

Measurement of Quality Factor of Tunable On-Chip Silicon Ring Resonators

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Research Motivation

Amplitude Response

$$Q = \frac{\omega_{res}}{\Delta\omega_{FWHM}}$$

Phase Response

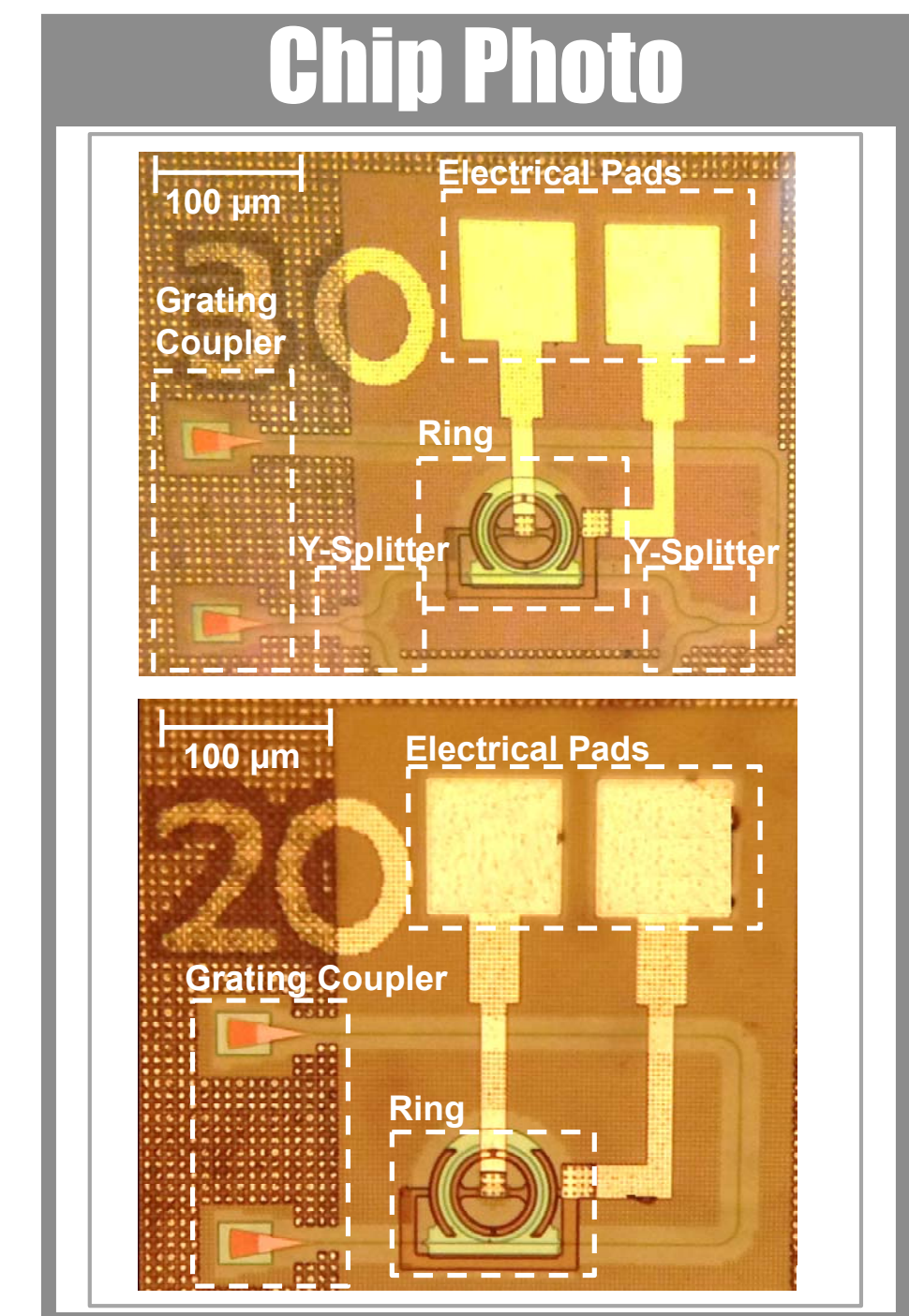
Slope $\propto Q$

$$Q = (2\pi)^2 \frac{n_{eff} R}{\lambda_{res}} \frac{\alpha \rho}{1 - (\alpha \rho)^2}$$

α : Round trip field loss
 ρ : In-out field transmission
 $\delta(\omega)$: Round trip phase shift

Ring Resonator With PN Modulator

330 nm 320 nm
 220 nm Si Si Si Si 160 nm
 SiO₂ 1 μm
 500 nm Output Grating Coupler
 Input Grating Coupler
 Gap Size = 250 nm
 R = 30 μm
 500 nm
 130 nm n+ n p p+ 90 nm
 SiO₂ 250 nm 1 μm



Q-Measurement Using Phase To Amplitude Conversion

@ Resonance:

Depth of Notch: $D = \left| \frac{E_b}{E_a} \right|$

@ Slightly off-resonance:

$|E_c| \approx |E_a|$

$E_t = \frac{E_{in}}{2D} + \frac{E_{in}}{2}$

$E_t = \frac{E_{in}}{2D} e^{j\theta} + \frac{E_{in}}{2}$

$P_1 = |E_t|^2 = \left(\frac{1}{2D} + \frac{1}{2} \right)^2 |E_{in}|^2$
 $P_2 = |E_t|^2 = \left(\frac{1}{2D} e^{j\theta} + \frac{1}{2} \right)^2 |E_{in}|^2$

$\Delta P = P_1 - P_2 = \frac{|E_{in}|^2}{D} \sin^2\left(\frac{\theta}{2}\right)$
 $\sqrt{\Delta P} \approx \frac{|E_{in}|}{2\sqrt{D}} \theta$
 $\tau_g = \frac{\partial \theta}{\partial \omega}, Q = \frac{\tau_g \omega_{res}}{2}$
 $Q = \frac{\omega_{res} \sqrt{D}}{\sqrt{P_{in}}} \frac{\partial \sqrt{\Delta P}}{\partial \omega}$

Measurement Results

Tunability of Resonance Wavelength

Reverse Bias Forward Bias

Resonance Wavelength [nm]
 1556.9
1556.8
1556.7
1556.6
1556.5
1556.4
1556.3
1556.2
 V_a [Volts]
 -10 -8 -6 -4 -2 0 2

Q obtained from amp = 86,494

Q obtained from MZI = 82,950

Measured Q

T = 23.5°

100000
90000
80000
70000
60000
50000
 Resonance Wavelength [nm]
 1556.2 1556.4 1556.6 1556.8 1557

Q-Measurement Using Opto-Electronic Oscillator

On-Chip Ring as Variable Delay Element

$\Delta\phi = \angle E_{out} - \angle E_{in}$
 $\tau_g = -\frac{\partial \phi}{\partial \omega}$
 $\Delta\tau_{g,max}$

Laser Intensity Modulator BPF Spectrum Analyzer
 V_{in}(t) V_A(t)
 P_{IM}(t₁) P_{IM}(t - τ)
 Connector Delay On-Chip Ring as Variable Delay Element
 Temperature Controller Power Supply
 GPIB MATLAB GPIB

Spectrum
 Δf = 1/τ
 Possible Oscillation Frequencies
 Spectrum of V_A(t)
 ω_{osc} = K / (τ₀ + τ_R)
 τ_R << τ₀ → K = [ω_{osc} τ₀]
 τ_R = ω_{osc} / K
 Q = τ_R ω_{osc} / 2 @ ω = ω_{osc}

Measurement Results

@ Resonance:

$\tau_{R,max}$

$\lambda_{res} = \lambda_1$

@ off-resonance:

λ_2

Spectrum of V_A(t)

$f_1 = \frac{K}{\tau_0 + \tau_{R,max}}$

Spectrum of V_A(t)

$f_1 = \frac{K}{\tau_0}$

$\tau_0 + \tau_{R,max} = \frac{K}{f_1}, \tau_0 = \frac{K}{f_2}$

$\tau_{R,max} = \frac{K}{f_1} - \frac{K}{f_2}$

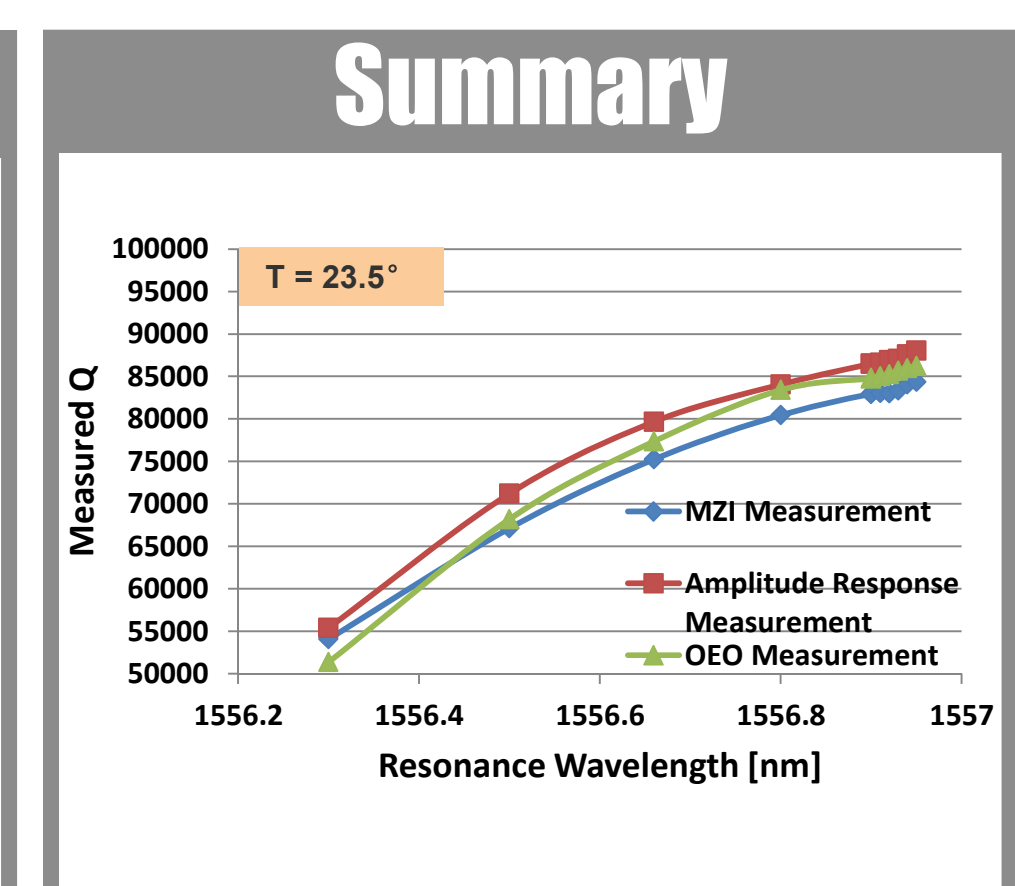
$Q = \frac{\tau_{R,max} \omega_{res}}{2} = \frac{\pi C \tau_{R,max}}{\lambda_{res}}$

Measured Group Delay [ps]

V_a = 0.6 V, T = 23.5°

Δτ_{g,max} = 140 ps → Q = 84,750

8.64
8.62
8.6
8.58
8.56
8.54
8.52
8.5
8.48
8.46
8.44
 1556.6 1556.7 1556.8 1556.9 1557 1557.1



Conclusion

Various techniques are used to measure the quality factor of on-chip tunable Silicon micro-resonators in the 1556.3-1556.95nm range to be 51,000-88,000.

Future Work

Utilize compact tunable Silicon micro-resonators as variable phase shifters and variable attenuators in large-scale monolithic phased arrays.