Design, Fabrication and Measurement of Integrated Bragg-Grating Filters

presented by:

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in collaboration with

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OUTLINE

A. Introduction to Bragg Gratings
   1. Why they are needed
   2. How they work

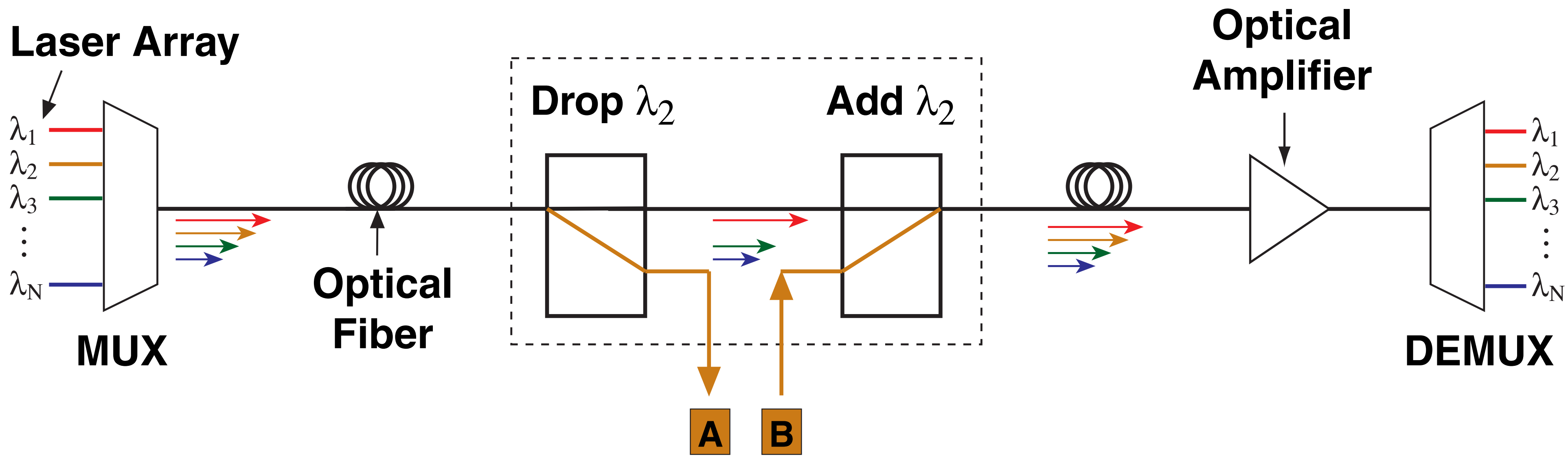
B. Applications of Grating Filters
   1. Add/Drop Filtering
   2. Noise Filtering

C. Waveguides and Couplers
   1. Fabrication Processes
   2. Insensitive Couplers

D. Integrated Bragg Gratings
   1. Lithographic Tools
   2. Alignment Mechanism
   3. Gratings on Waveguides
   4. Measurements

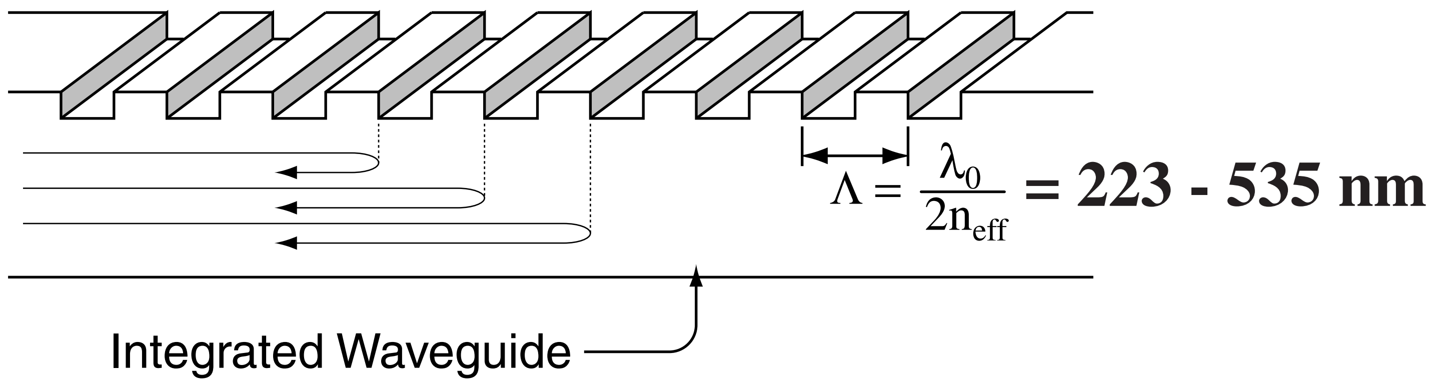
E. Conclusions / Future Work

All-Optical Communications System:
(the need for Filters)



Filters are used at transmitting end, receiving end, and intermediate points

Integrated Bragg Gratings



Sub-micron-period grating acts as narrow-band reflector (filter)

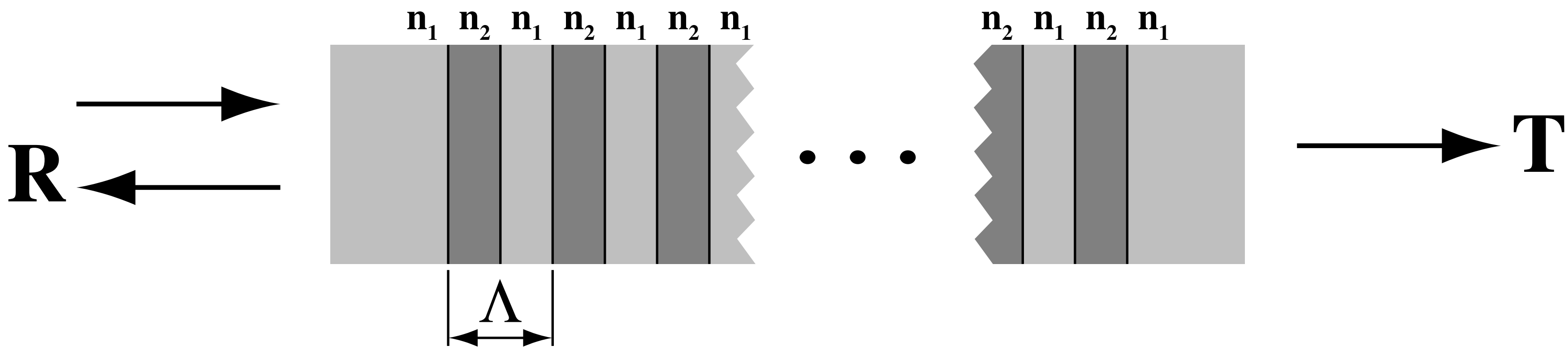
APPLICATIONS:

Lasers (DFB, DBR)
Dispersion Compensation
Add/Drop Filters
Noise Filtering
Gain Equalization
Sensors
Fiber Coupling (mode size transformers)

Bragg Grating Filters:

principle of operation

Dielectric Stack Filter (eg Mirror)

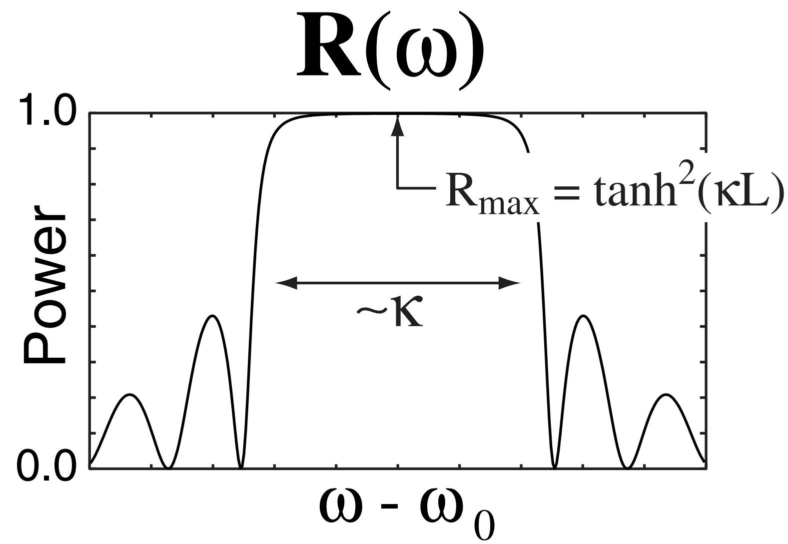


Coupling of Forward (+) and Backward (–) Waves:

$$\frac{d}{dz} A_+(z) = +i\delta A_+(z) + \kappa A_-(z)$$

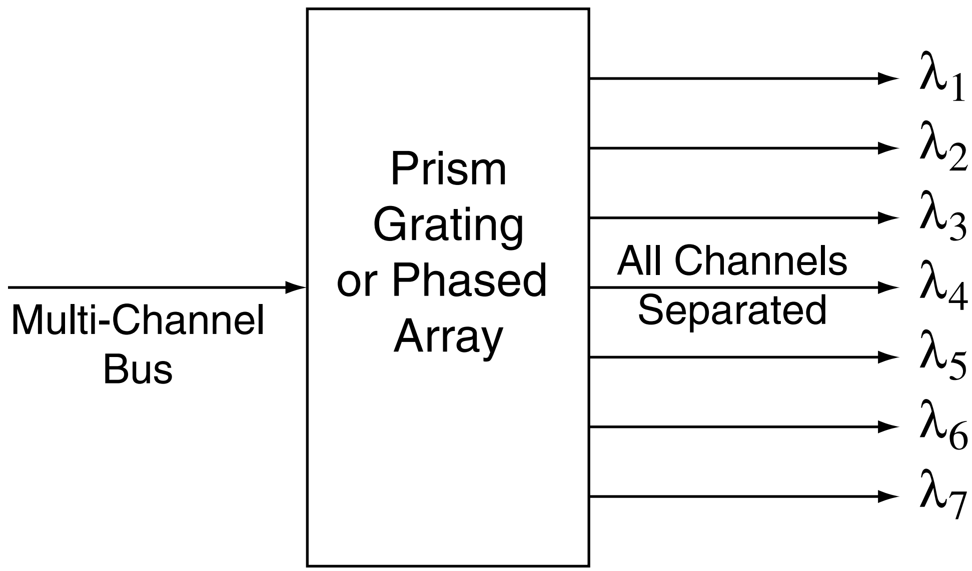
$$\frac{d}{dz} A_-(z) = -i\delta A_-(z) + \kappa^* A_+(z)$$

$$\delta = \beta - {}^{\pi}/_{\Lambda}$$



Filtering Strategies in WDM

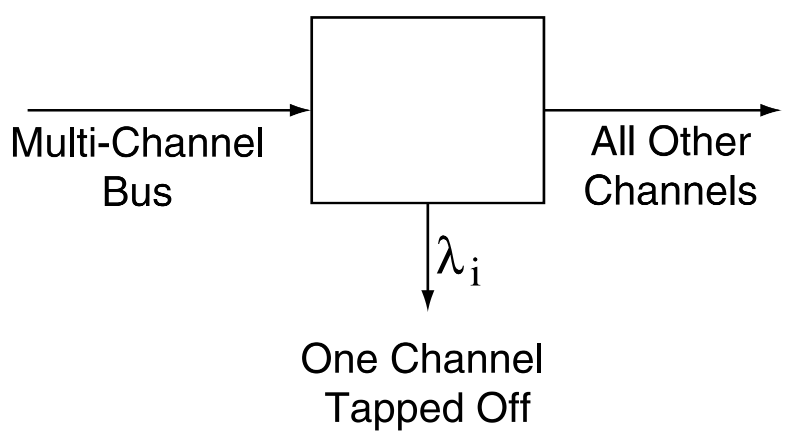
Full Spectral Resolving Filter



All channels must be resolved, even if only one is needed.

Filter becomes more complex as channel number increases

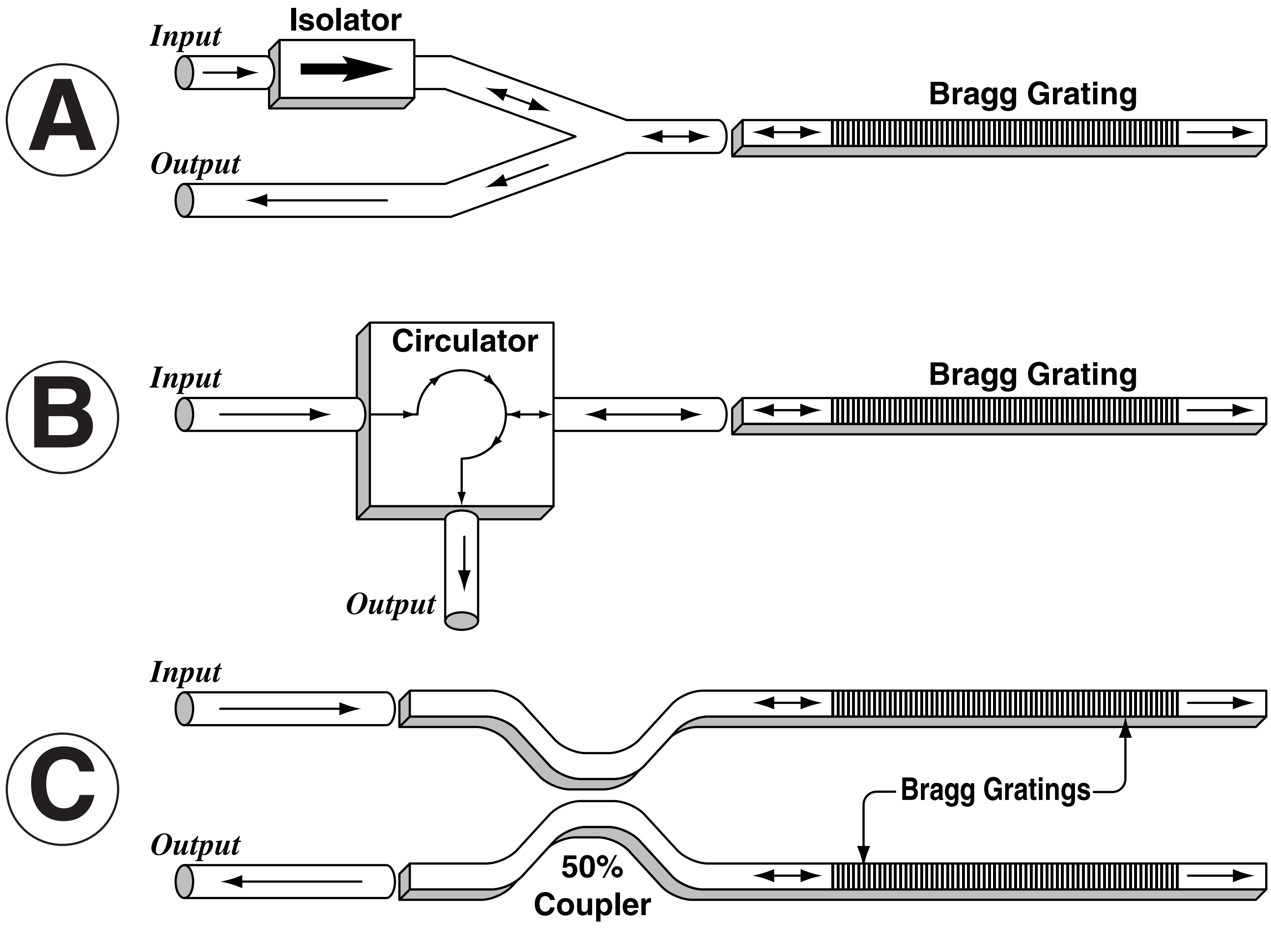
Channel Dropping Filter



One channel may be added or dropped without effecting the others

System can be easily expanded to include more channels

Grating Filter Configurations

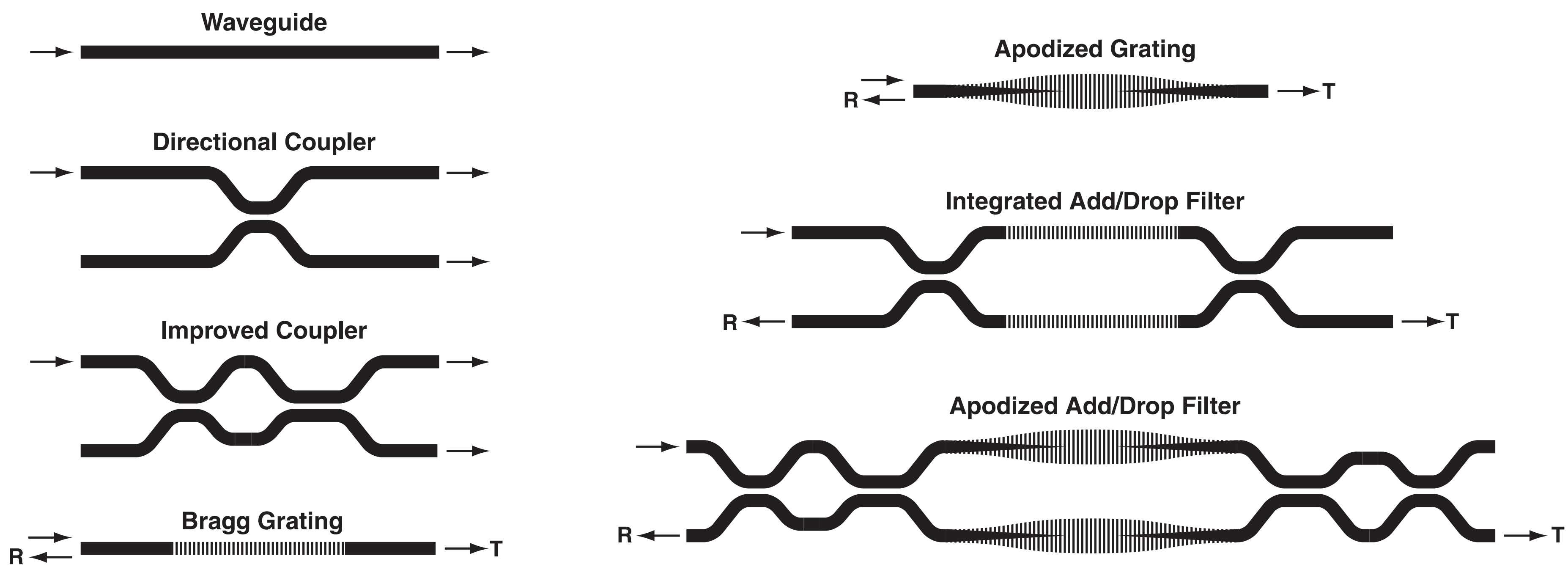


Key Integrated Components:

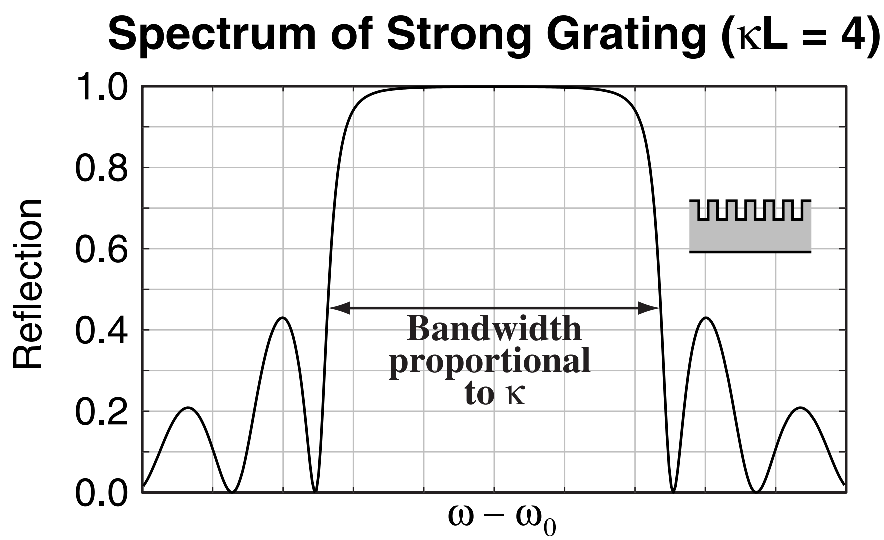
waveguides, couplers and gratings

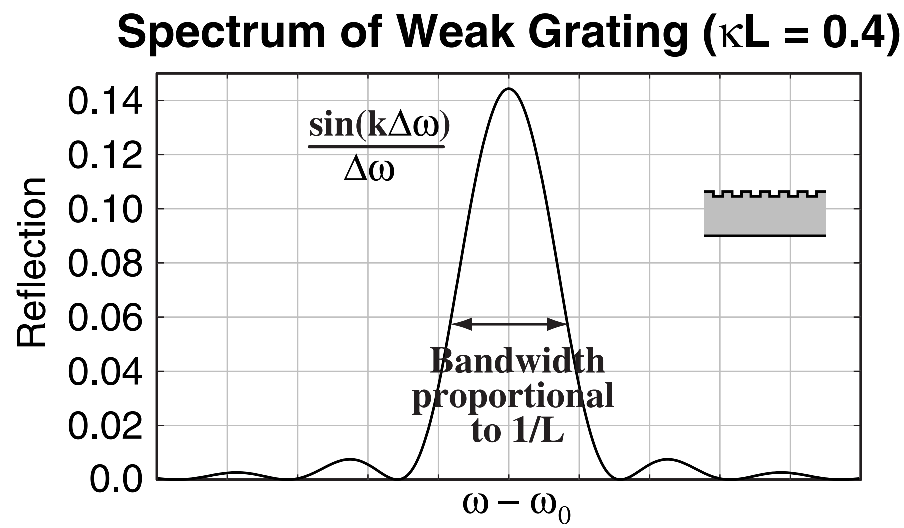
Building Blocks:

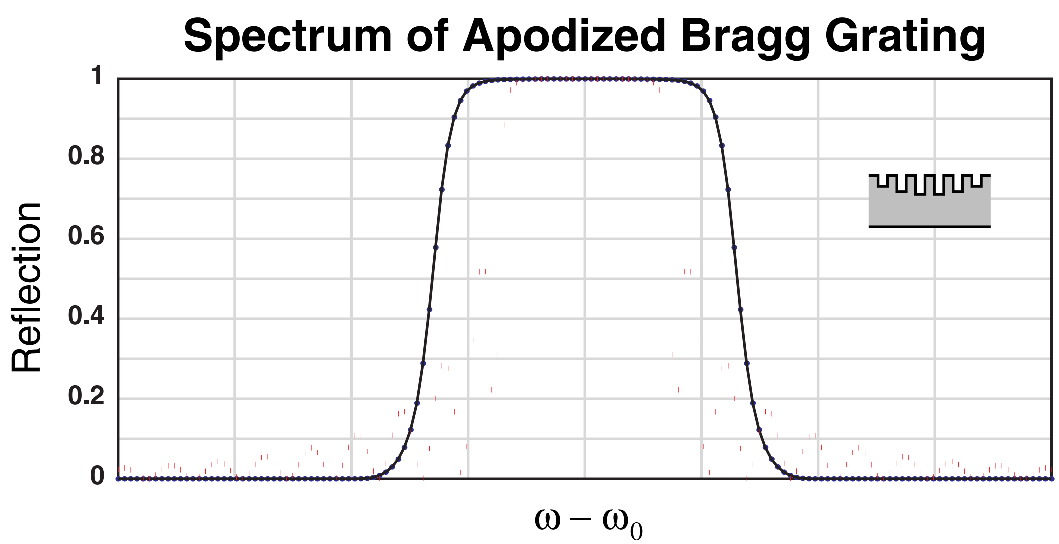
Advanced Devices:



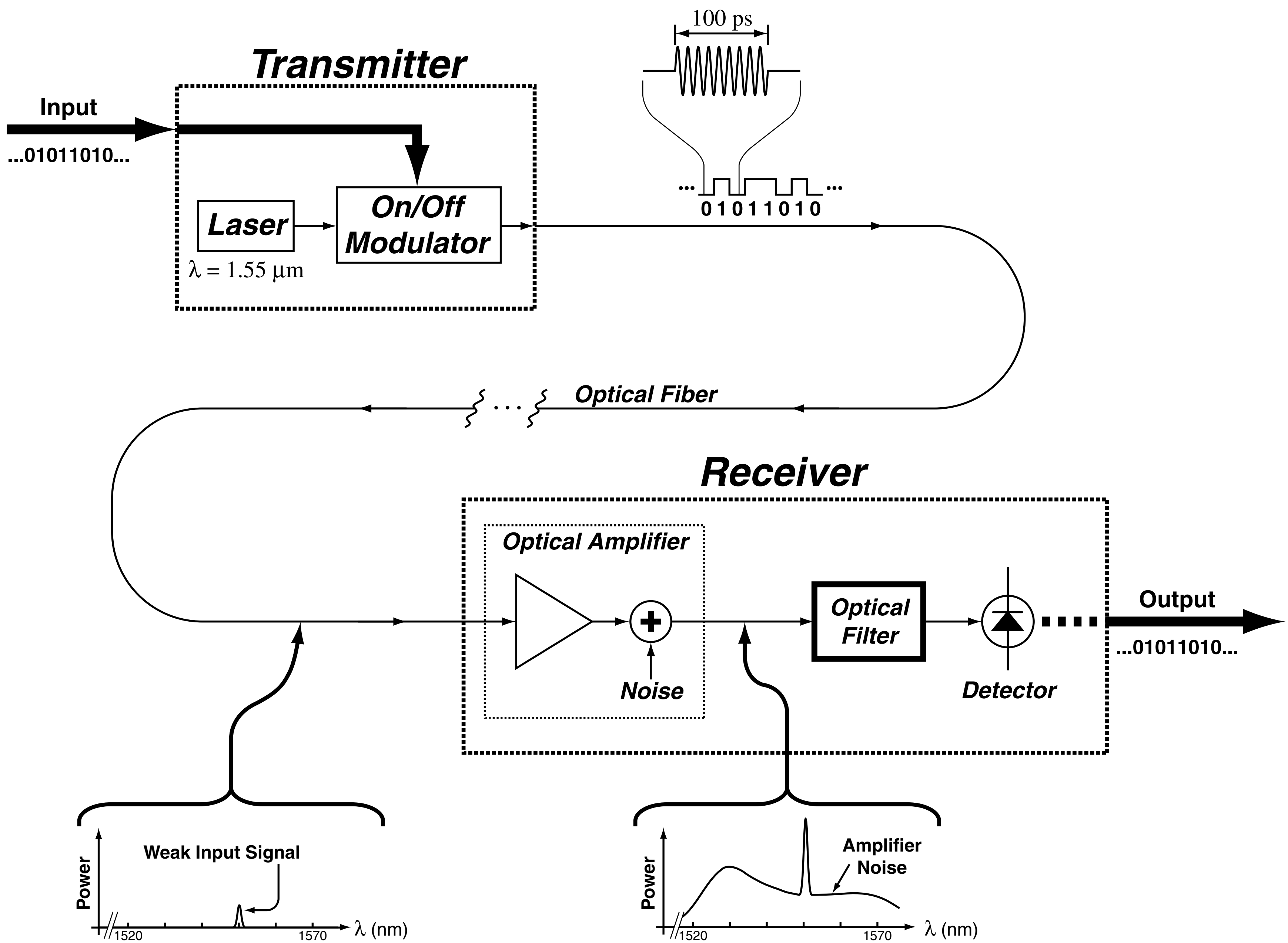
Types of Bragg Gratings



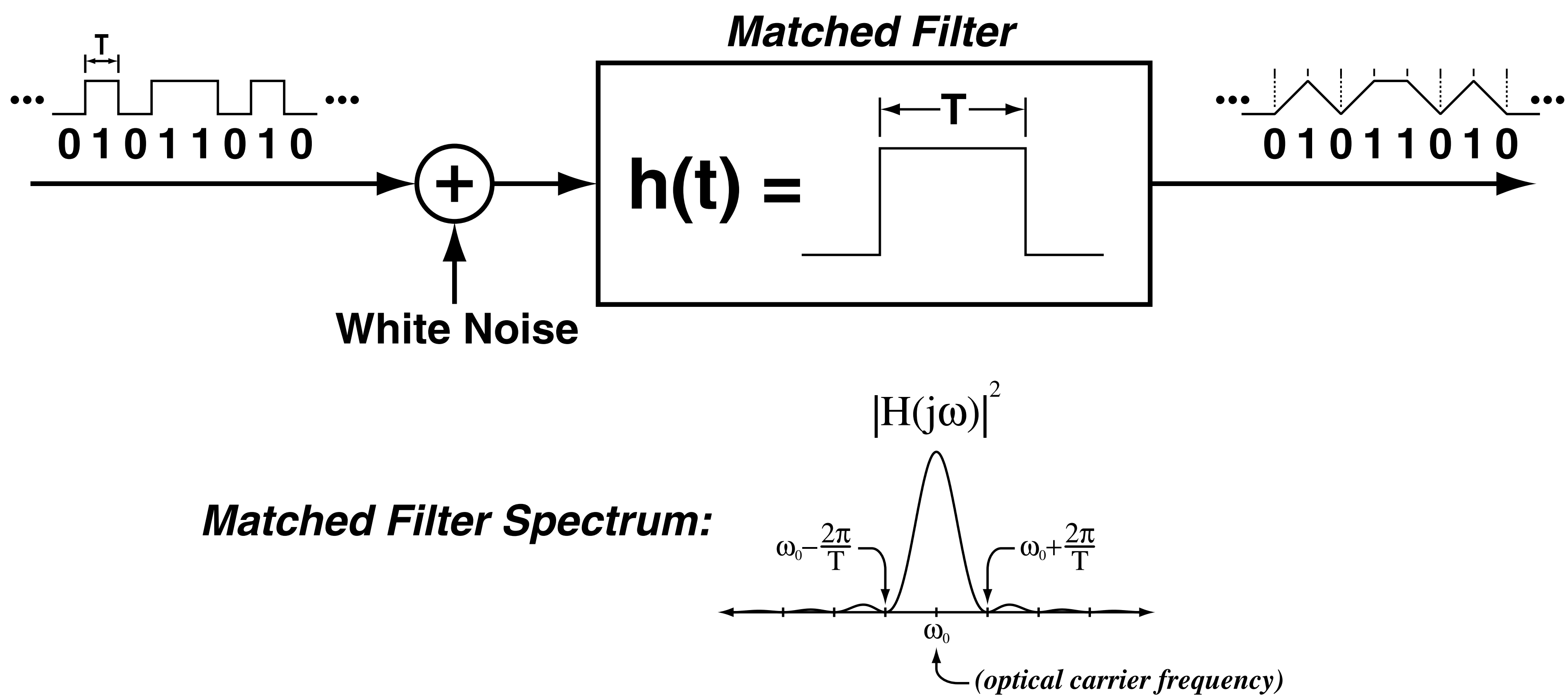




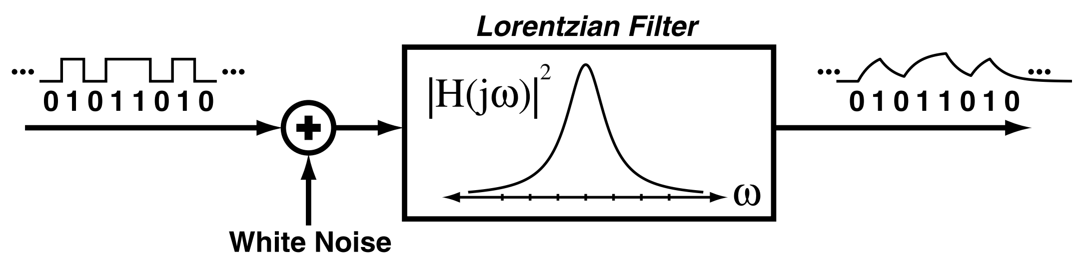
Noise Filtering In Optical Communications



Matched Filter / Correlation Filter

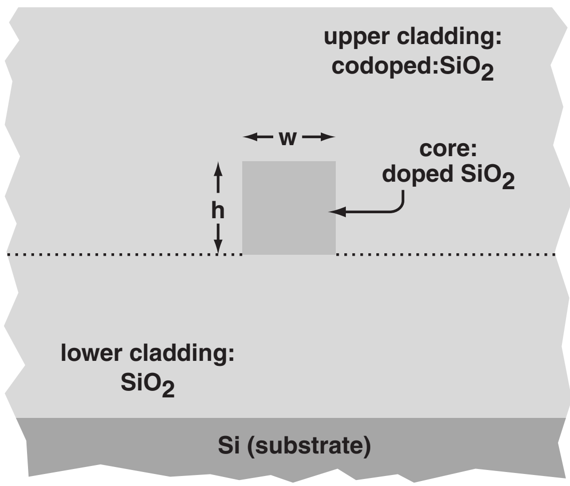


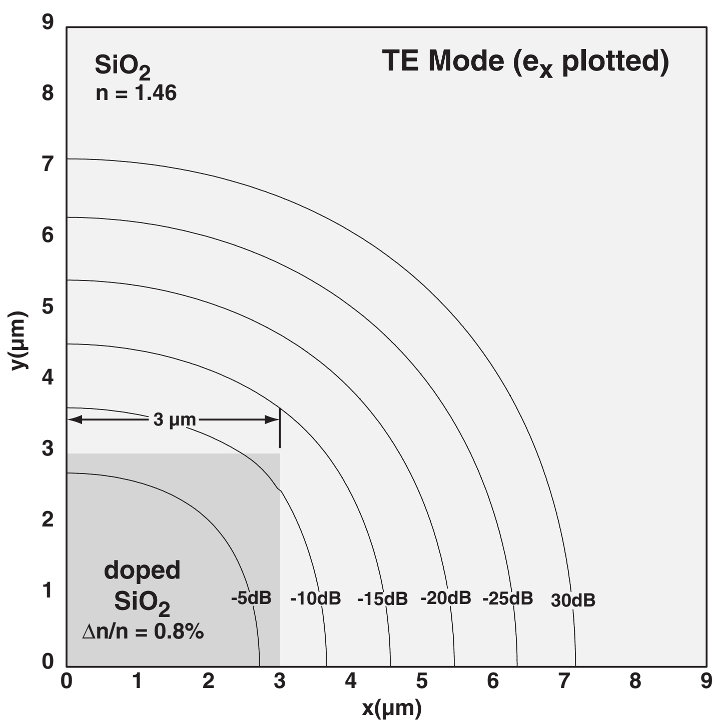
Fabry-Perot Filter (currently used)



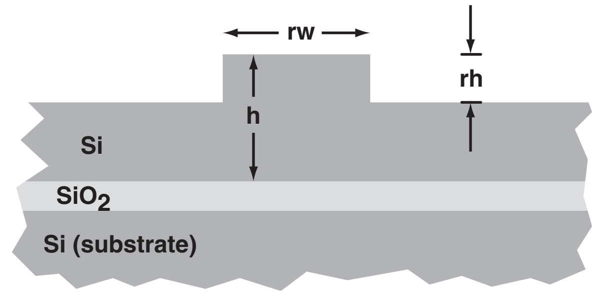
Types of Waveguides Considered

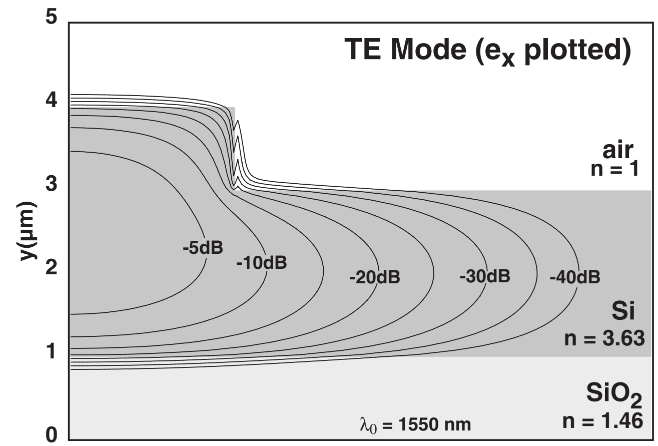
Doped-Glass Channel Waveguide

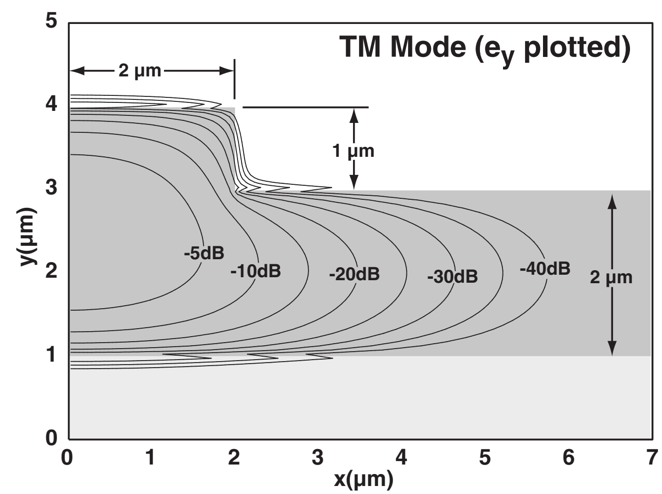




Silicon-on-Insulator Ridge Waveguide

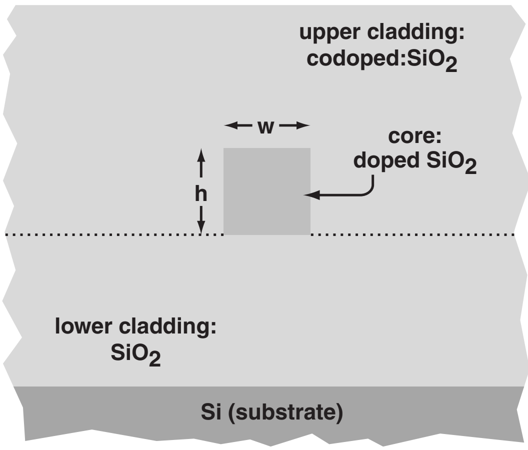






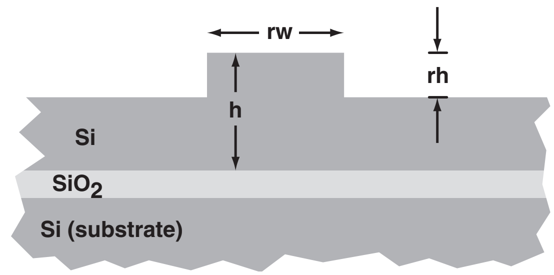
Comparison of Waveguide Types

Doped-Glass Channel Waveguide



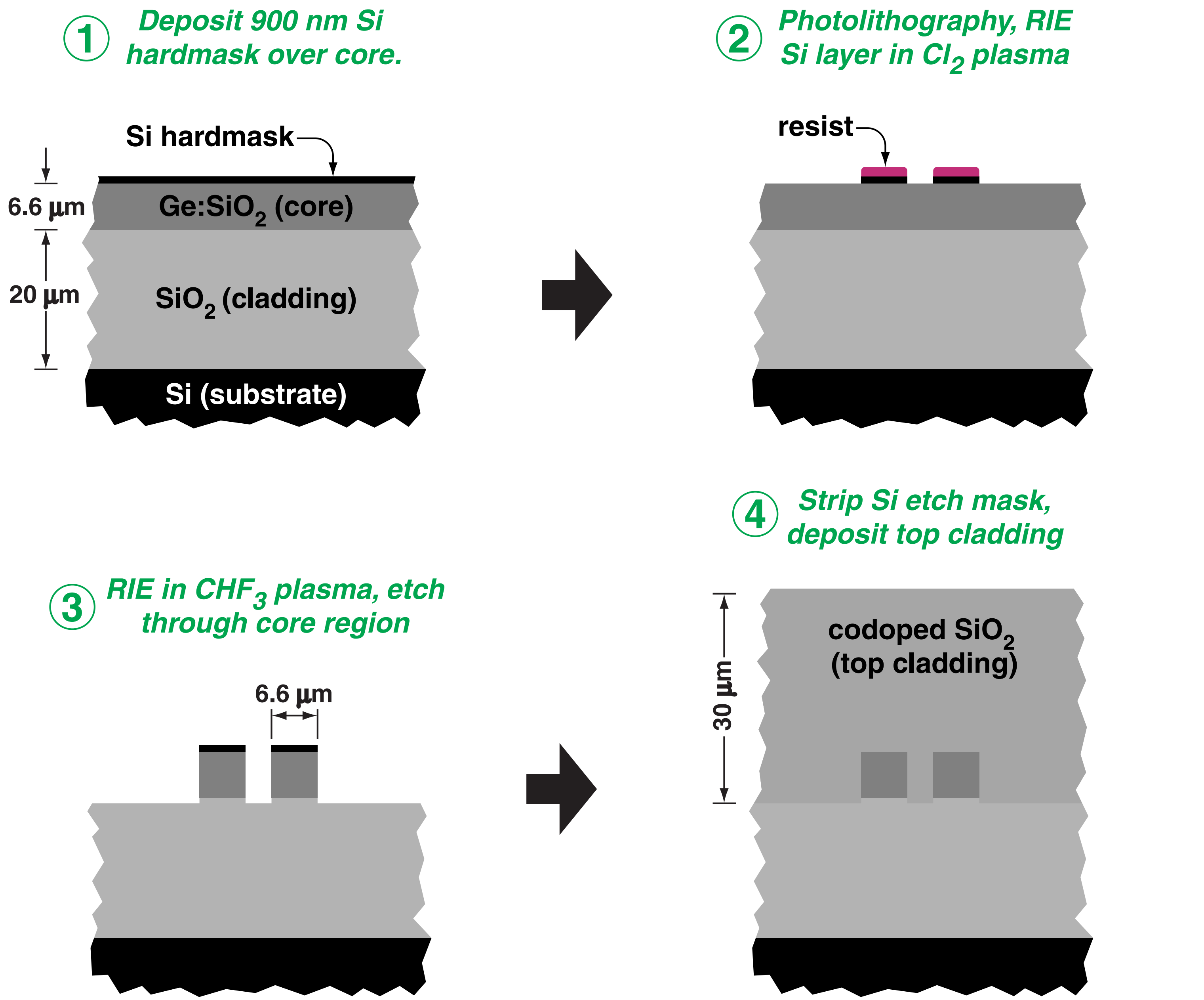
- Low propagation loss
- Efficient coupling to fiber
- Typically relatively long
- Low birefringence
- Large bending radius
- Multiple deposition technologies:
  - Flame Hydrolysis
  - Chemical Vapor Dep. (CVD)
  - PECVD

Silicon-on-Insulator Ridge Waveguide



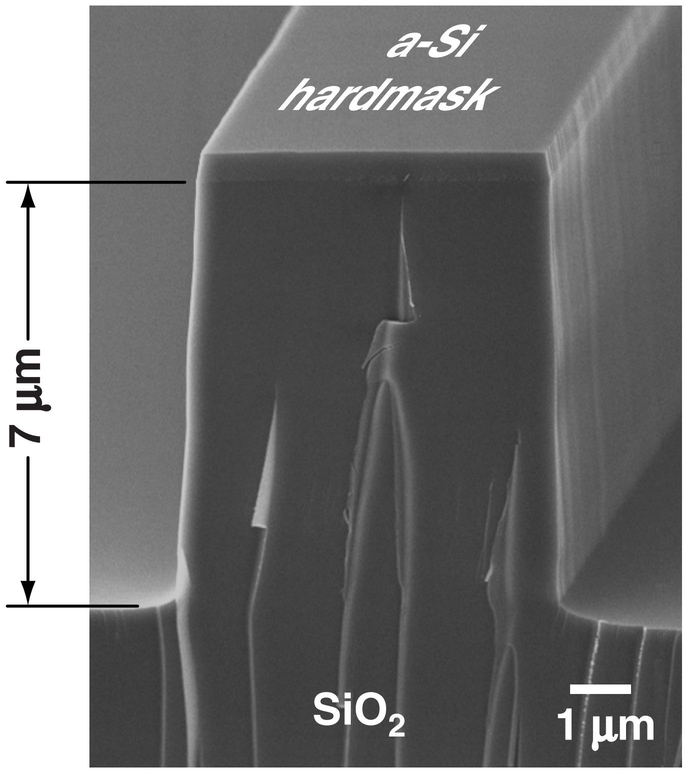
- Mature technology
- Commercially available, inexpensive
- Somewhat higher loss
- Efficient coupling to fiber possible
  (requires ARC, shallow ridge)
- Can be made relatively short
- Higher birefringence
  & polarization dependence
- Does not require overgrowth

Glass Waveguide Fabrication

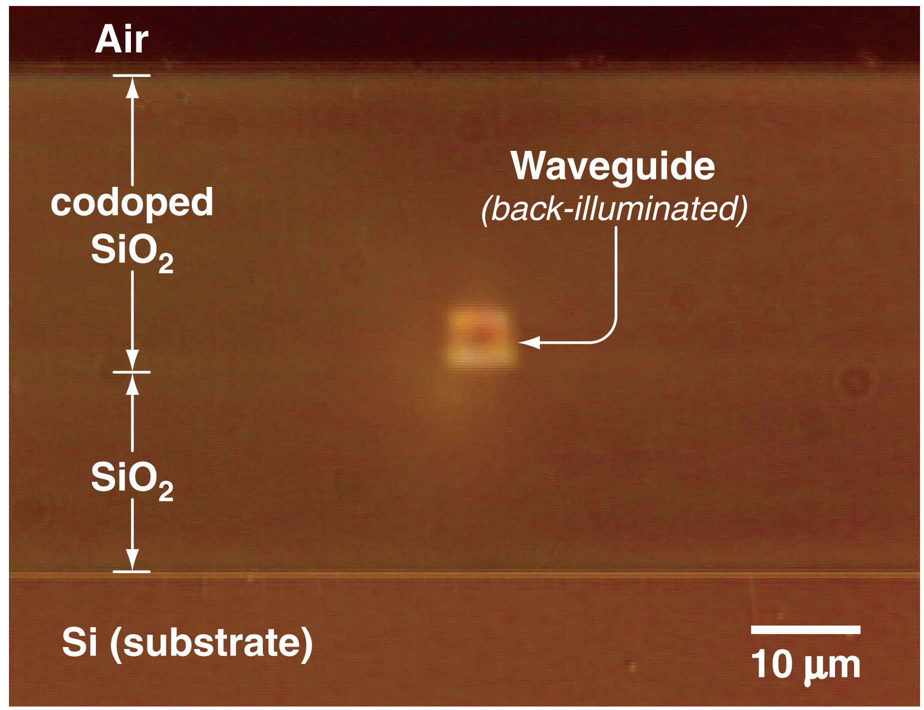


Micrographs of Integrated Glass Waveguide

Etched Waveguide

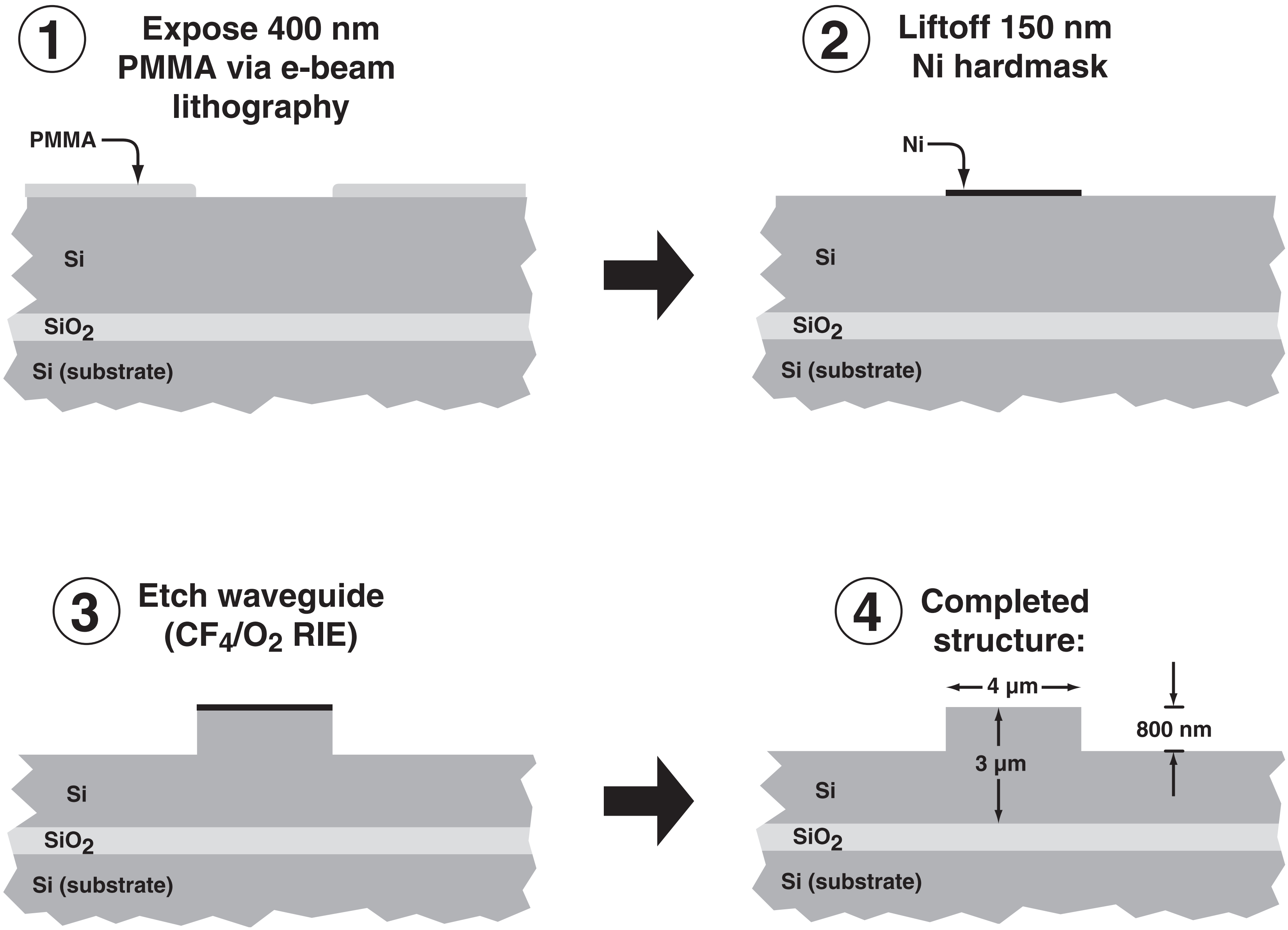


Optical Micrograph of Polished Chip Facet

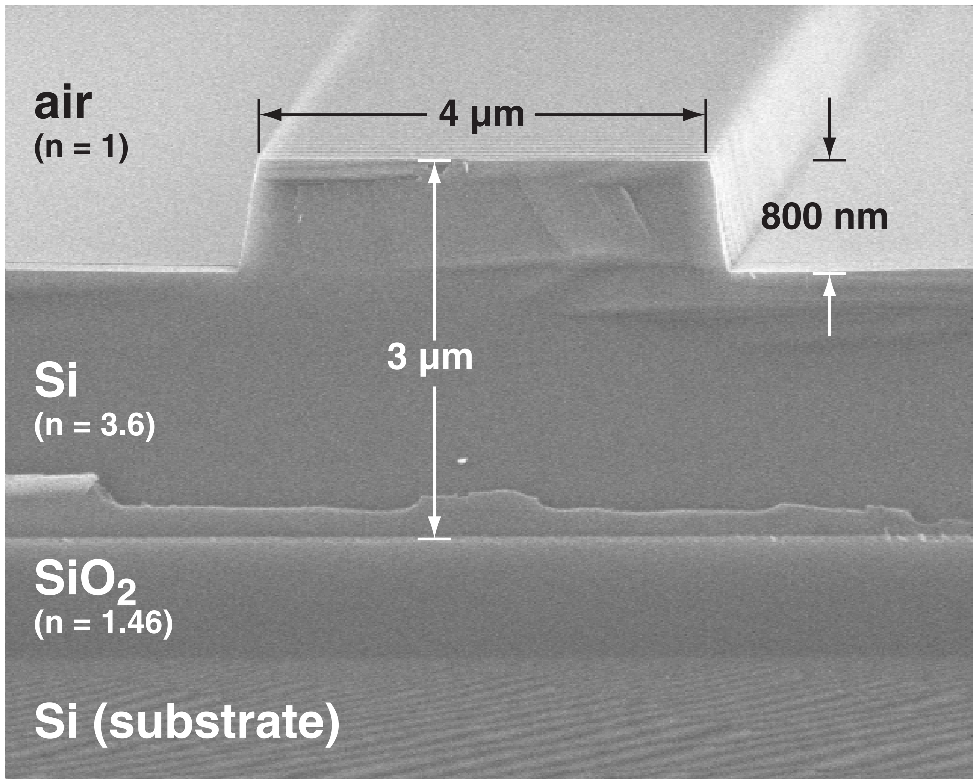


Raw materials and deposition by PIRI, Inc.
Flame Hydrolysis Deposition (Ge, Ti dopants)
nominal index contrast: $\Delta n/n = 0.3$ %

Silicon Waveguide Fabrication

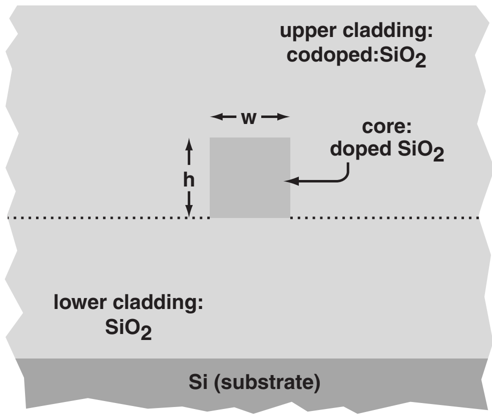


Completed Silicon-on-Insulator Ridge Waveguide



Summary of Waveguide Performance

Doped-Glass Channel Waveguide



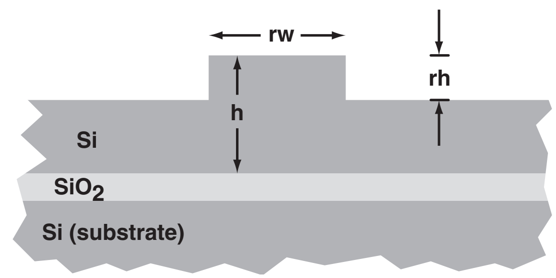
Total Insertion Loss:
< 1 dB over 2 cm

Coupling to Fiber:
< 0.2 dB per facet
(butt-coupled)

Bending Radius
20-40 mm (typical)

Polarization Dependent Loss:
< 1 dB

Silicon-on-Insulator Ridge Waveguide



Total Insertion Loss:
~12 dB over 1.7 cm

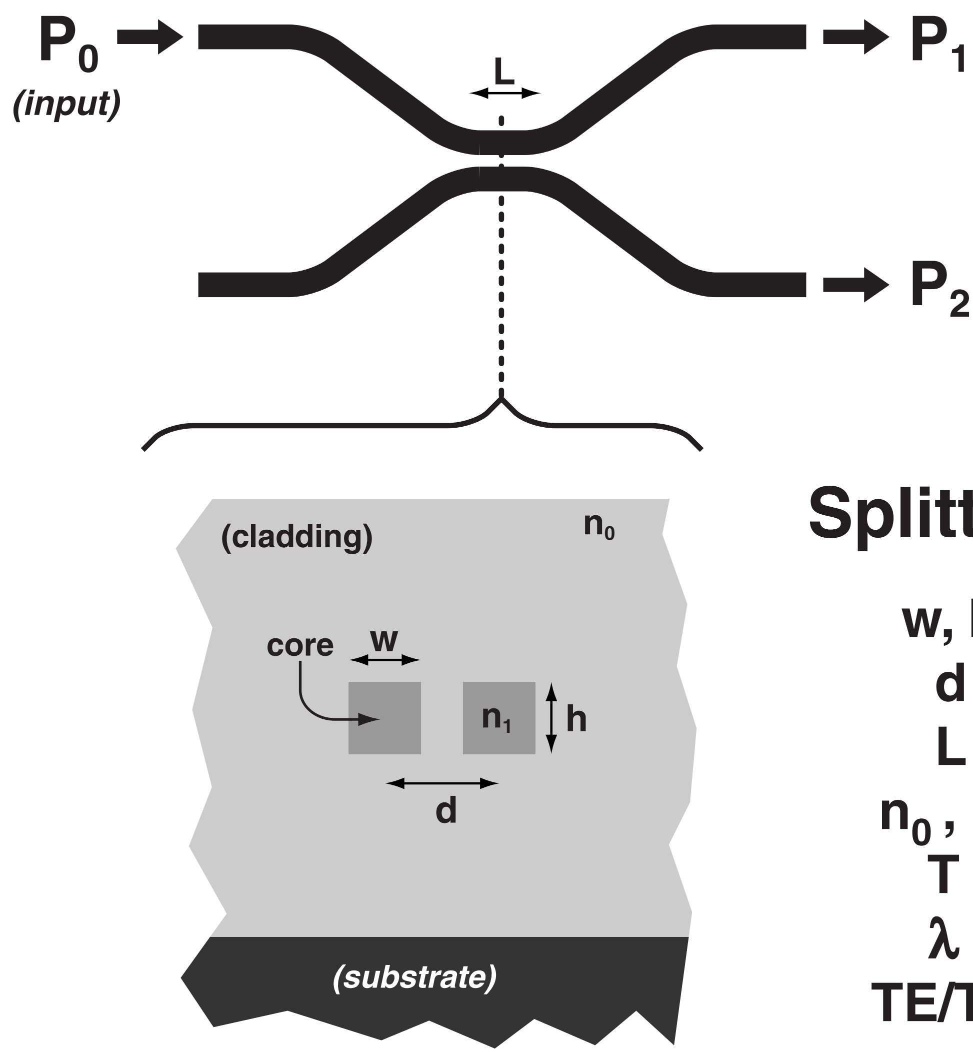
Propagation Loss:
~2-6 dB/cm

Bending Radius
10-15 mm (typical)

Polarization Dependent Loss
<1 dB

Birefringence: ~50 GHz

Conventional Integrated Directional Coupler



Splitting Ratio:

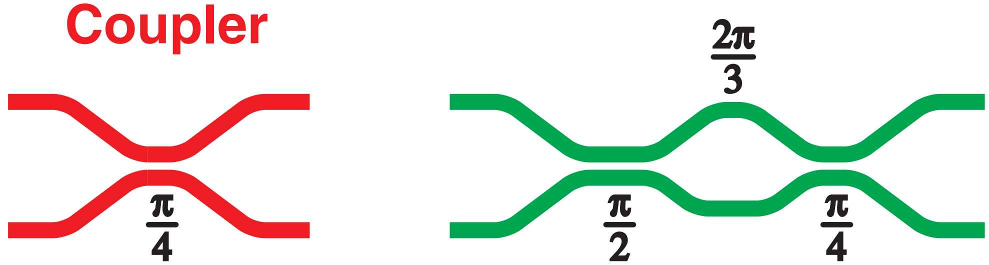
$$S = \frac{P_2}{P_1 + P_2} = \sin^2(\mu L)$$

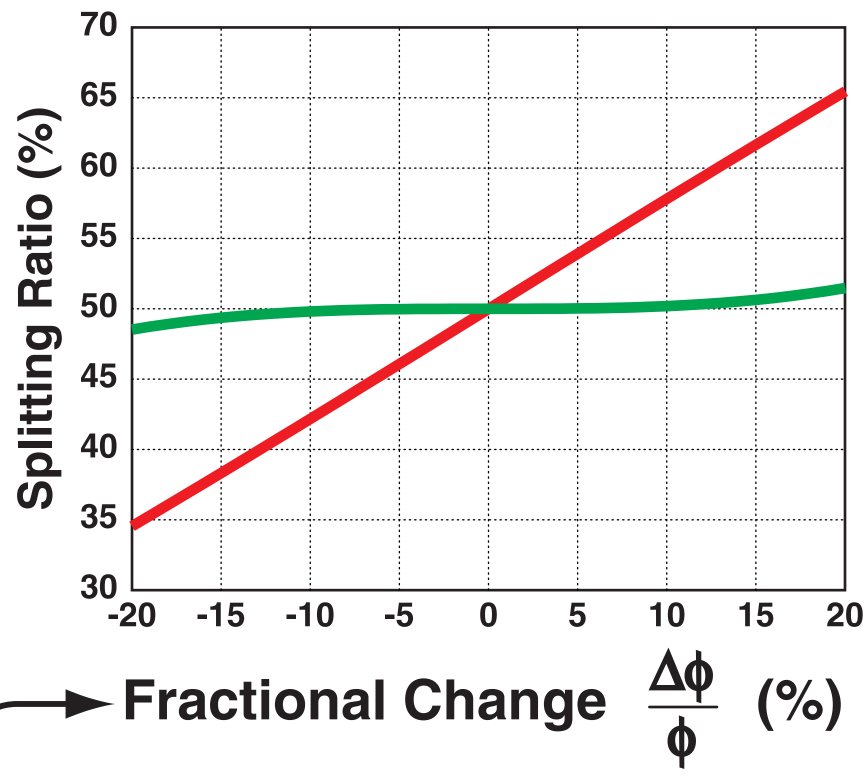
Splitting Ratio Changes With:

w, h	(width, height)
d	(center-to-center separation)
L	(interaction length)
n_0 , n_1	(core/cladding index)
T	(temperature)
λ	(wavelength)
TE/TM	(polarization)

An Improved Directional Coupler

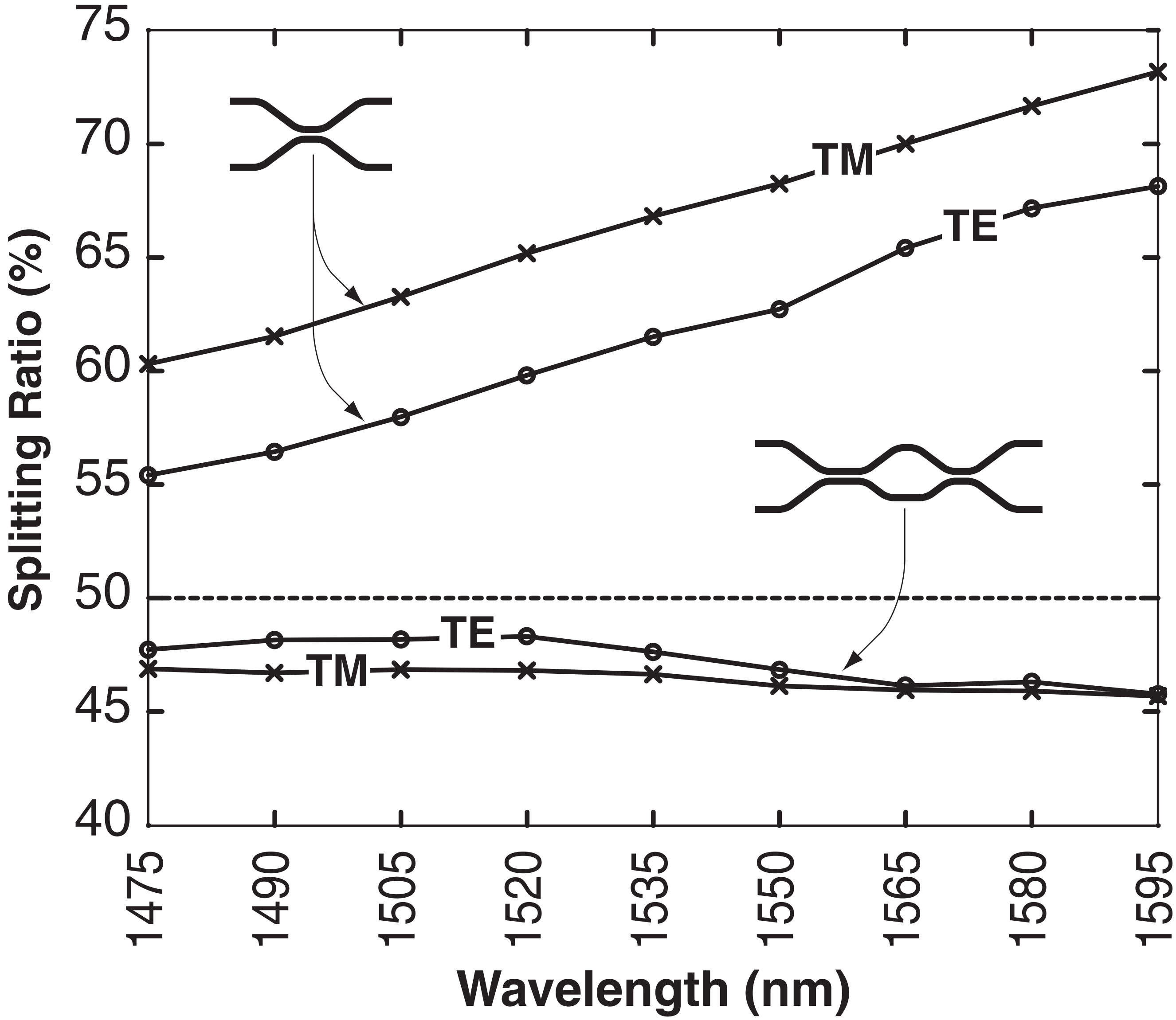
Regular 50% Coupler **Insensitive 50% Coupler**



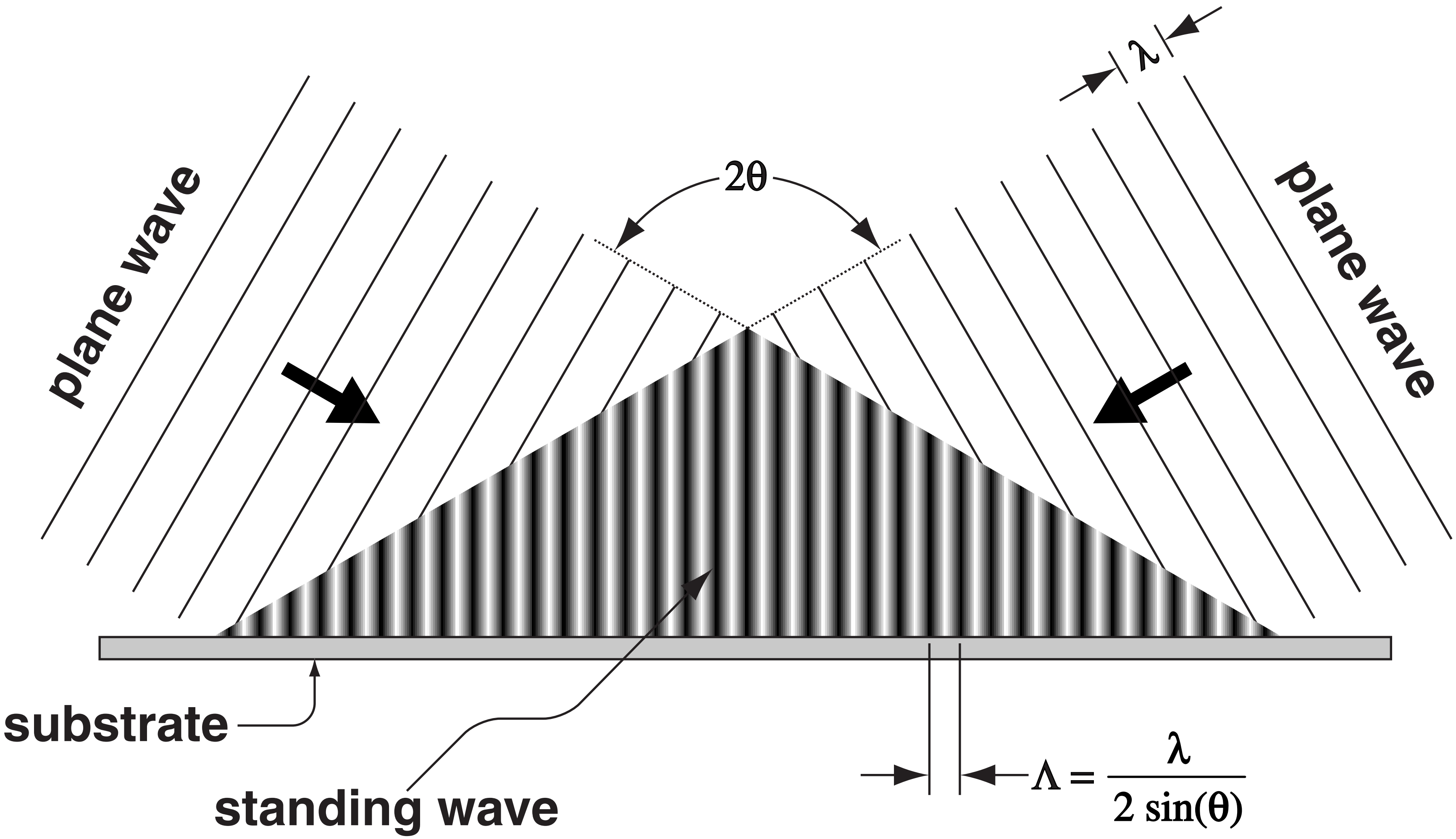


Caused by changes in polarization, wavelength, materials dimensions, temperature, refractive indices, etc...

Performance of Insensitive Couplers

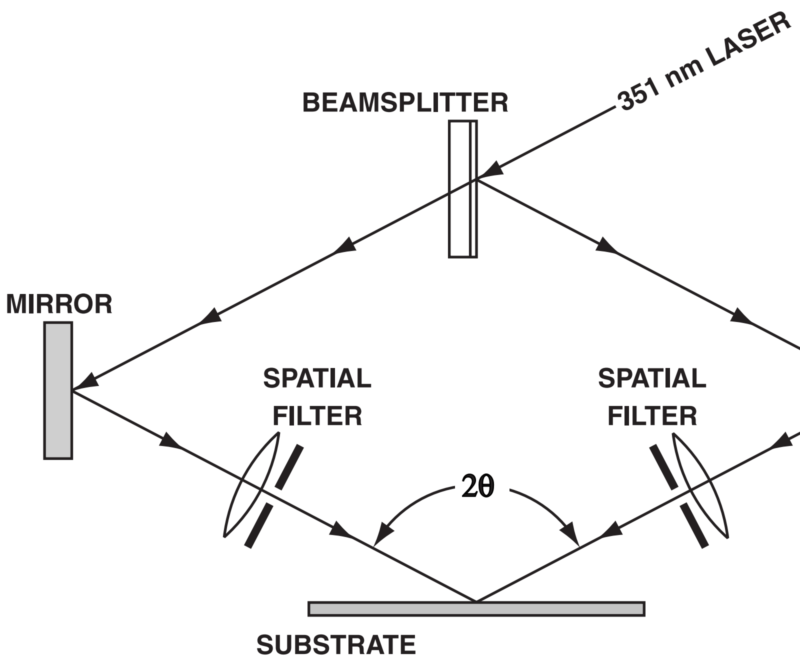


Interference Lithography

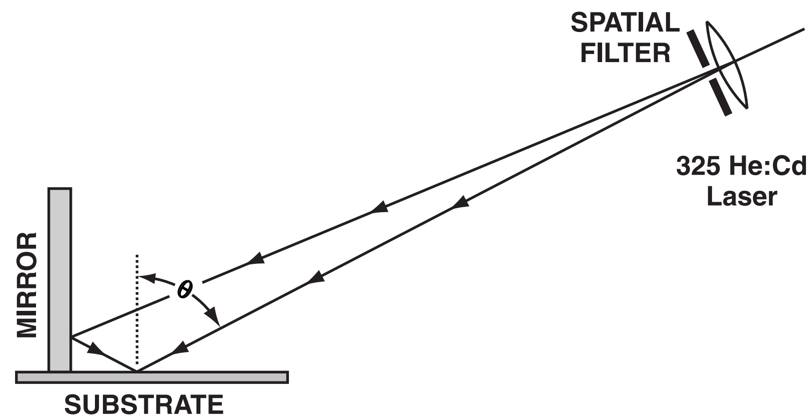


Interference Lithography Systems

Split-beam Interferometer



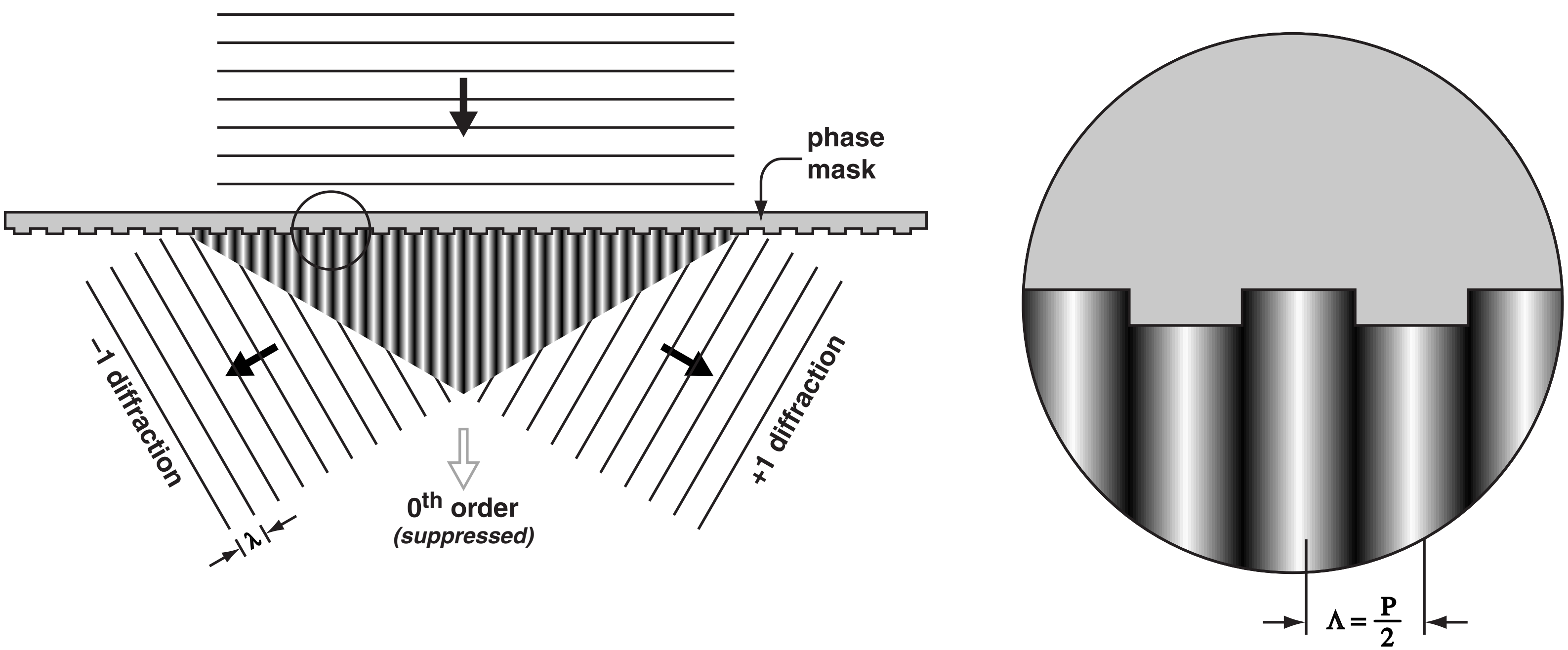
Lloyd's Mirror Interferometer



Finge-locking required
Change period by adjusting θ
(or by raising substrate)
Spherical wavefronts interfering
at substrate

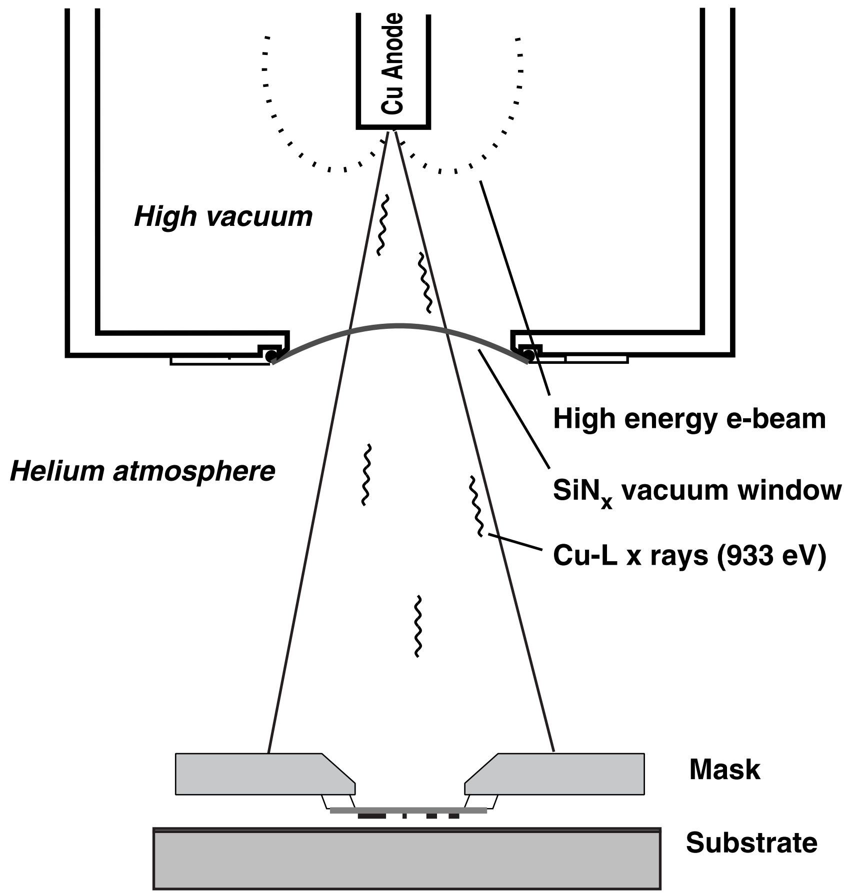
Change period by rotating
mirror-substrate assembly
Spherical wavefronts, but
larger R is possible

Phase Mask Interference Lithography

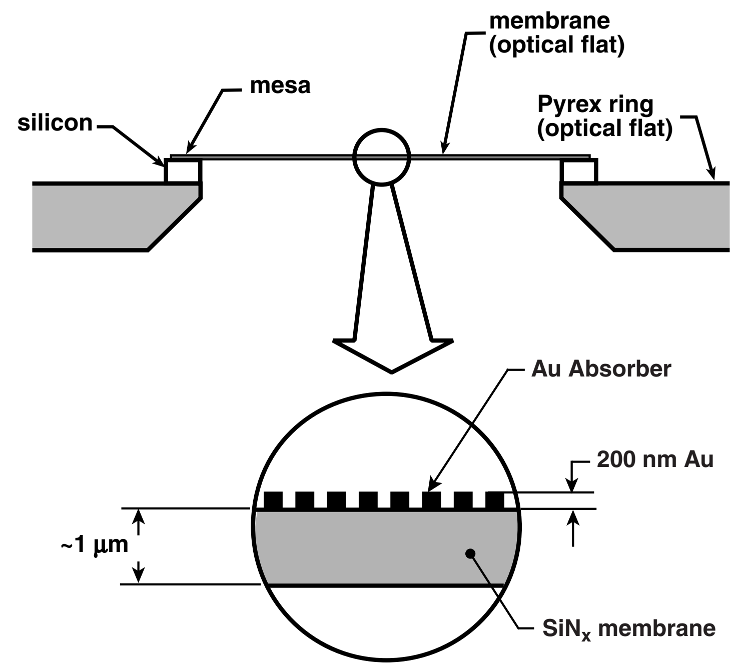


Does not require coherent illumination
Period of grating is P/2 (cannot be adjusted without changing phase mask.)
High contrast exposure requires small 0th order
Phase mask must be made by some other technique

X-ray Nanolithography

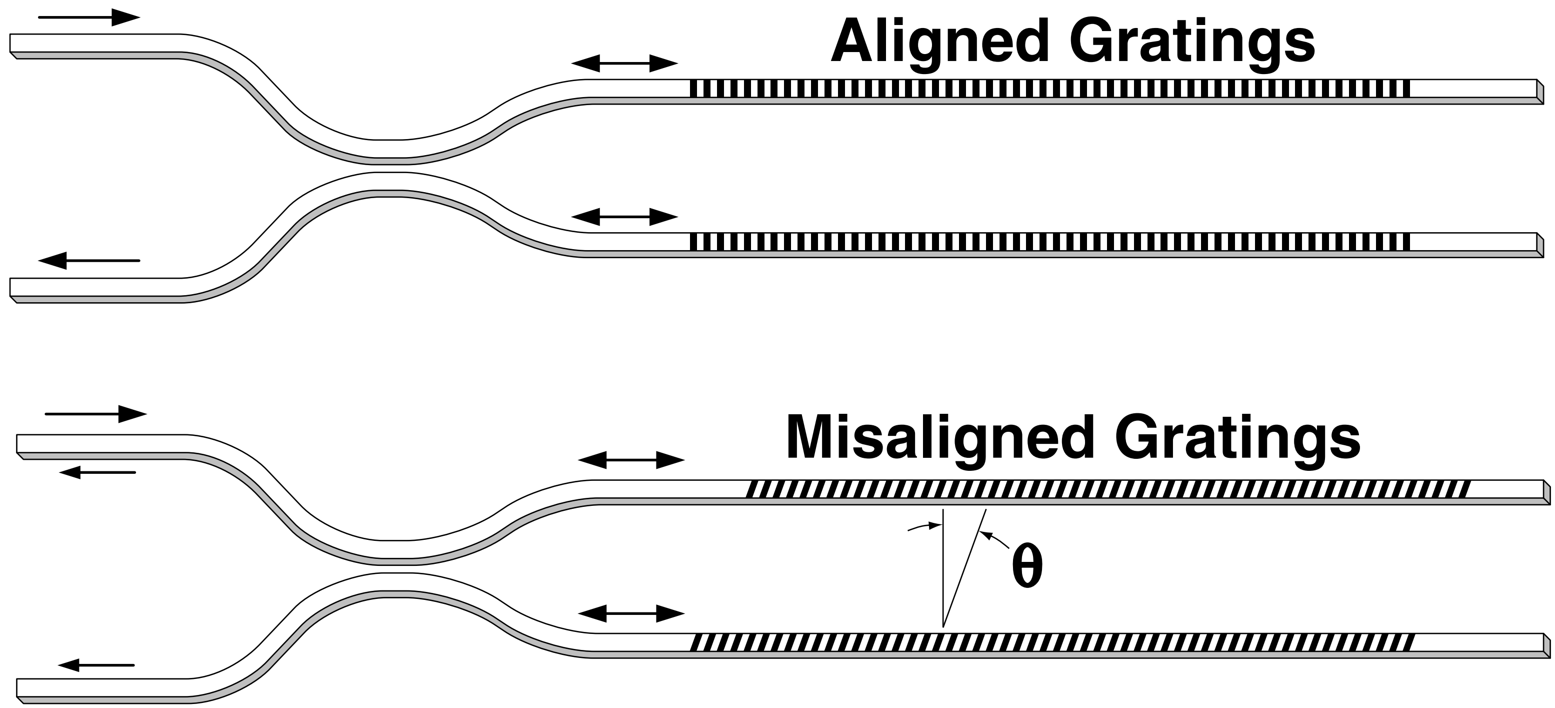


x-ray mask (may be generated by IL, e-beam)



High resolution (~30 nm)
Does not require antireflective coatings

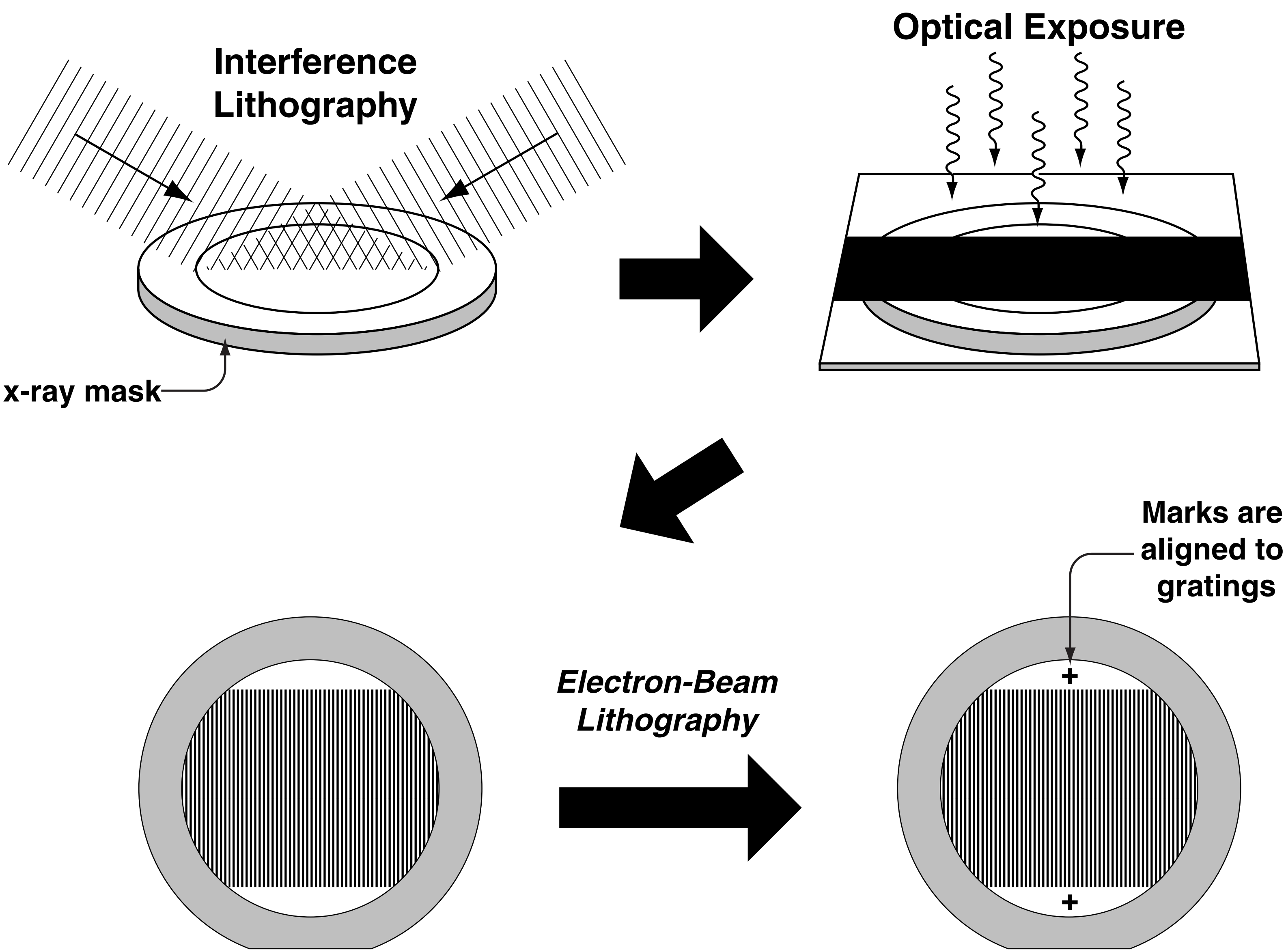
Alignment of Gratings to Waveguides



FOR INTEGRATED INTERFEROMETER DEVICES, ANGULAR ALIGNMENT OF GRATING TO WAVEGUIDE IS CRITICAL

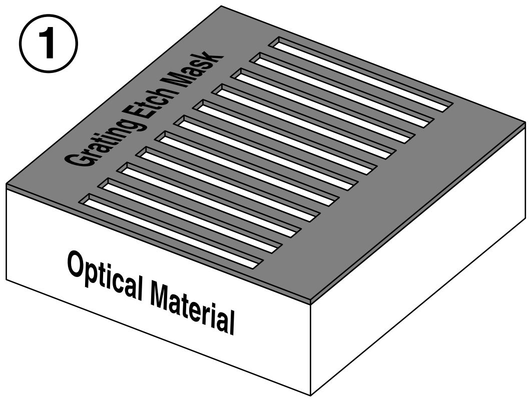
$$\theta < 0.2 \text{ milliradians}$$

Adding Alignment Marks to X-ray Mask

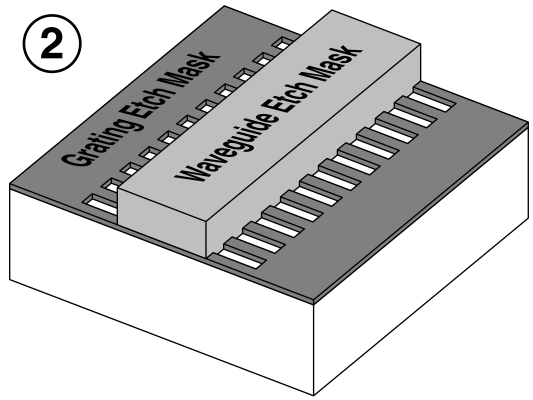


Dual Hard Mask Procedure

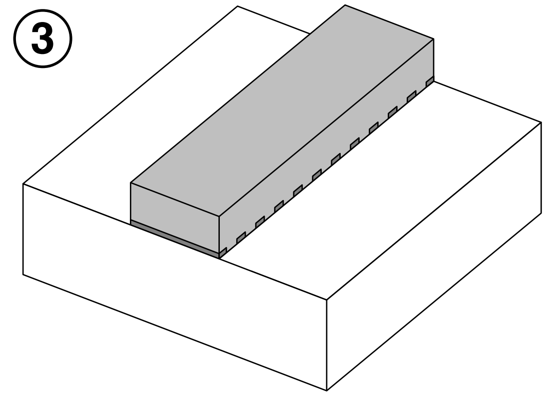
Pattern grating etch mask on substrate



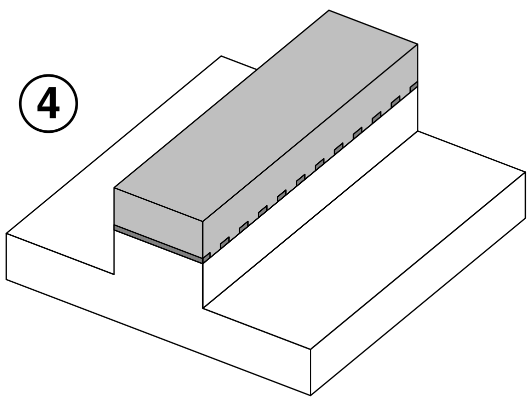
Pattern waveguide mask over grating mask



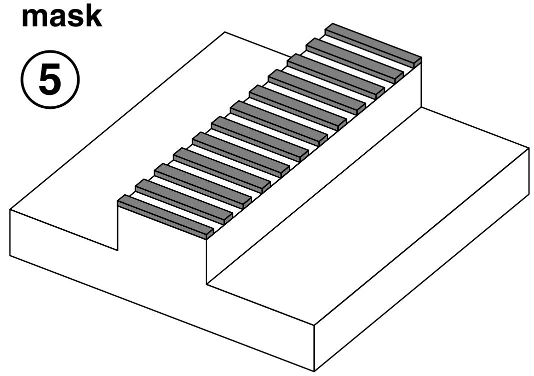
Remove excess grating mask, exposing substrate



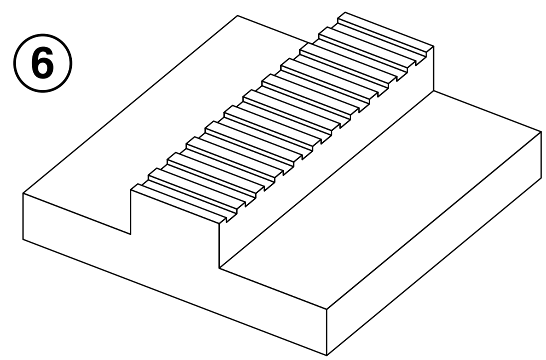
Etch waveguide features



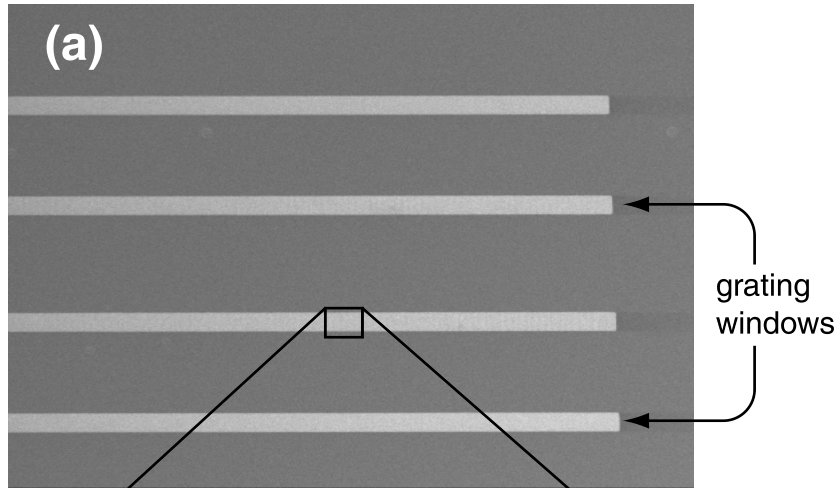
Remove waveguide mask, revealing underlying grating mask

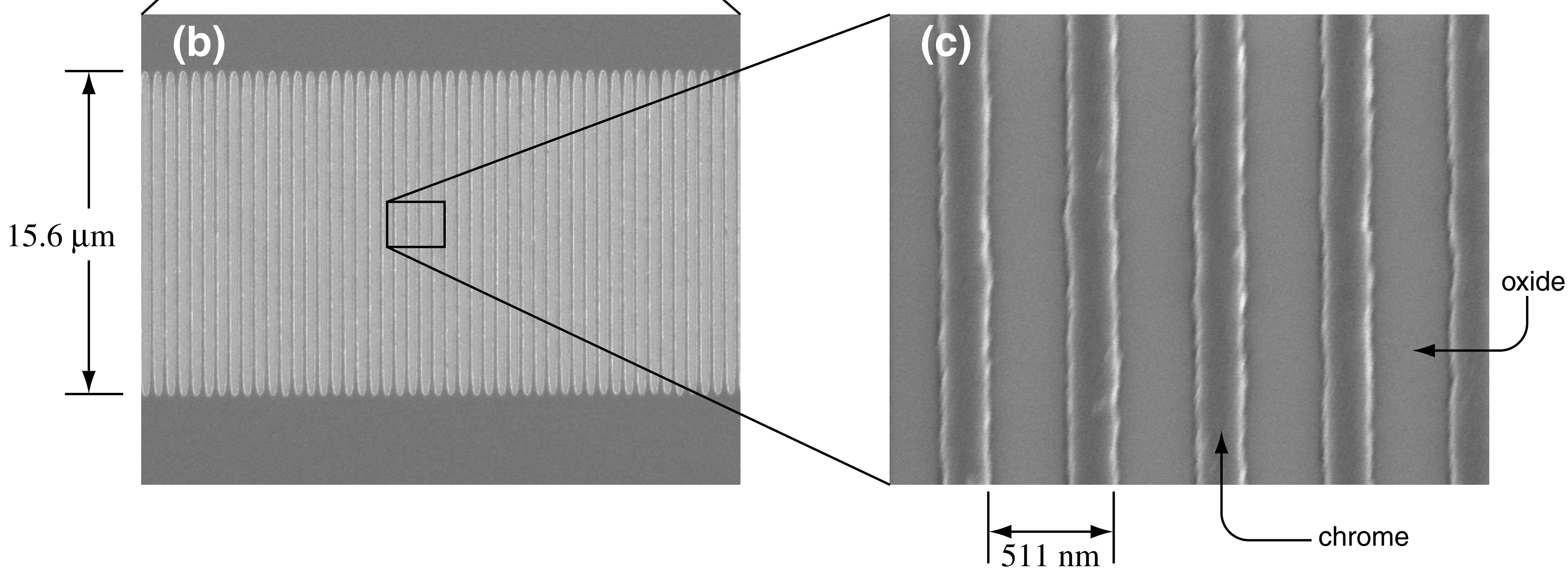


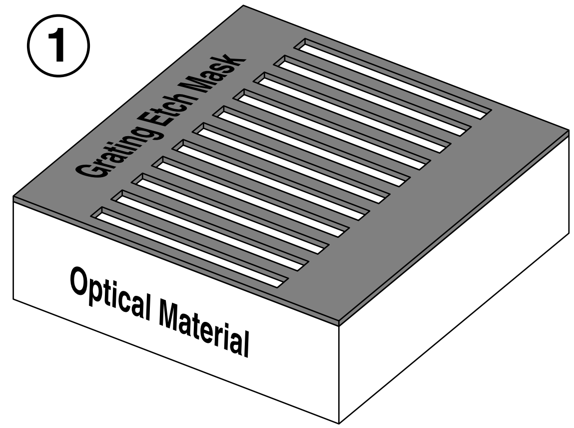
Etch shallow grating features, then remove grating mask



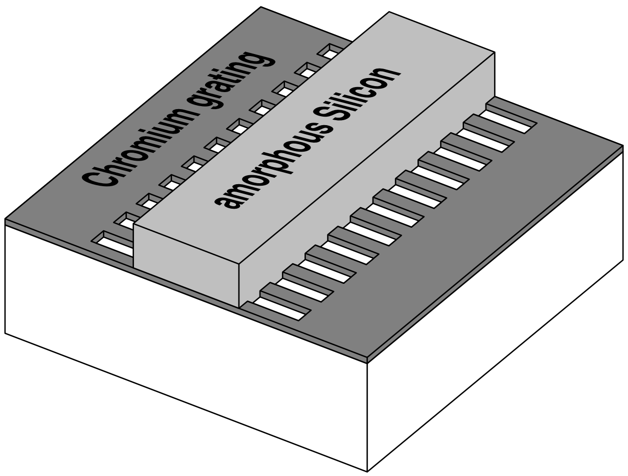
Pattern Grating Hard Mask

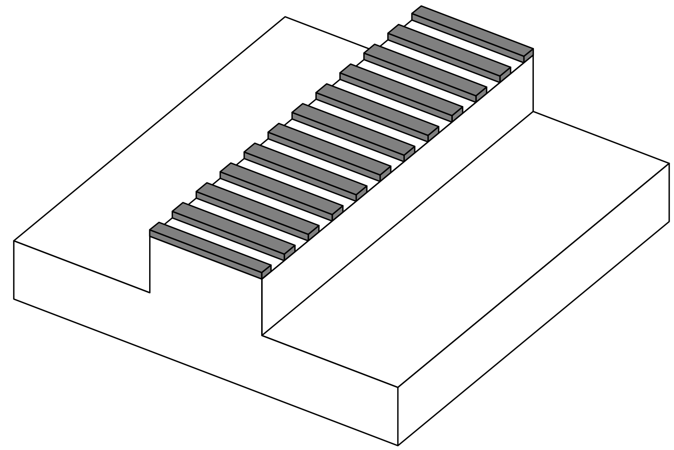


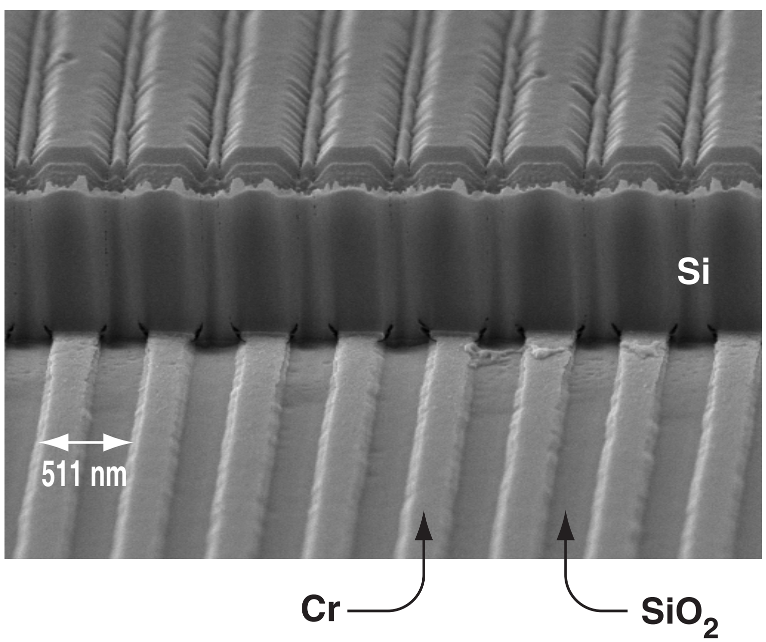


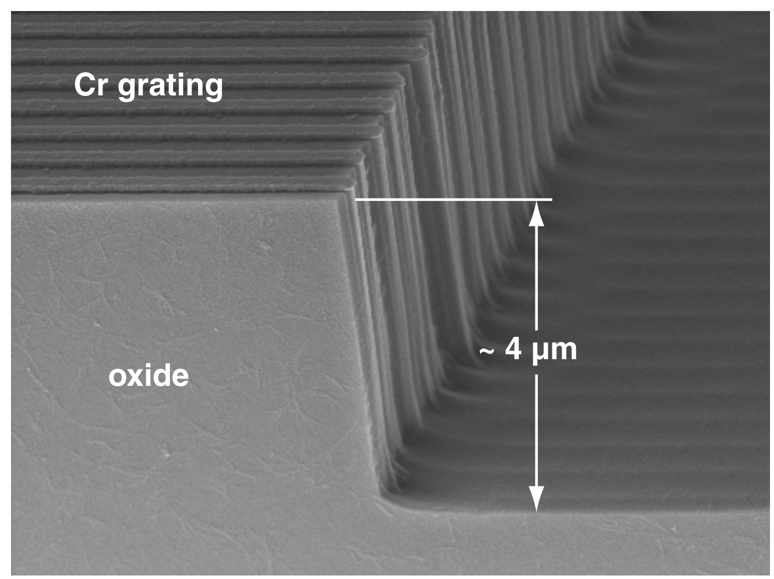


Patterning Bragg Gratings over Glass Waveguides

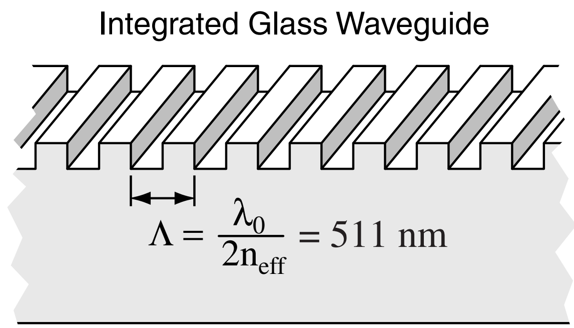


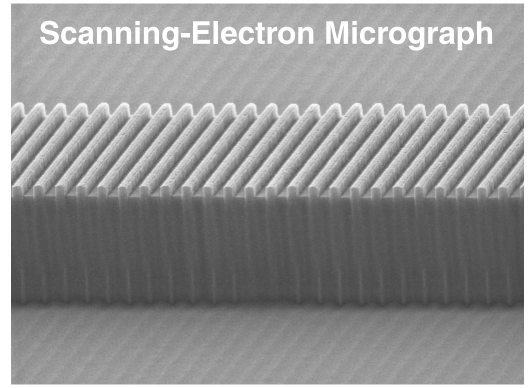


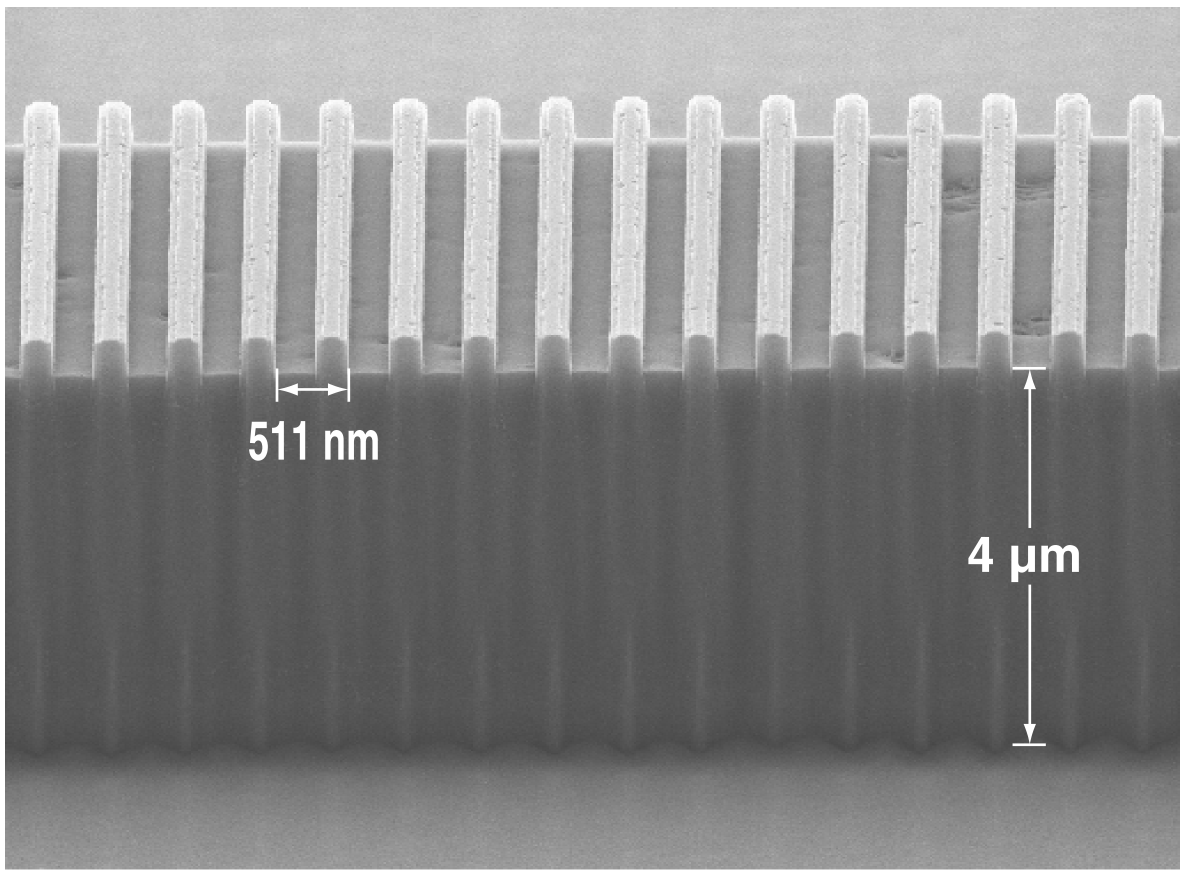




Bragg Grating on Glass Waveguide

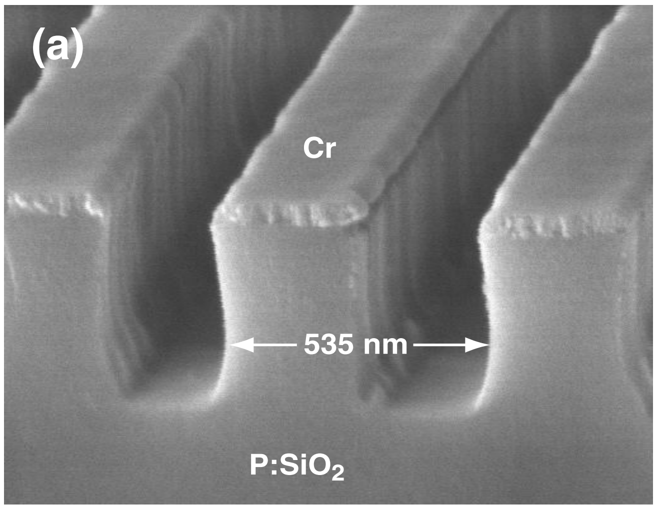




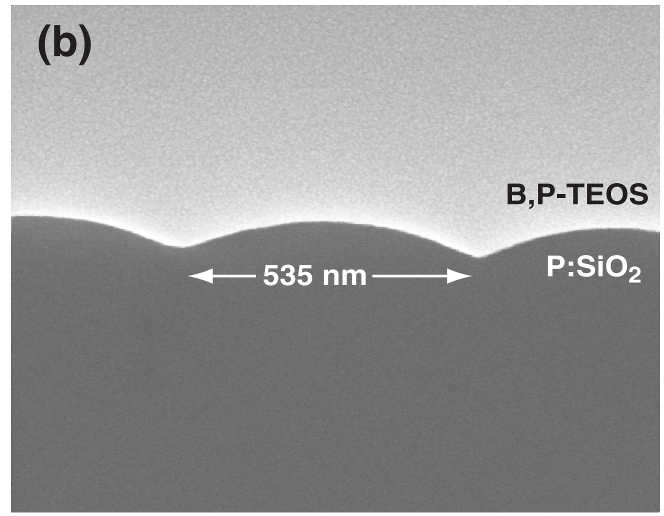


Overgrowth on Bragg Gratings

Prior to Overgrowth



After Overgrowth



Possible Solutions:

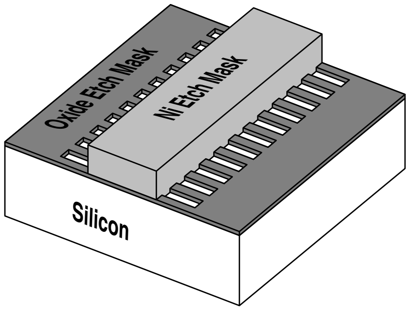
Modify composition (raise T_g)

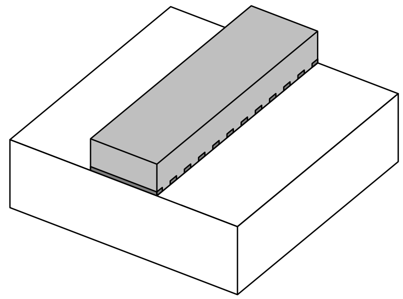
Change deposition parameters

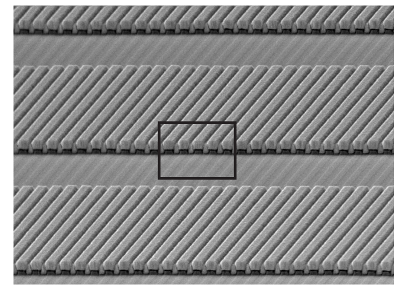
Pattern grating in bottom cladding

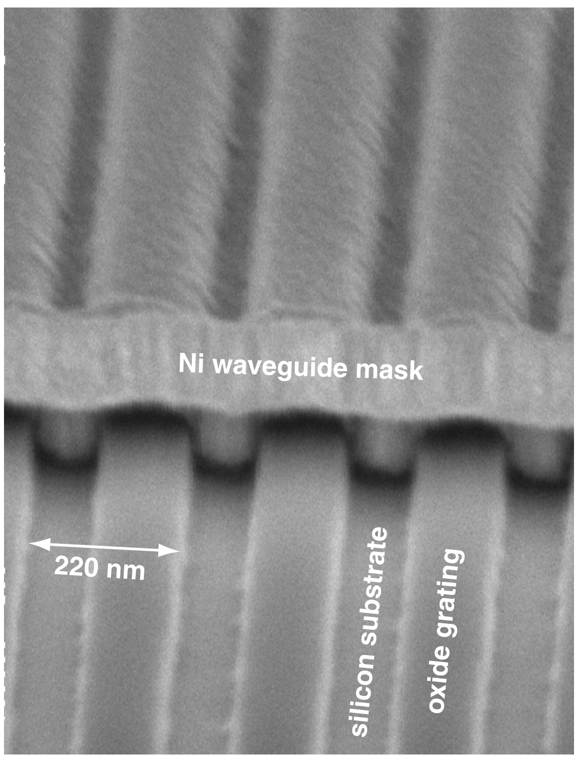
Alternative grating materials (nitride?)

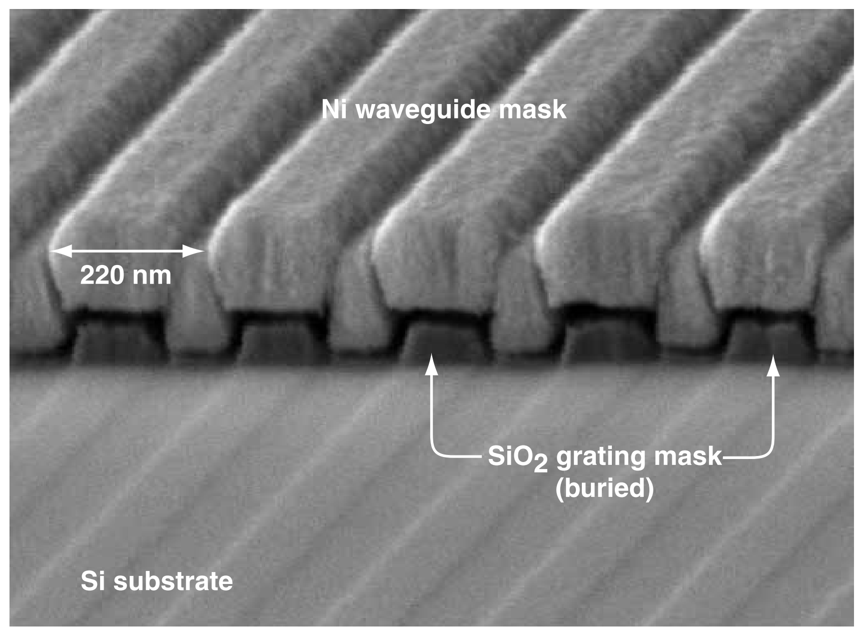
Dual Hardmask Process for SOI ridge Waveguides





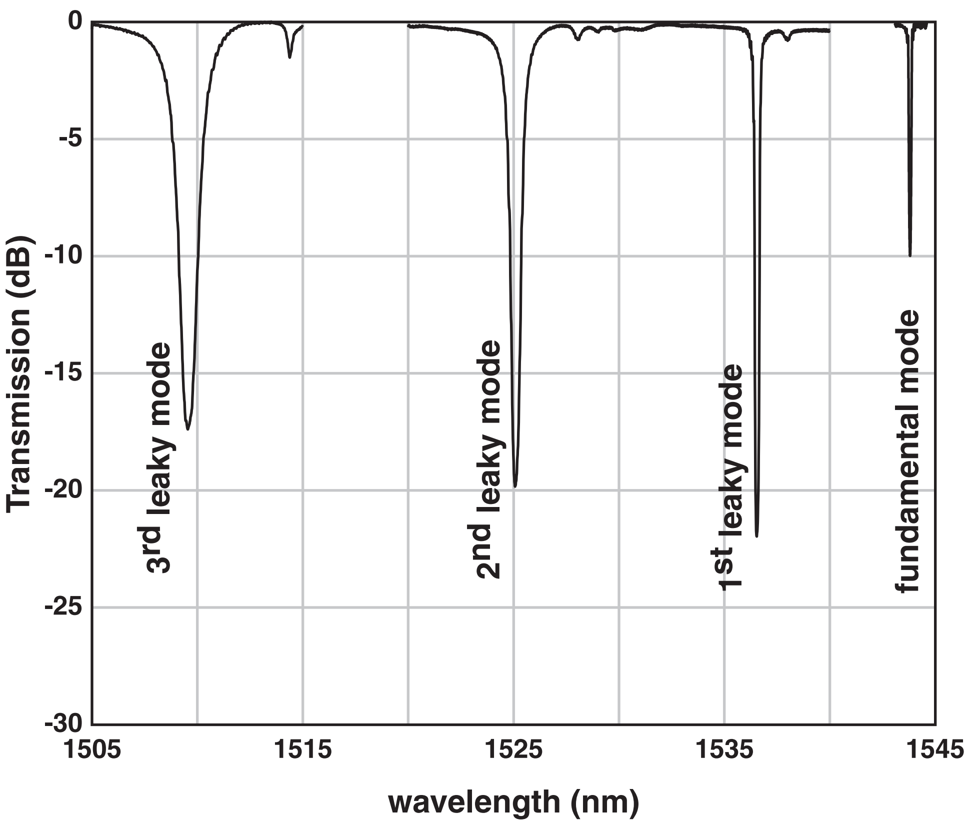




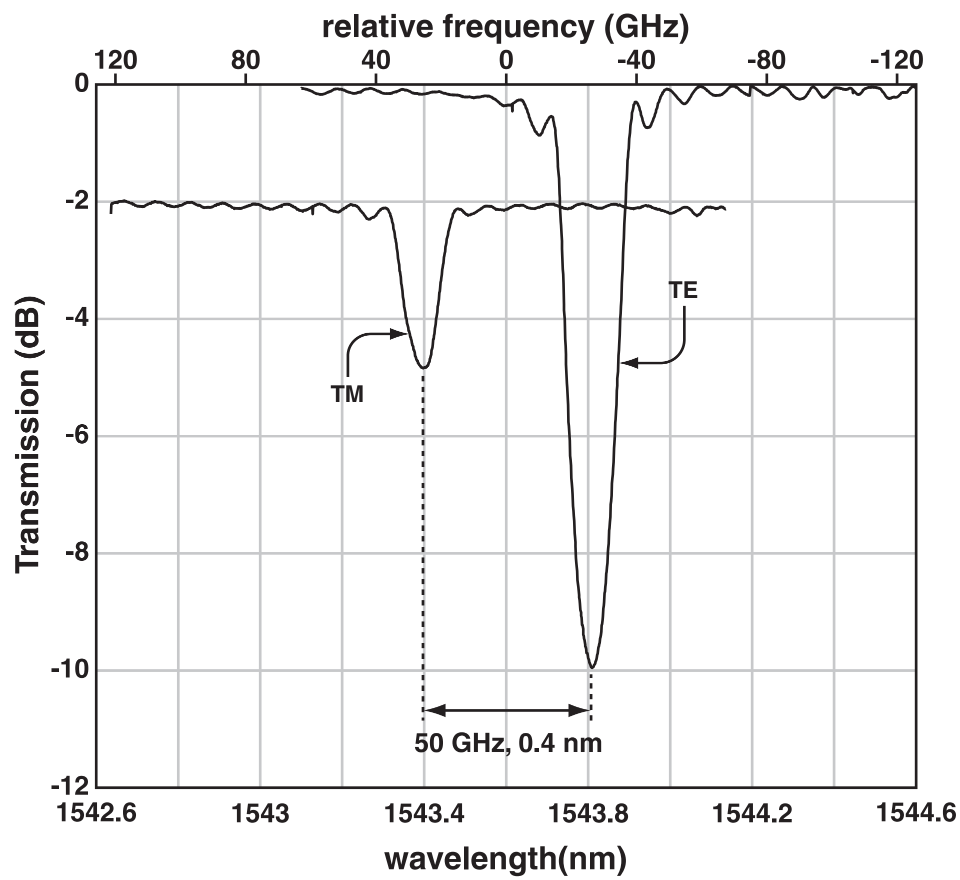


Transmission Spectrum for 4 mm Bragg Grating on SOI ridge waveguide

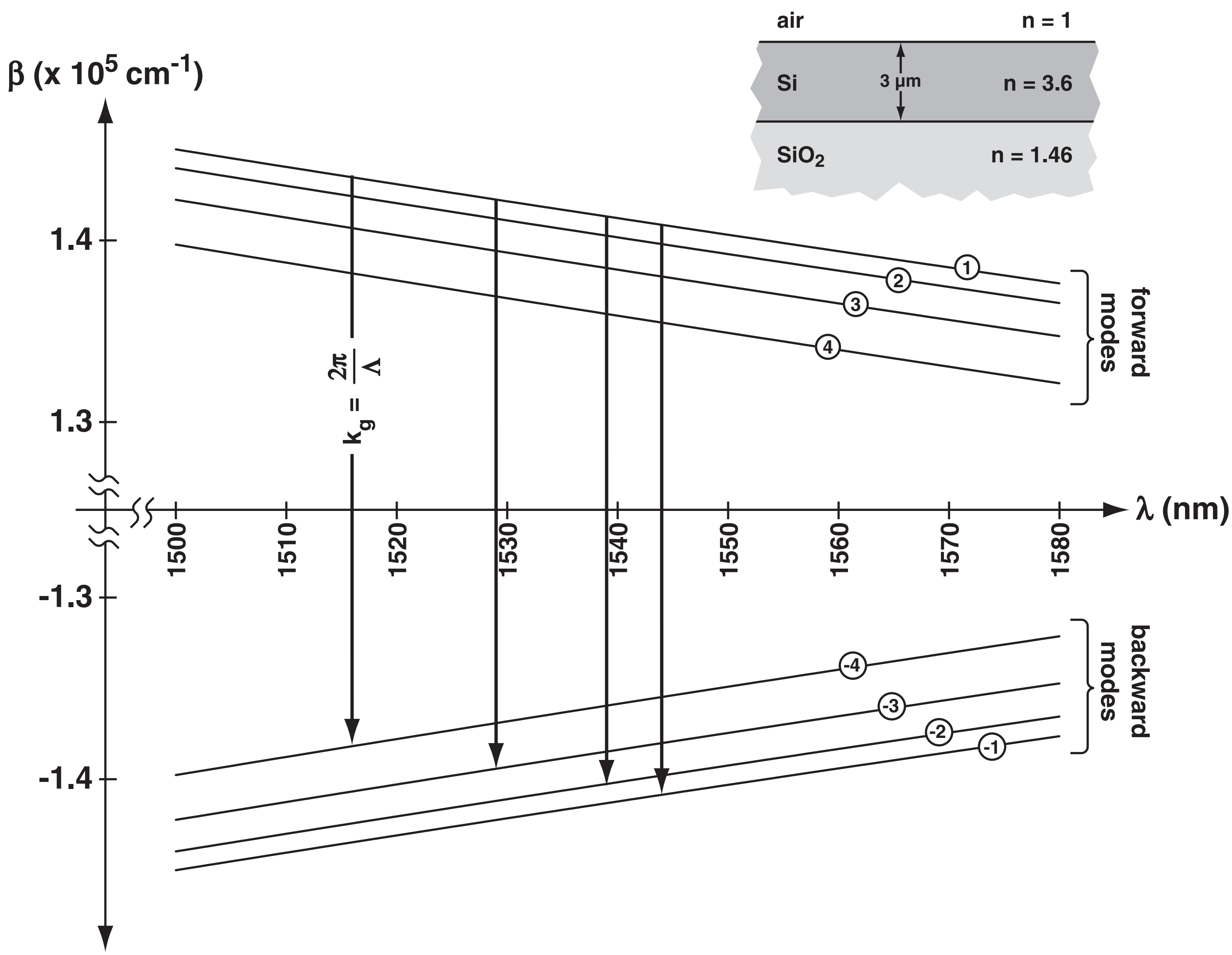
Coupling to Leaky Modes (TE Polarization)



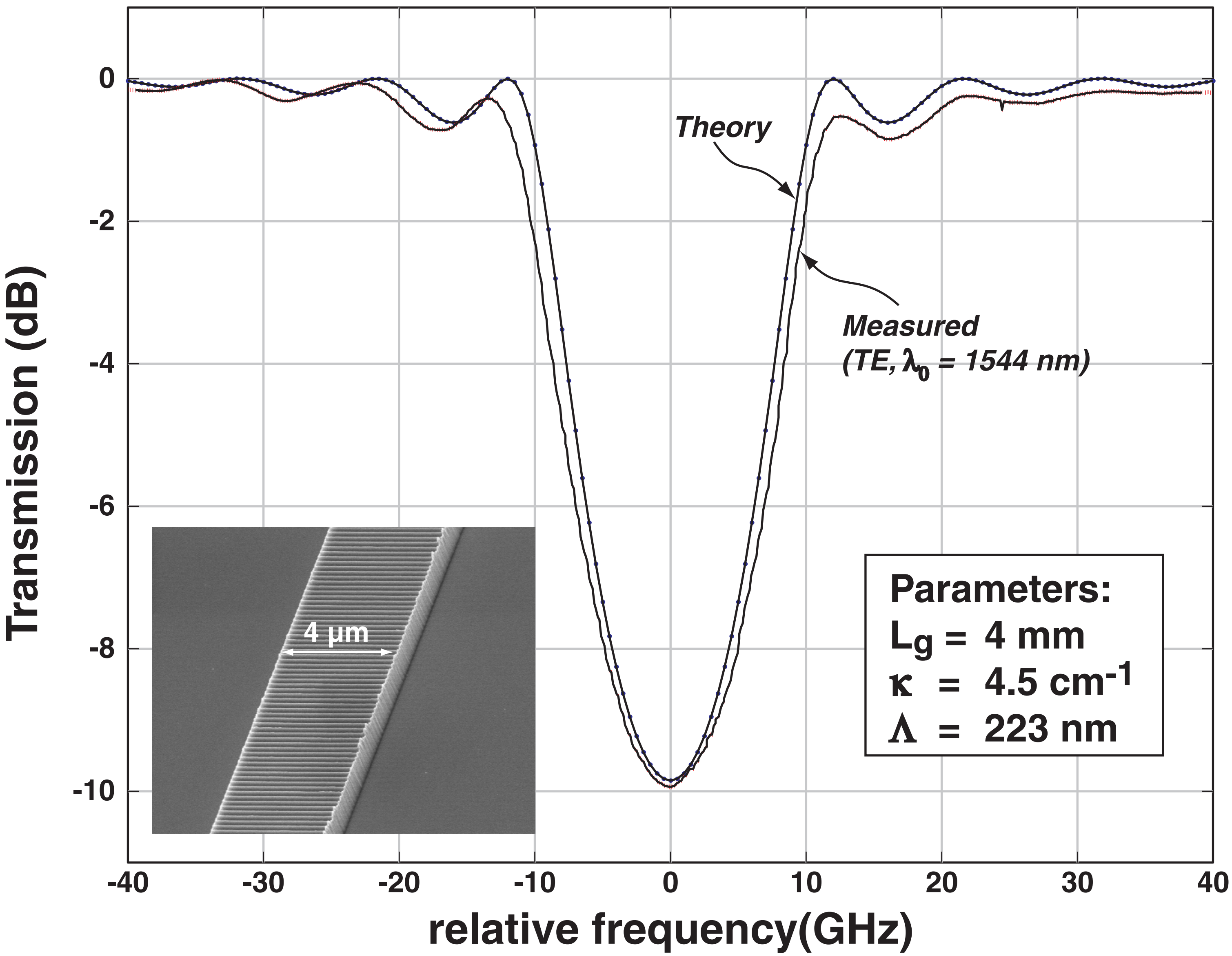
Grating Spectrum at λ = 1544 nm (fine scan)



Grating-Assisted Coupling to Leaky Modes
(a simple model)

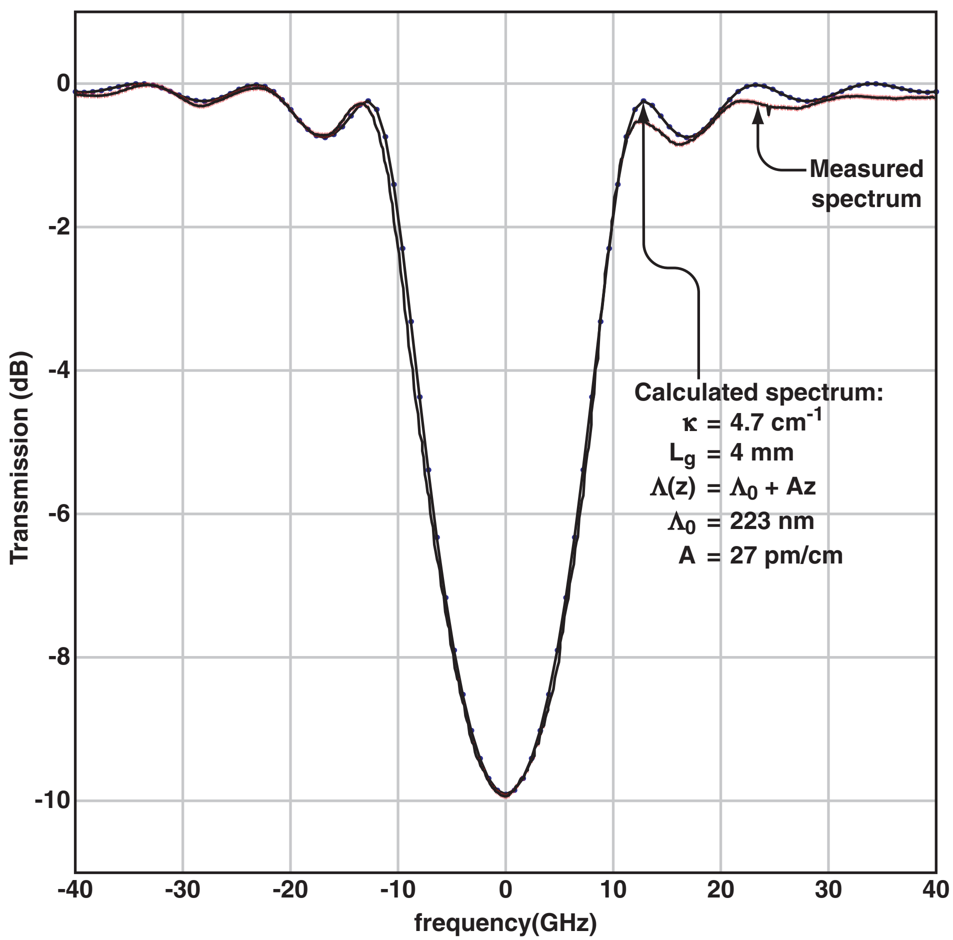


Transmission Spectrum of Bragg Grating: Theory vs. Measurement

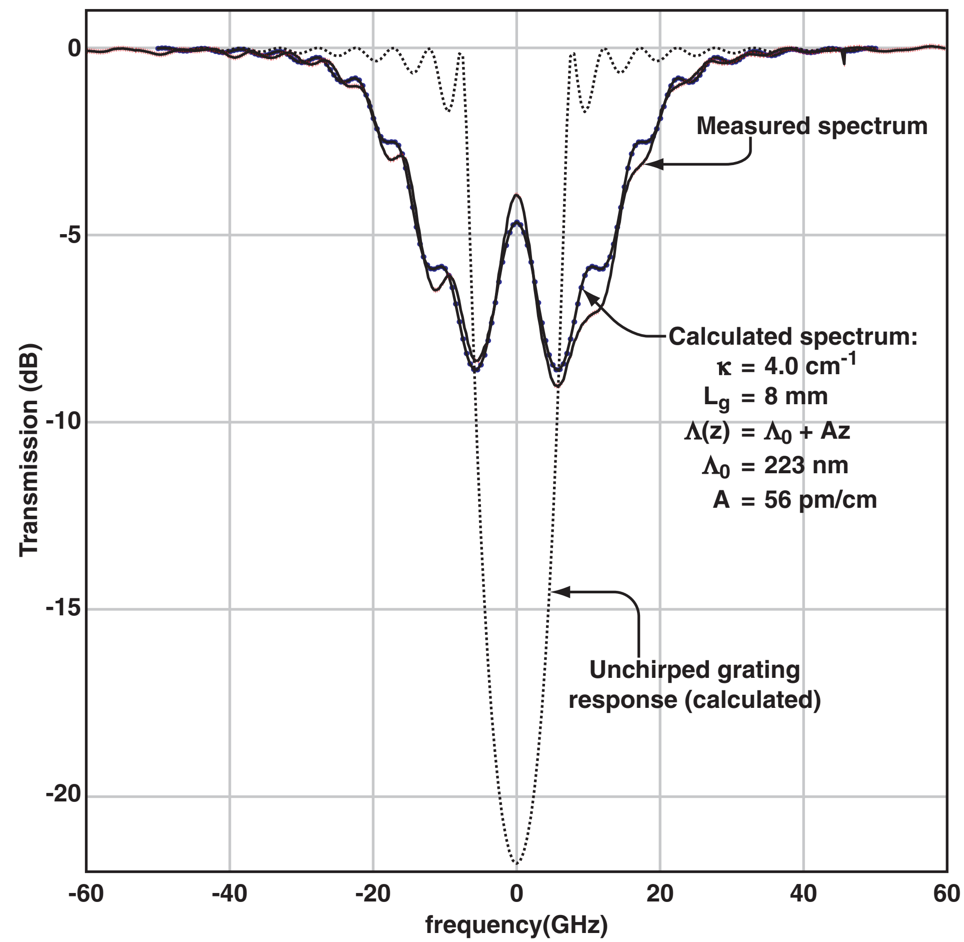


Evidence of Chirp in Bragg Gratings

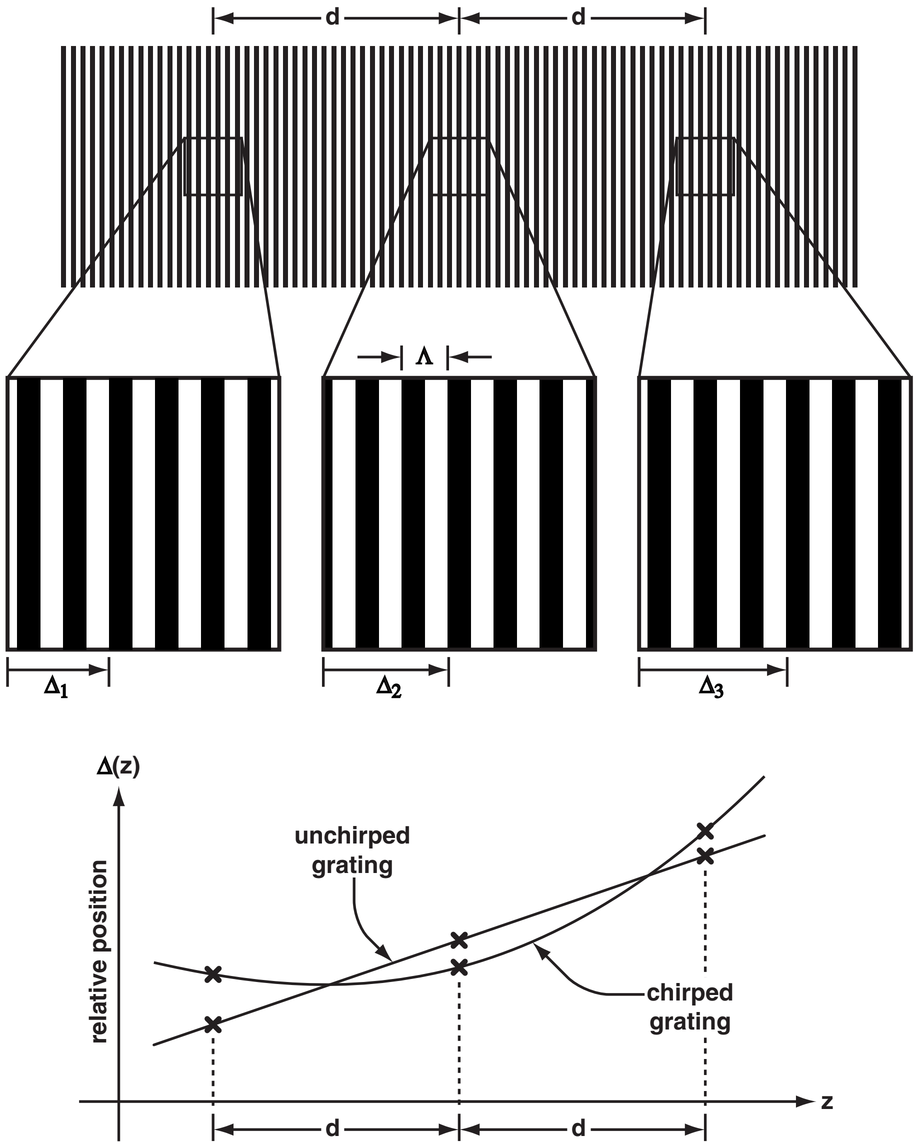
(4 mm-long grating)



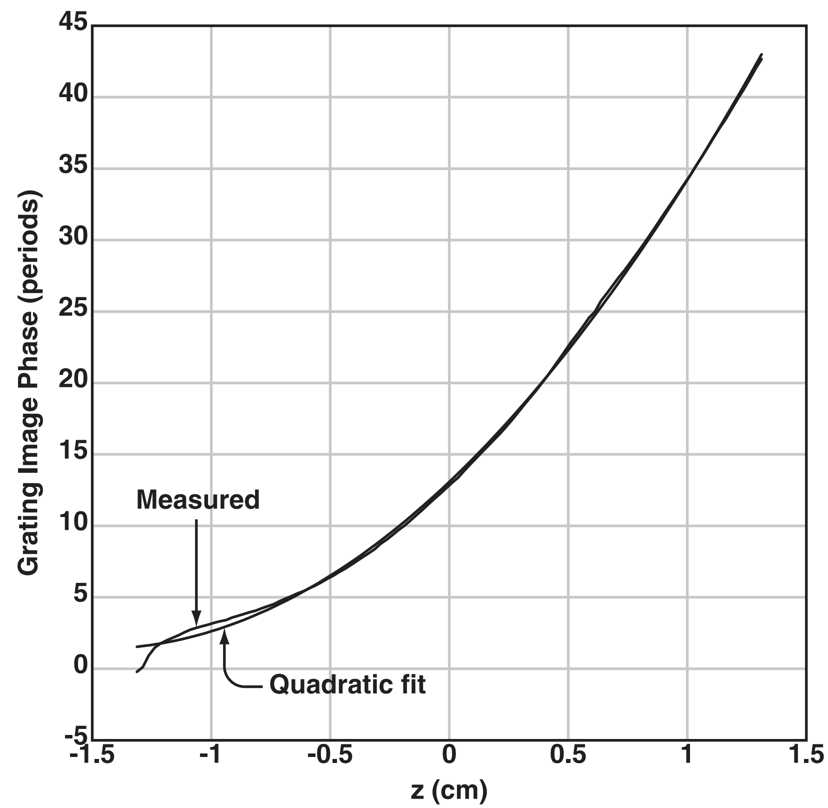
(8 mm-long grating)



Measuring Chirp via E-beam Metrology



Measured phase profile from grating produced via interference lithography



Conclusions

Bragg gratings could play an important role in many areas of optical communications

We have developed flexible fabrication methods for constructing waveguides, couplers, and Bragg gratings

Demonstrated wavelength- and polarization-insensitive directional couplers

Measured integrated Bragg gratings in SOI ridge waveguides

FUTURE WORK:

Improve overgrowth technique for glass grating structures

Construct integrated Add/Drop filter by combining couplers and gratings

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Peggy Carney
Desmond Lim
The Hightower Family
L. C. Kimerling
Dario Gil
Howard Ramseur
Patricia Marra
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Oliver Stolz
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Dave Carter
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Dorothy Lemelson
Chuck Joyner
J. P. Laine
Erik Thoen
Brent Knowlton
Mark Sanchez
Alice White
Mom and Dad
The NSF
Erich P. Ippen
Ii-Lun Chen
Rajesh Menon
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THANK YOU!

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Mark Schattenburg
William Ruth
God
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