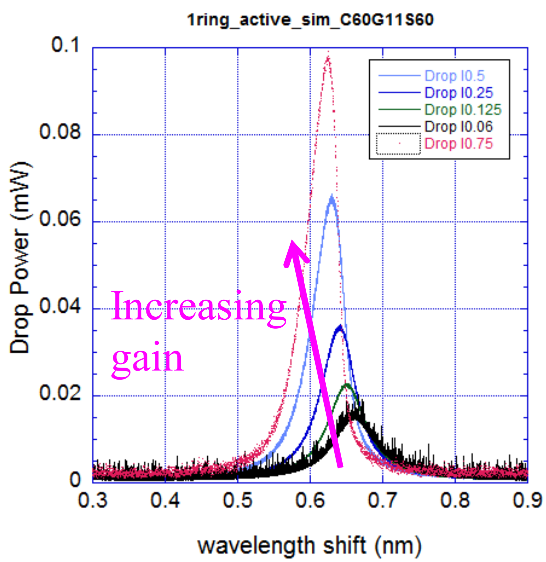
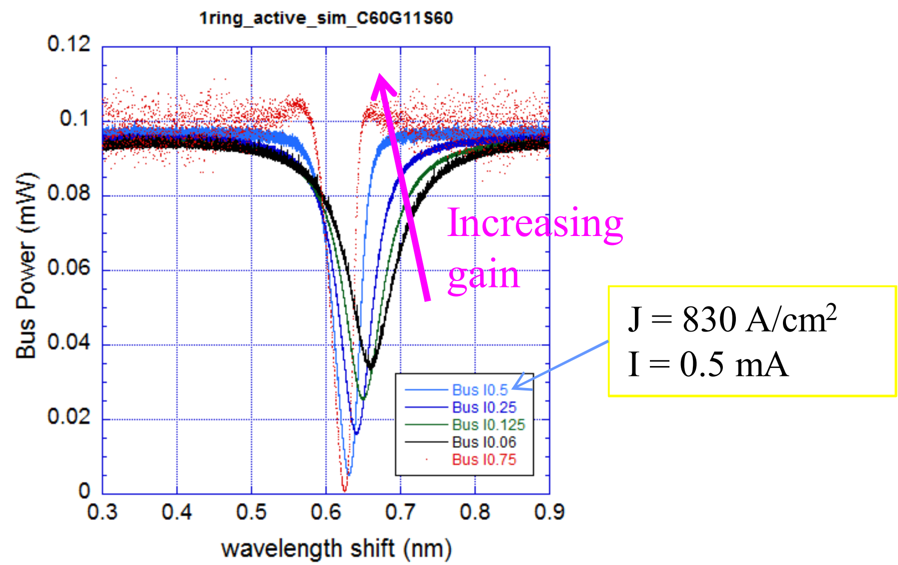
Model of Active Ring



Radius: 200 um
Couplers: 17% power cross-coupling
Passive guides: 3 cm^{-1}
SOA: 60 um long
- 7 QW centered, 25C
- 1 um wide BH
- current flow *only* in the MQW
- Spontaneous Coupling: 0.0037

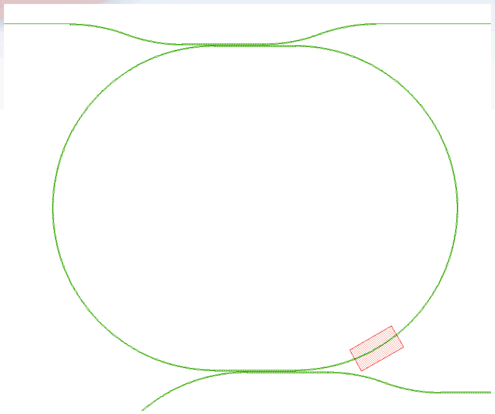




- Variation of SOA injection current
  - Insertion loss drops and bandwidth narrows as SOA current is increased

Model of Active Ring

0.1 mW
1.54 +/-Δ um



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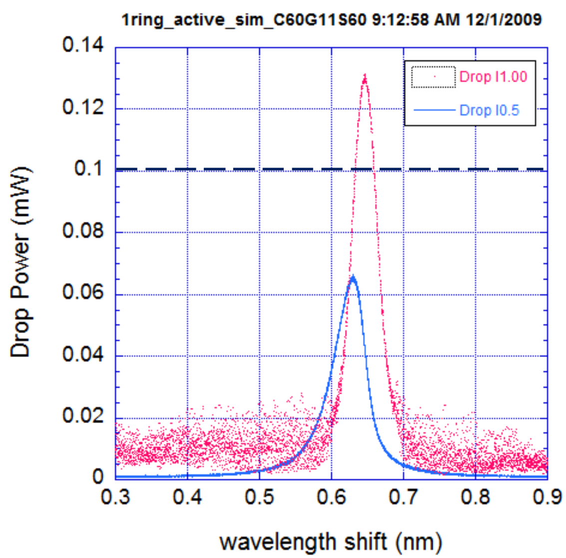

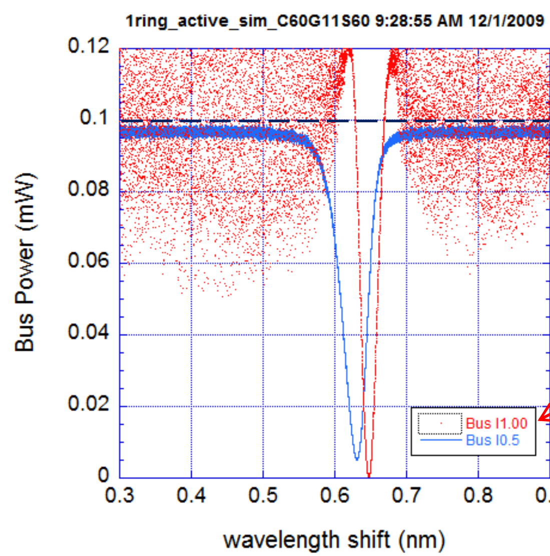

J = 1.67 KA/cm^2
I = 1.0 mA

- Operation at very high gain (SOA injected current)
  - Negative insertion loss achievable, but very noisy

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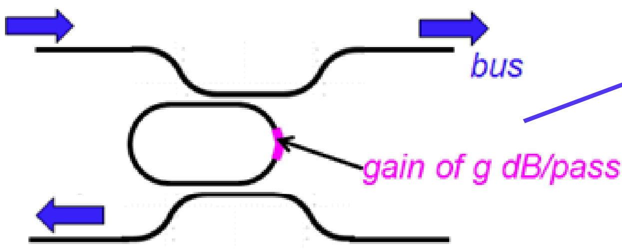
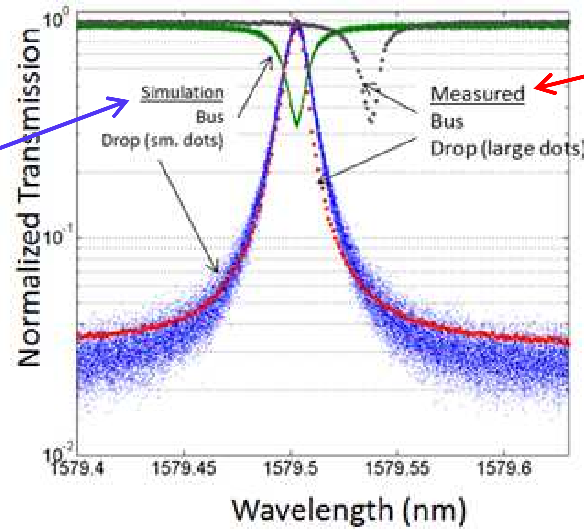
Single Ring Active Filter: Simulation Benchmark to Experiment



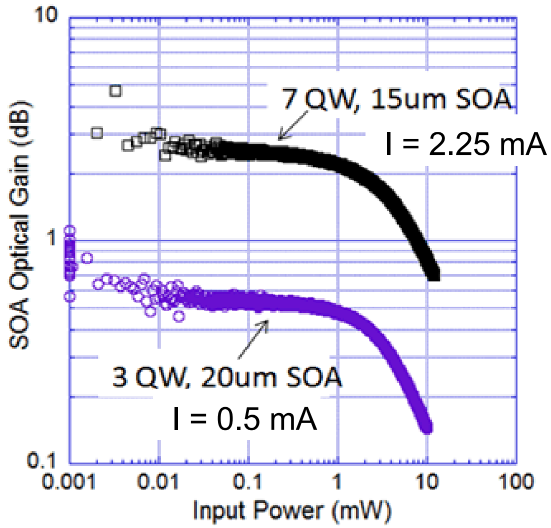
Blue & green data

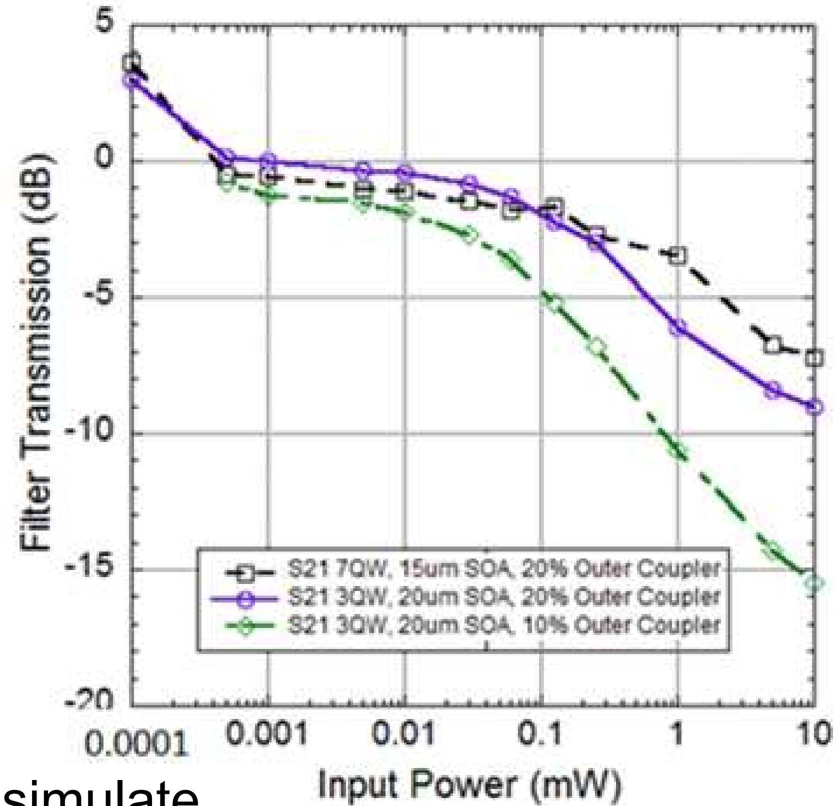


Red & black data

- Complete simulation of dynamic range and noise of active InGaAsP multi-ring filters
  - Include gain distortions and spontaneous emission noise
- Time dependent rate equation method
  - Gain and spontaneous emission modeled as function of injection current at all wavelengths simultaneously

3-ring active filter simulations





- For 3-ring maximally flat filters simulate
  - Linewidth, Insertion loss
  - Dynamic range and Noise floor
- SOA gain and power saturation depend on key factors
  - Number and configuration of QWs and Injected current
  - Simulate case of both 3 and 7 QW SOA

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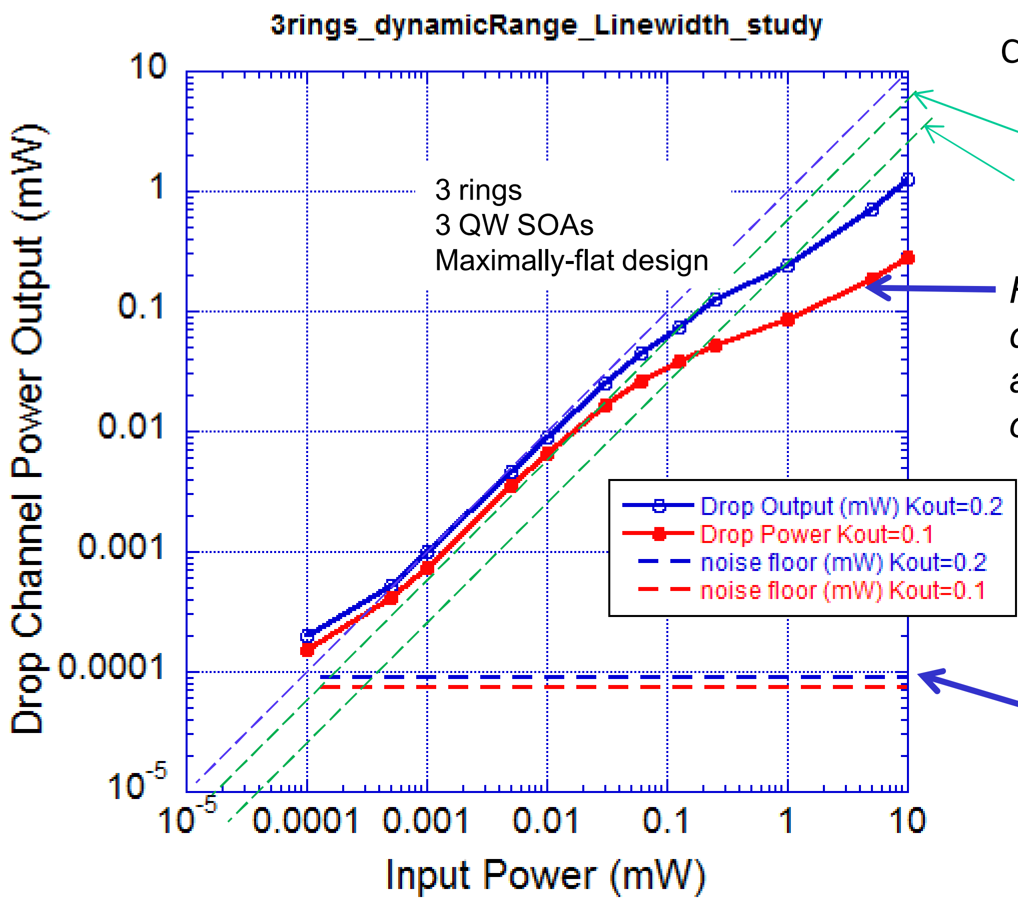
InP Filter Dynamic Range



Compare to passive, SiON filter loss = 0.2 dB/cm
ideal input coupling
-3 dB input coupling

Filter S_{21} compression due to SOA gain compression at high circulating optical power

Noise floor from SOA spontaneous emission

- Active InGaAsP filter shows improved filter transmission compared to passive SiON design over >30 dB dynamic range
- Spontaneous emission noise in SOAs limits SNR at lowest input optical powers
- SOA saturation causes compression of filter S_{21} at resonance at high end of input power

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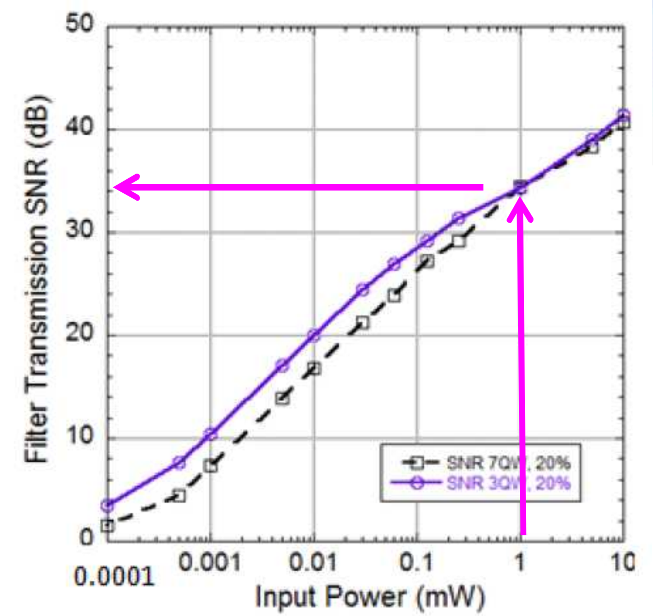
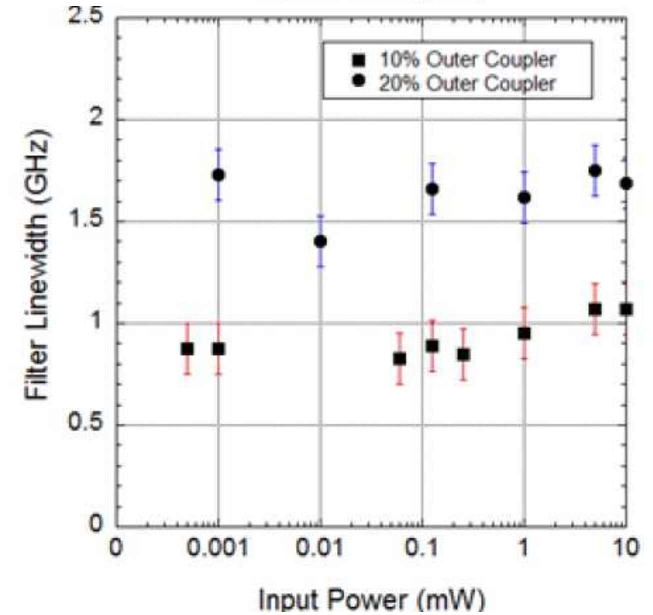
Summary

- Time domain model of active ring with SOAs developed
  - SOA model includes gain saturation and ASE
- 3-ring filter with 3 and 7 quantum well gain sections simulated
  - Optical linewidth
  - Noise floor
  - Linearity and dynamic range of S_{21} versus input power
- InP active filters show promise for frequency-domain signal processing in monolithic integrated photonic integrated circuits
  - 50 dB input dynamic range
    - Output compressed at high power
  - 0 dB loss in mid range accessible for 1 GHz filters
  - Filters with power gain are possible but quickly become limited by noise
  - Possible methods to improve dynamic range
    - Reduce optical confinement factor
      - Balance against lower gain or more complex offset active lasers in remainder of PIC
    - Wider SOAs
    - More pump current





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