Nano-structured Optics for GW Detectors

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in collaboration with

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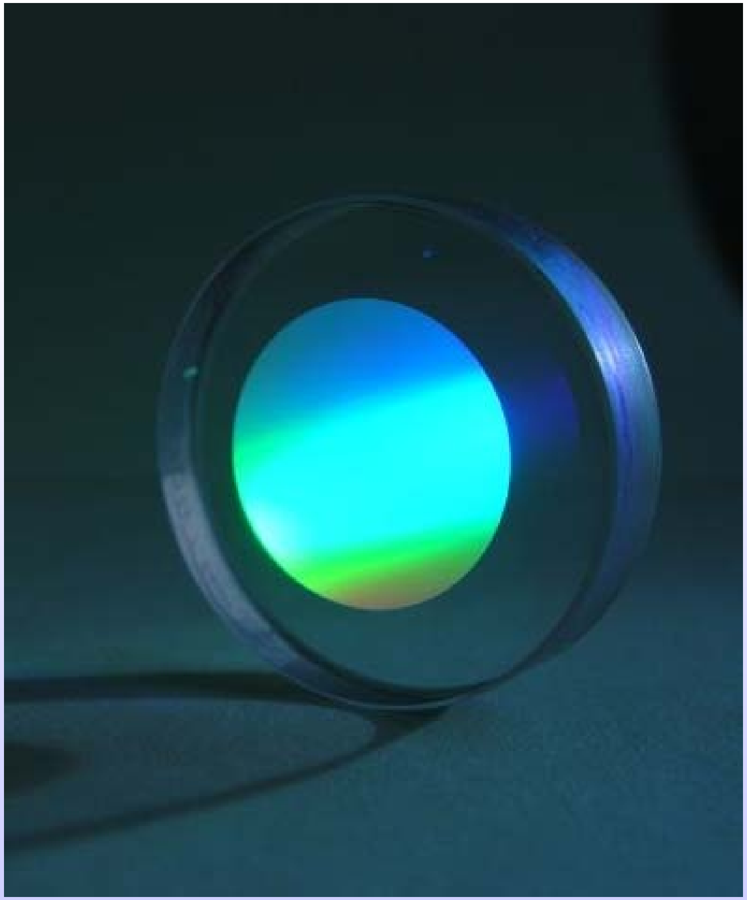
Outline

Summary of:
All-reflective
Interferomtry

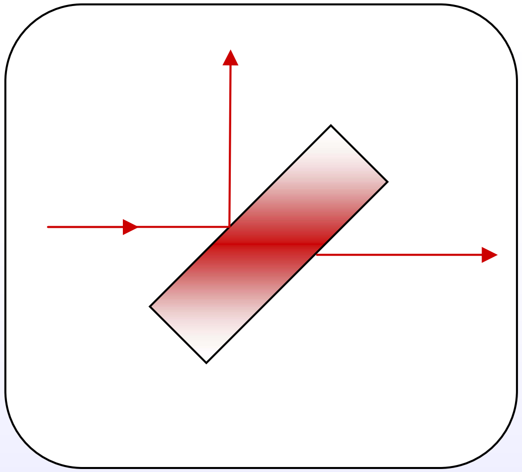
(with multilayer coatings)

Outlook to:
High reflective
diffractive structures

(without multilayer coatings)

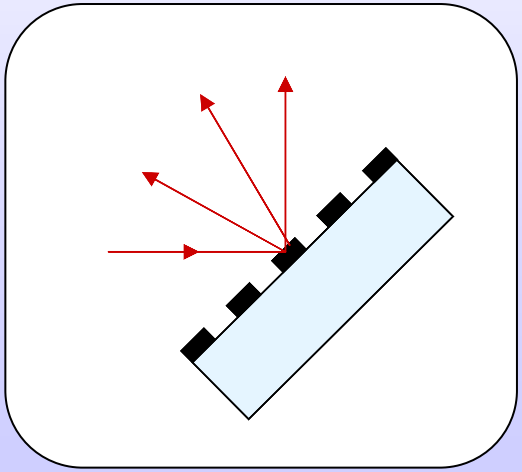


Motivation #1



Interferometers beyond LIGOII
(MW of power)

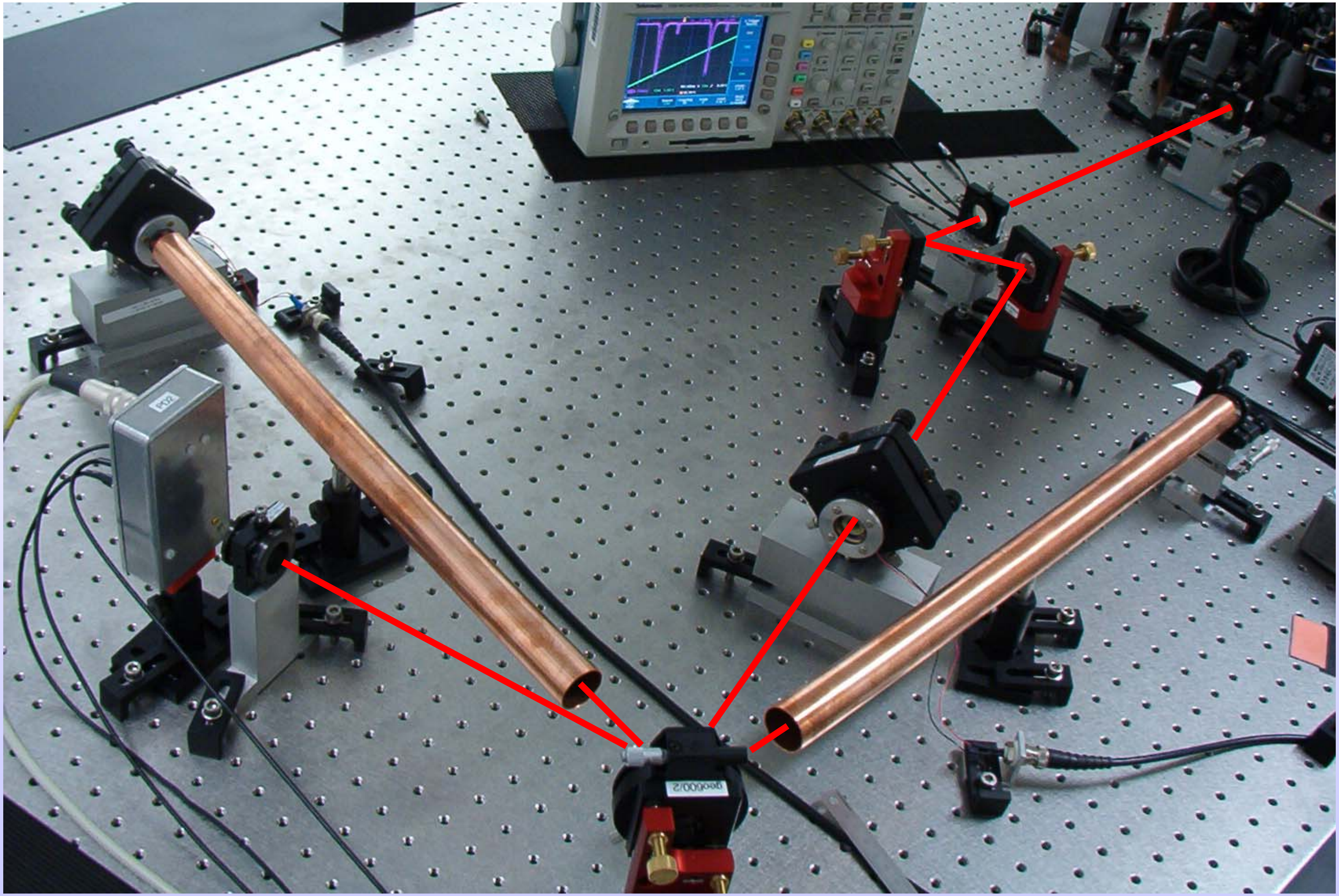
Transmission → Absorption
→ Thermal problems



All-reflective interferometers:

- Allow opaque test mass materials
- New interferometer topologies

MI with all-reflective beamsplitter



What kind of gratings?

Grating equation:

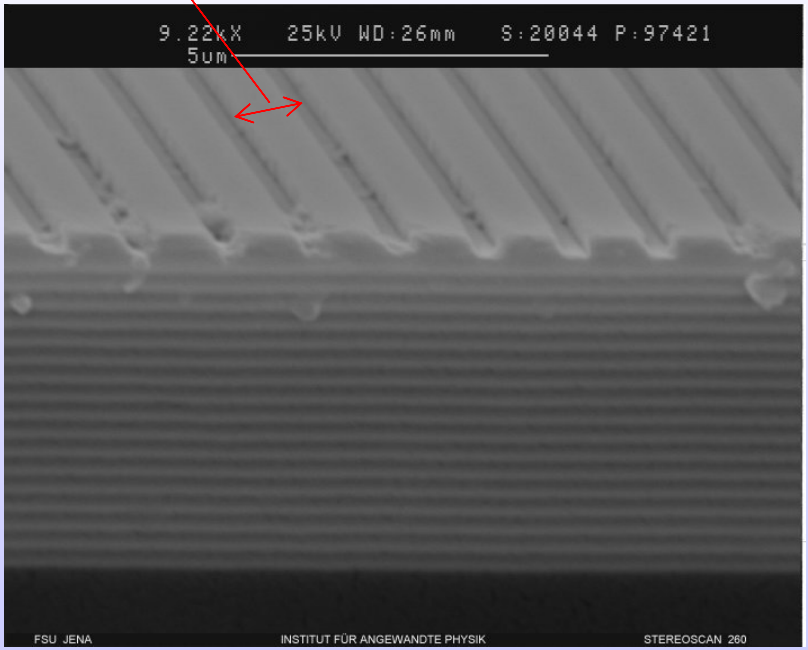
$$d(\sin\theta_m + \sin\theta_{\text{in}}) = m\lambda$$

Period defines # of orders & direction

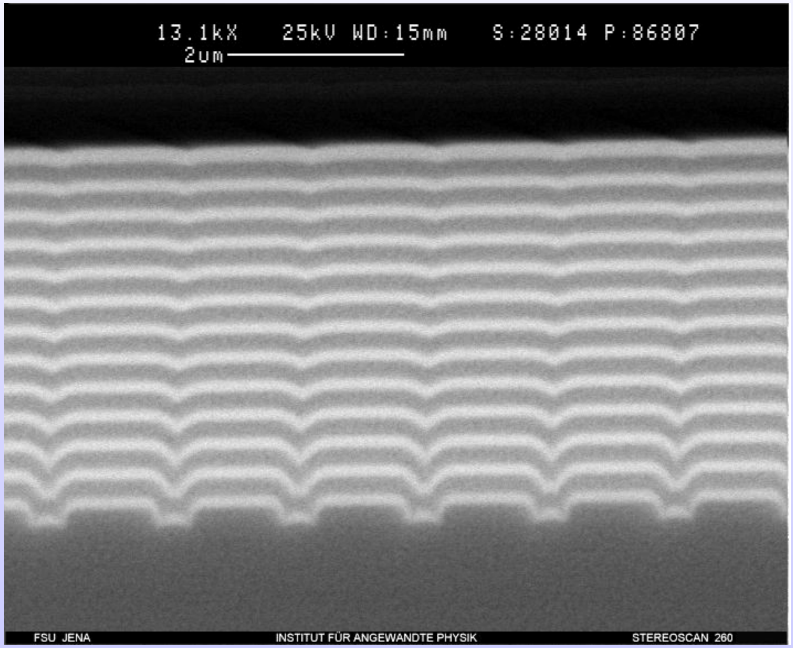
d>>λ: scalar approach

d~λ: rigorous theories (RCWA, Modal method)

d<<λ: effective medium theories (ETM)



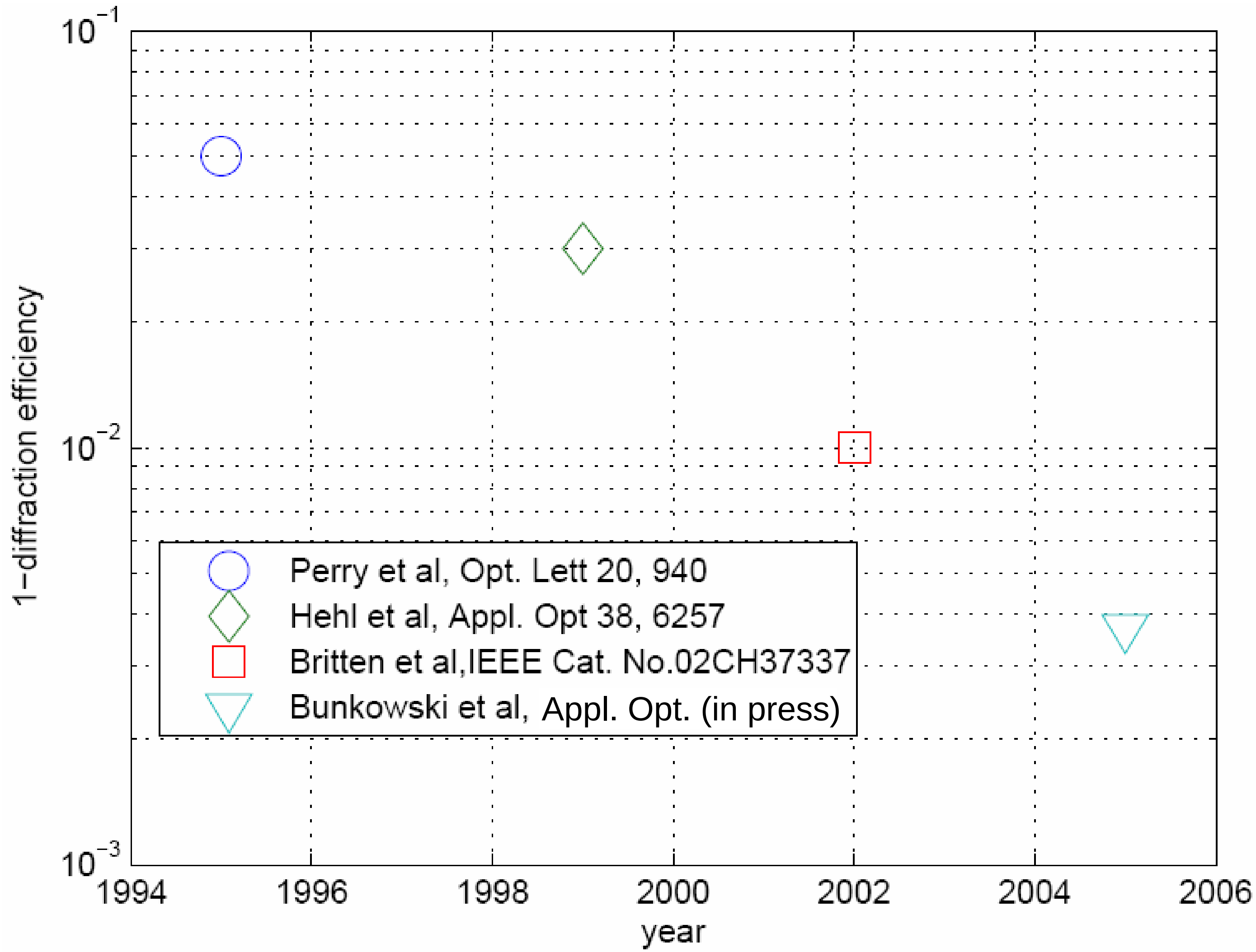
Coating below

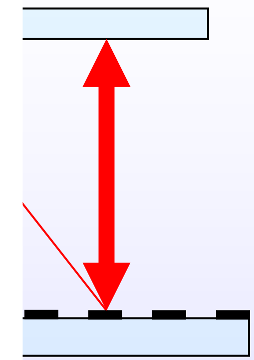


Coating on top

Cavity couplers

Inpu

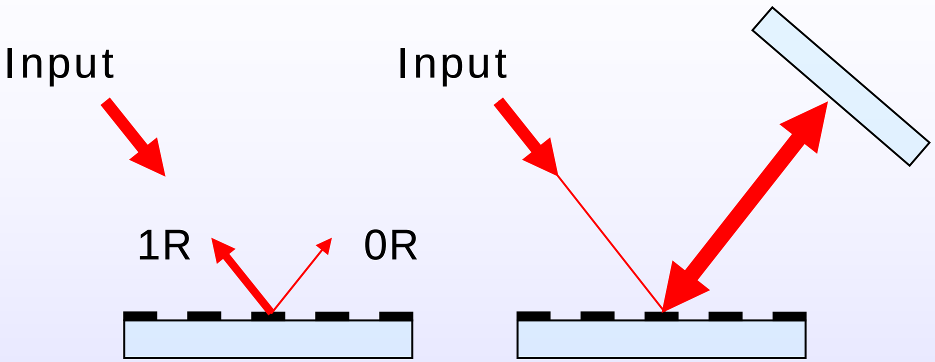




A. Bunkowski *et al,* Applied Optics (in press) http://ao.osa.org/upcoming_pdf.cfm?id=66481

Cavity couplers

1st order Littrow

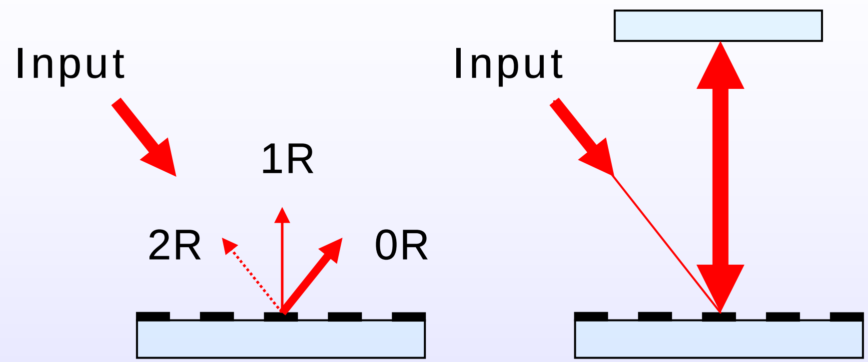


Need high efficiency

(which is hard
to achieve)

99.62% achieved
(Finesse of 1580)

2nd order Littrow

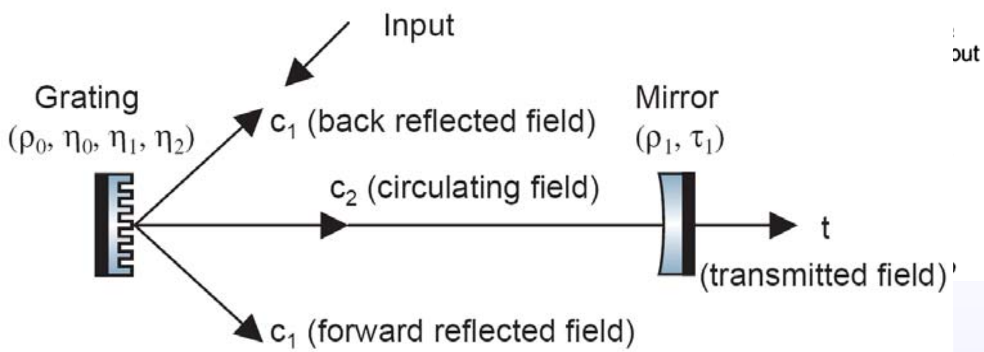


Only low efficiency

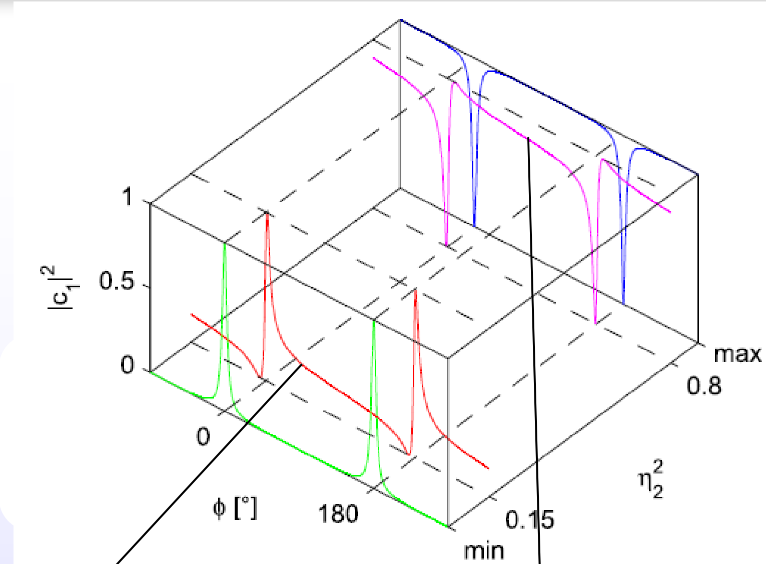
(3 ports are more
Complicated)

A. Bunkowski *et al,* Applied Optics (in press) http://ao.osa.org/upcoming_pdf.cfm?id=66481

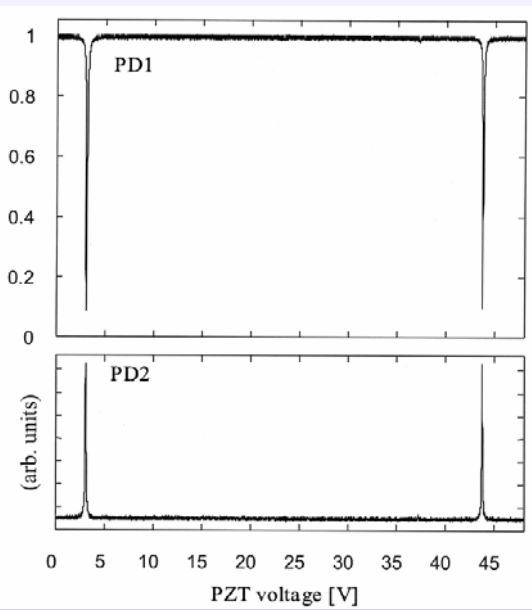
3-port couplers



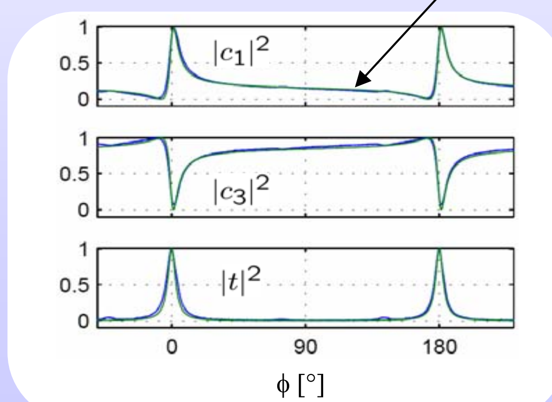
$$\mathbf{S}_{2p} = \begin{bmatrix} \rho & i\tau \\ i\tau & \rho \end{bmatrix}$$

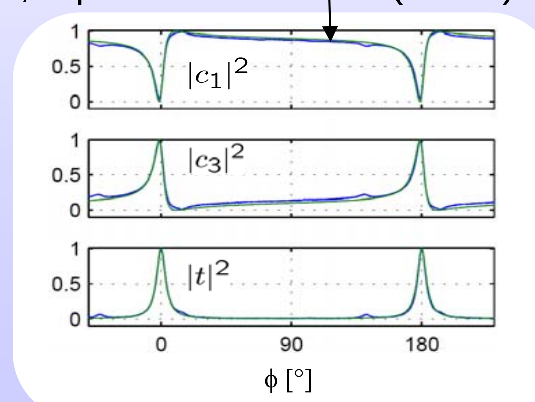


A. Bunkowski *et al*, Opt. Lett. **30**, 1183 (2005)
R. Schnabel *et al*, Opt. Lett. **31** 658 (2006)



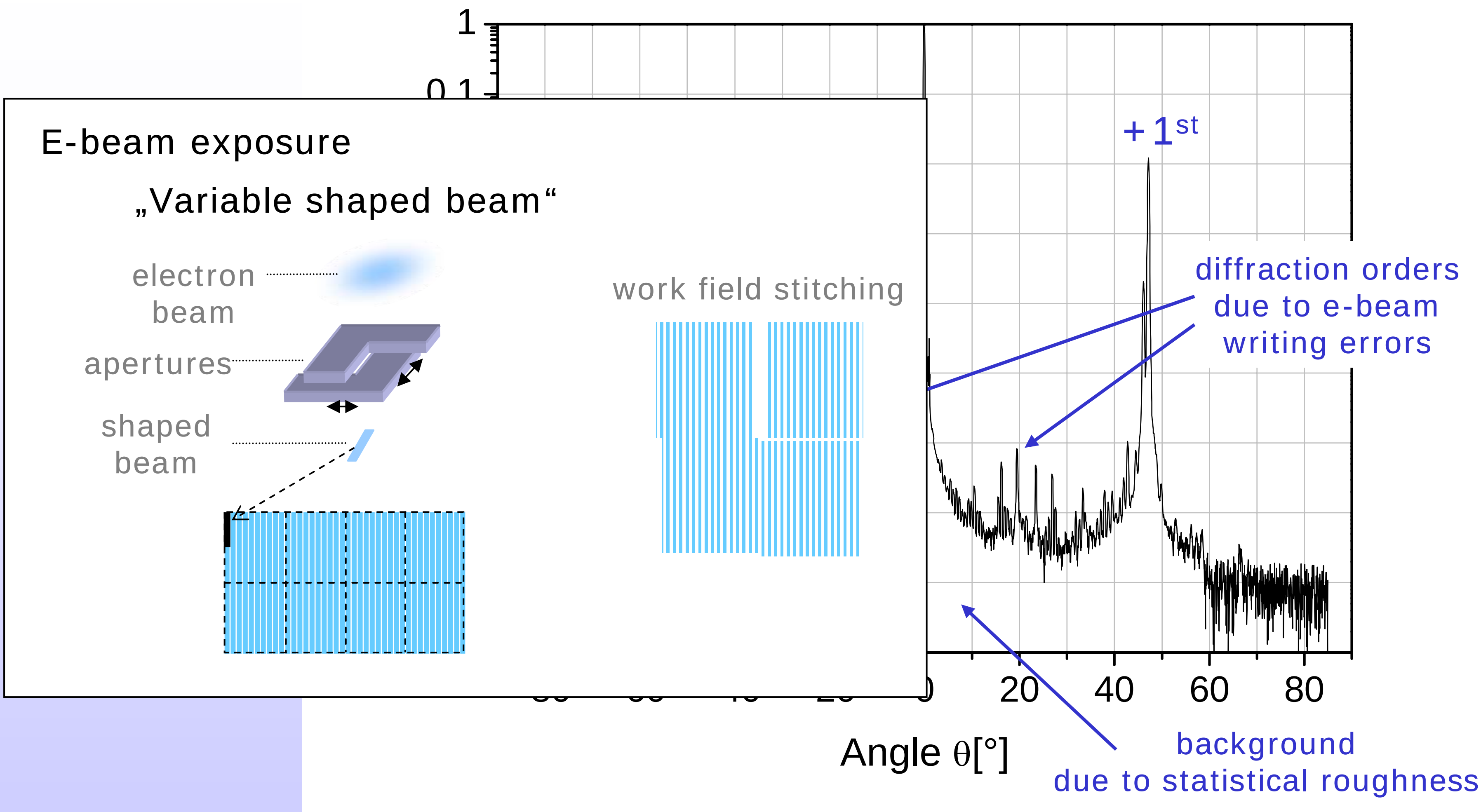
A. Bunkowski *et al*, Opt. Lett. **29,** 2342 (2004)





A. Bunkowski *et al*, Opt. Lett. (in press)
http://ol.osa.org/upcoming_pdf.cfm?id=69970

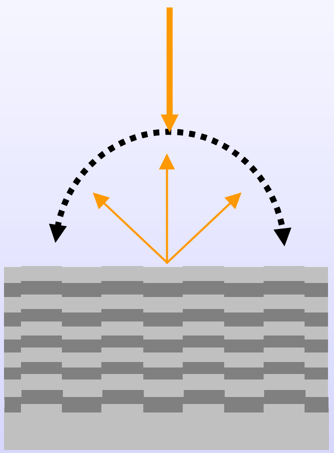
Angle resolved scattering

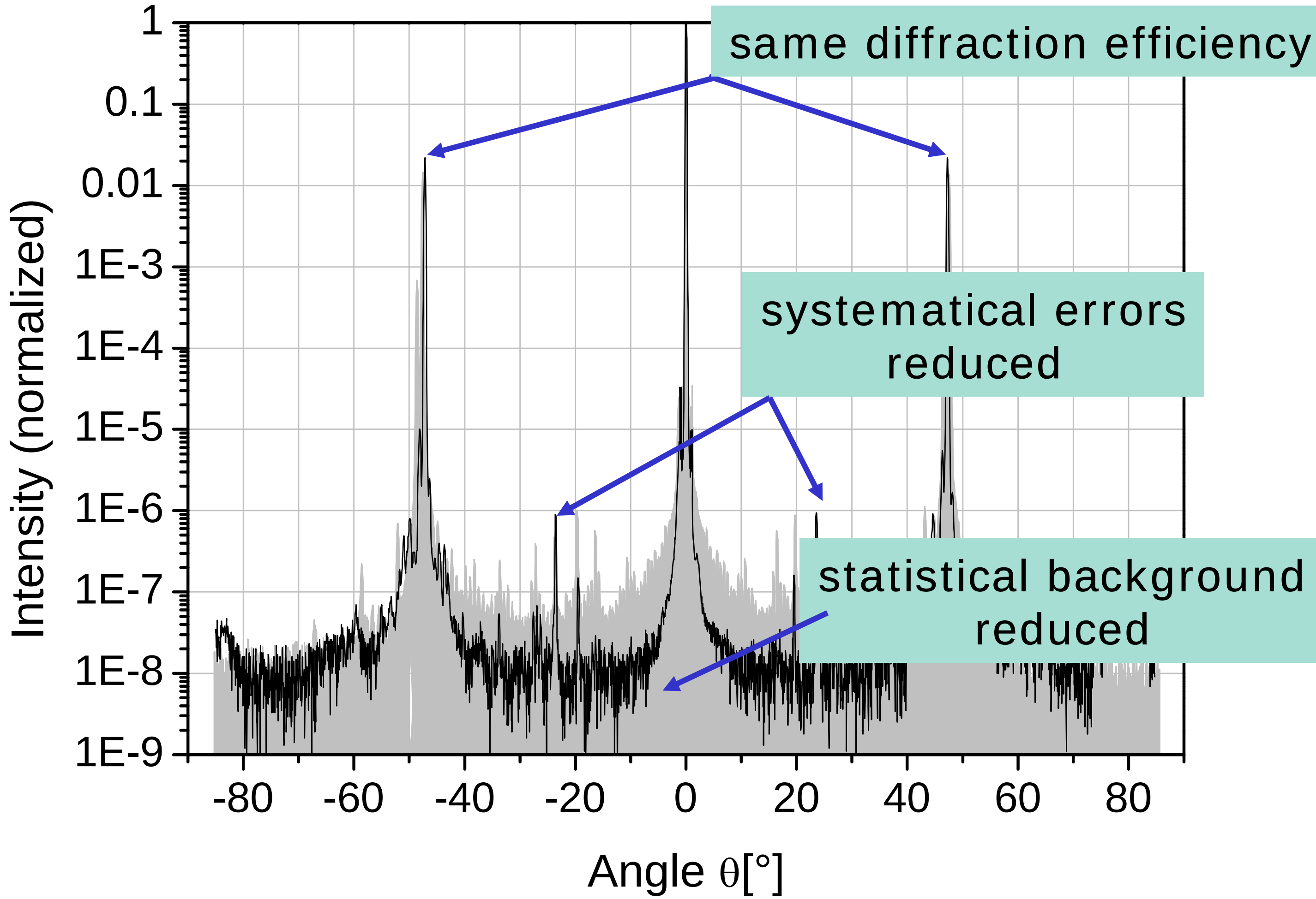


Grating beneath coating

Small fill factor

groove depth 40nm
fill factor 50%



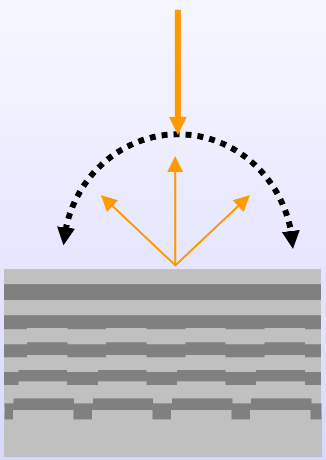


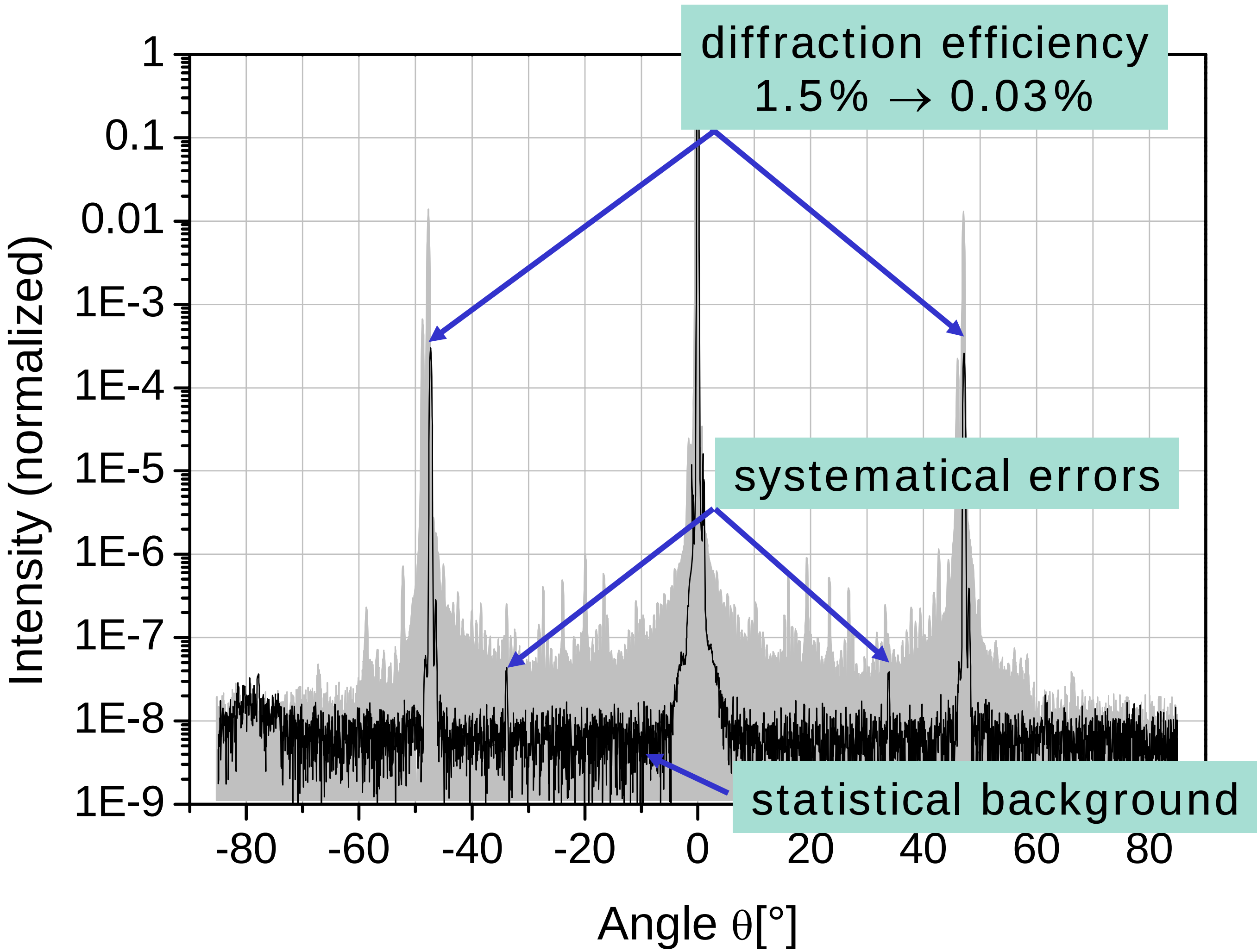
T. Clausnitzer *et. al.*, Optics Express, **13,** 4370 (2005)

Grating beneath coating II

Large fill factor

groove depth 40nm
fill factor 82%





T. Clausnitzer *et al,* Optics Express, **13,** 4370 (2005)

Conclusion #1

Summary:

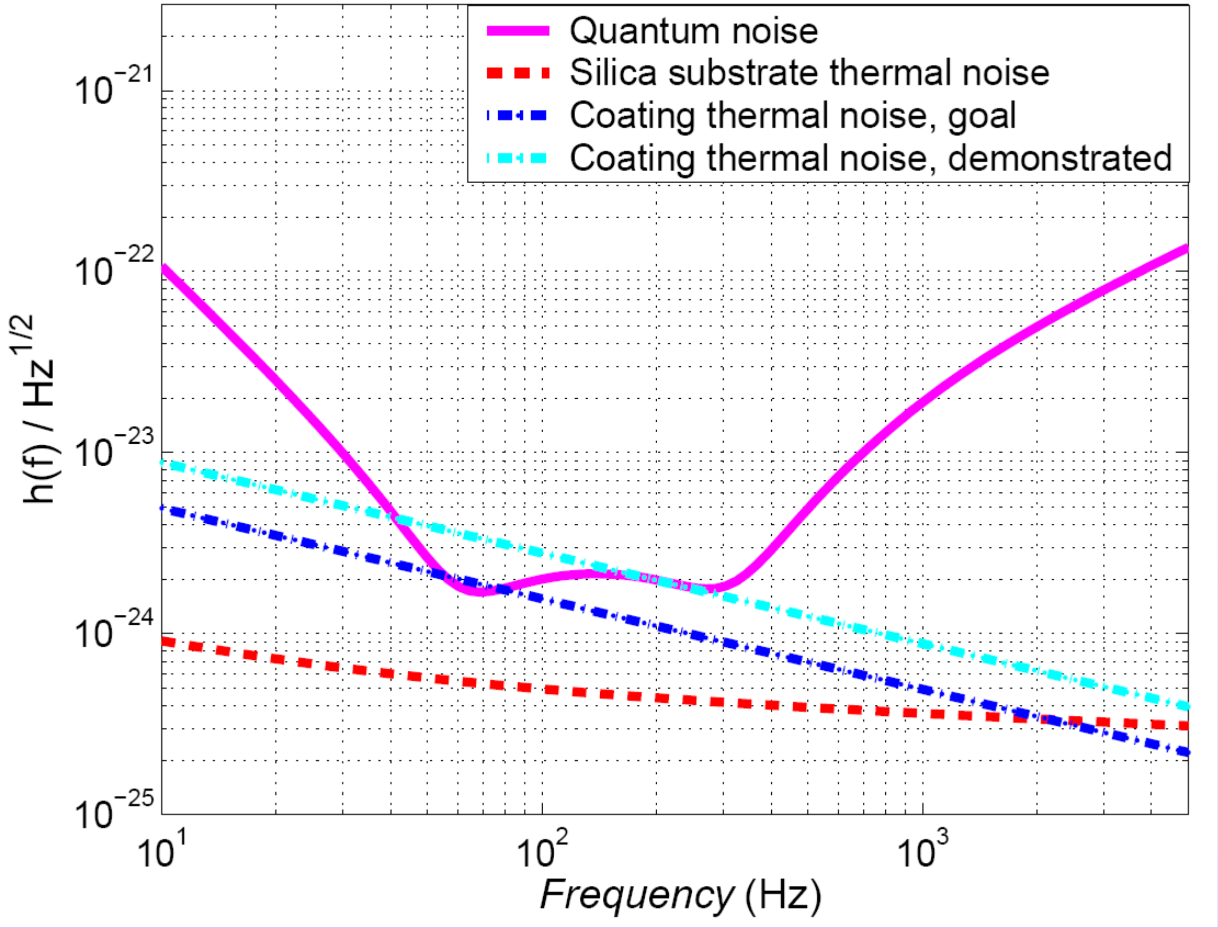
- High quality all-reflective components
- Demonstration of new cavity coupling concept
- Reduction of scattering loss

Outlook:

- Further reduction of loss
- Scale to large test mass
- Suspended 10 m all-reflected cavity to be built in Glasgow later this year

Motivation #2

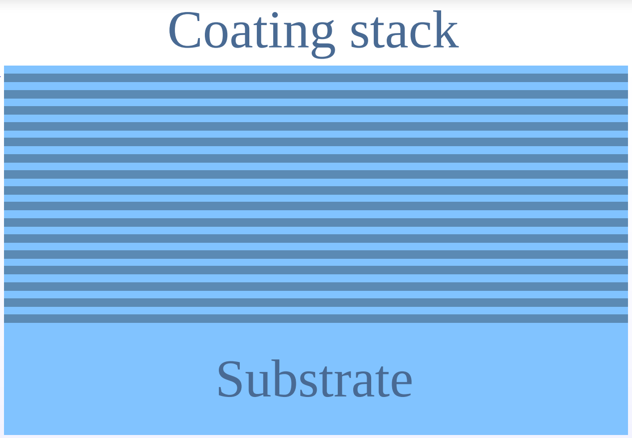
Several fundamental noise sources as currently estimated for advanced LIGO:



S. Penn *et.al*, LIGO-P050049-00-R (2005)

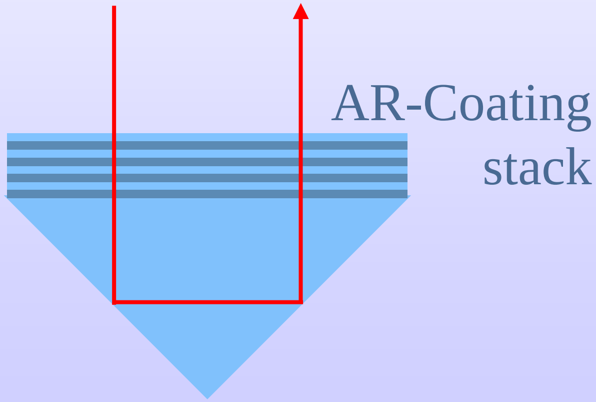
Beating Coating Noise

The high refractive material *tantala* (Ta_2O_5) has been identified to be the main source of *coating thermal noise*.

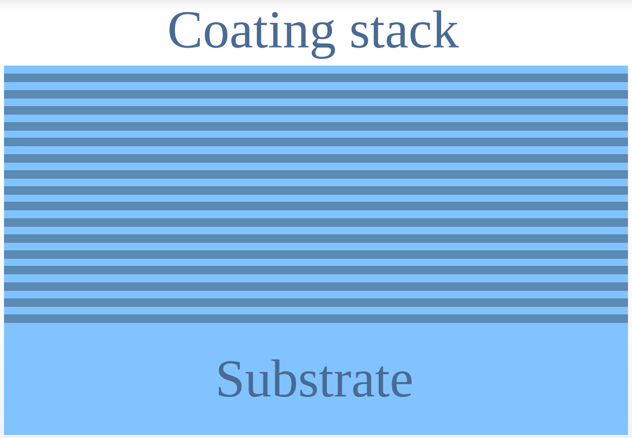


Some ideas so far:

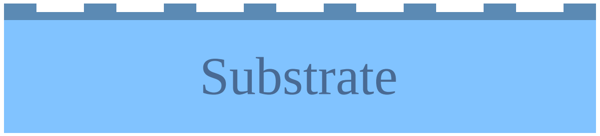
- Less tantala in stack
  → Innocenzo Pinto's talk
- Doping of tantala with TiO_2
  → Harry *et al*, Appl. Opt. **45**, 1569 (2006)
- Total internal reflection
  → Adalberto Giazotto's talk
  → V. Braginsky and S. Vyatchanin, Phys. Lett. A **324**, 345 (2004)



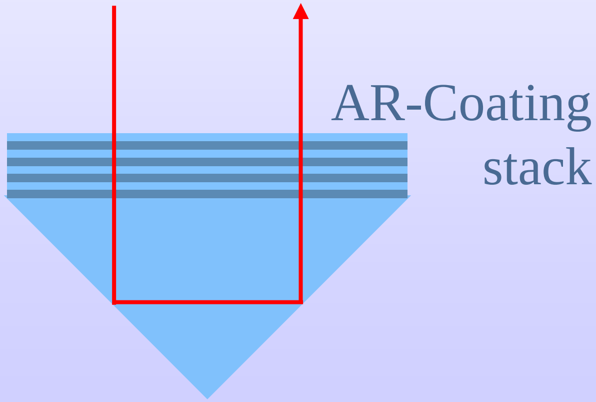
- Double mirrors:
  → F. Ya. Khalili, Phys. Lett. A **334,** 67 (2005)



Another approach:

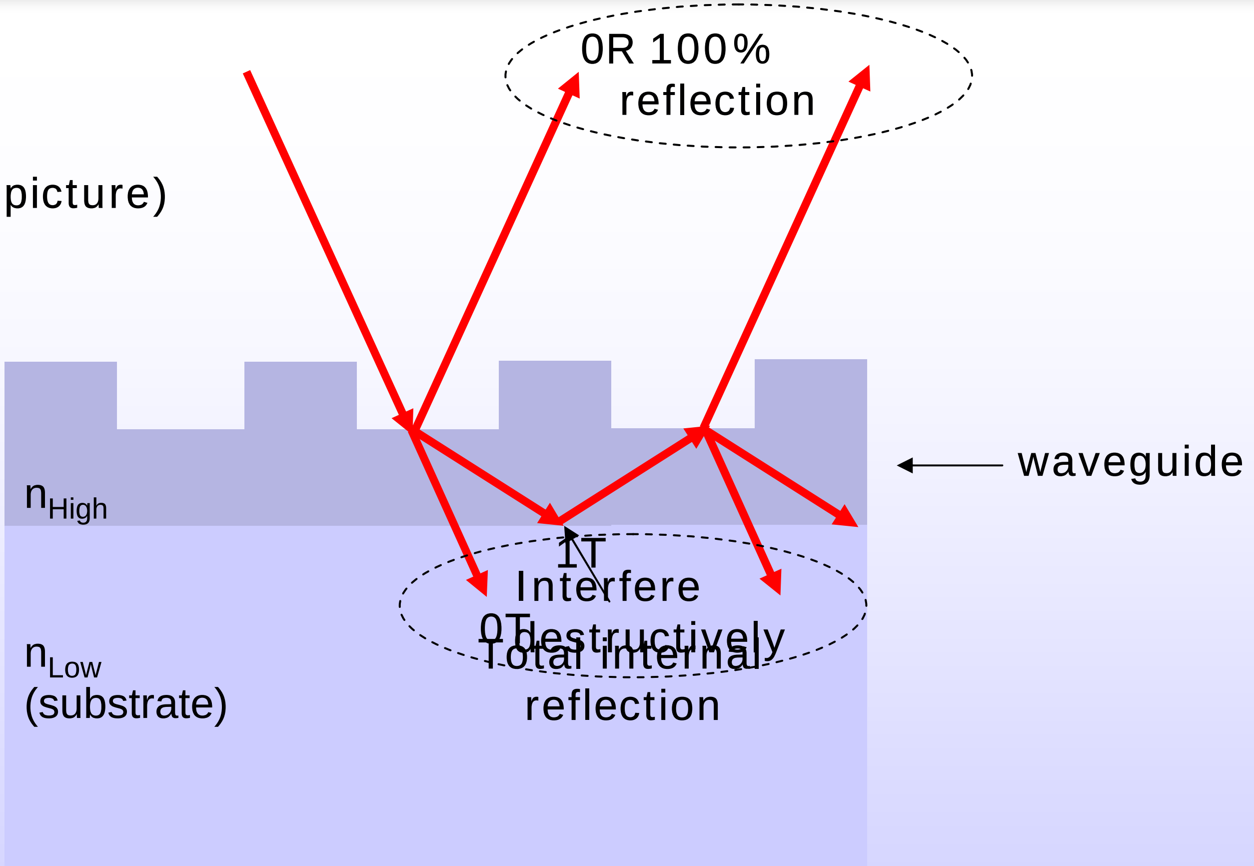


Grating waveguide reflector



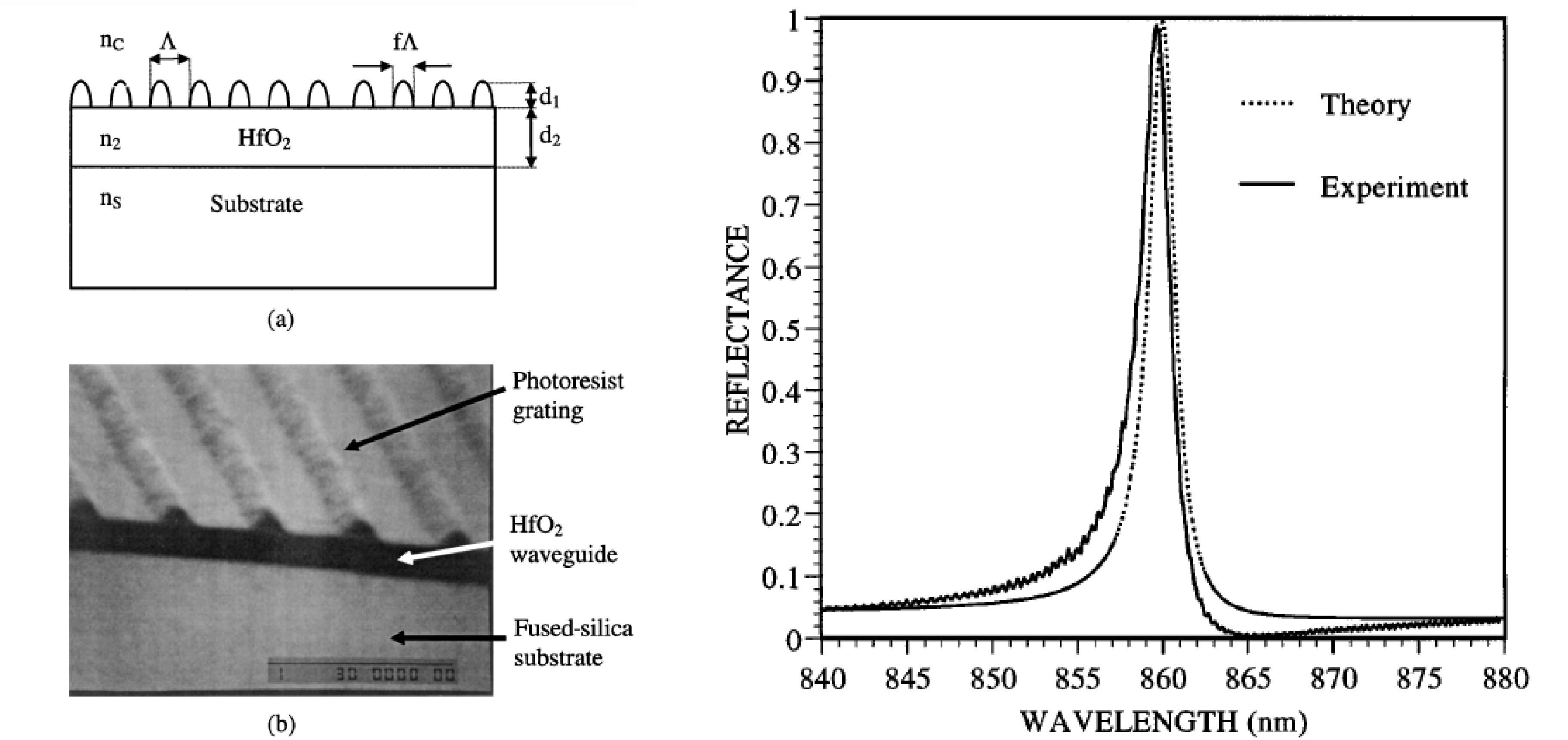
Grating waveguide Structures

(Simplified ray picture)



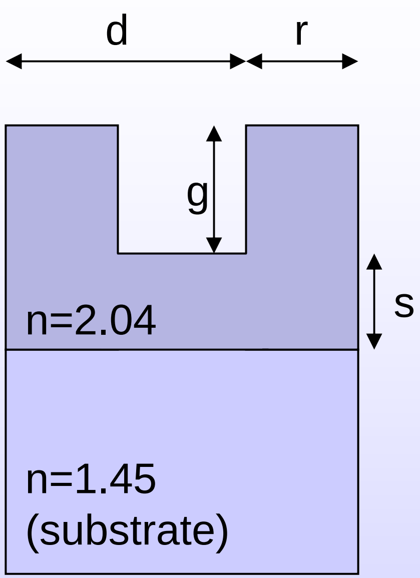
see for example: Sharon *et al*, J. Opt. Soc. Am. A, **14** (1997)

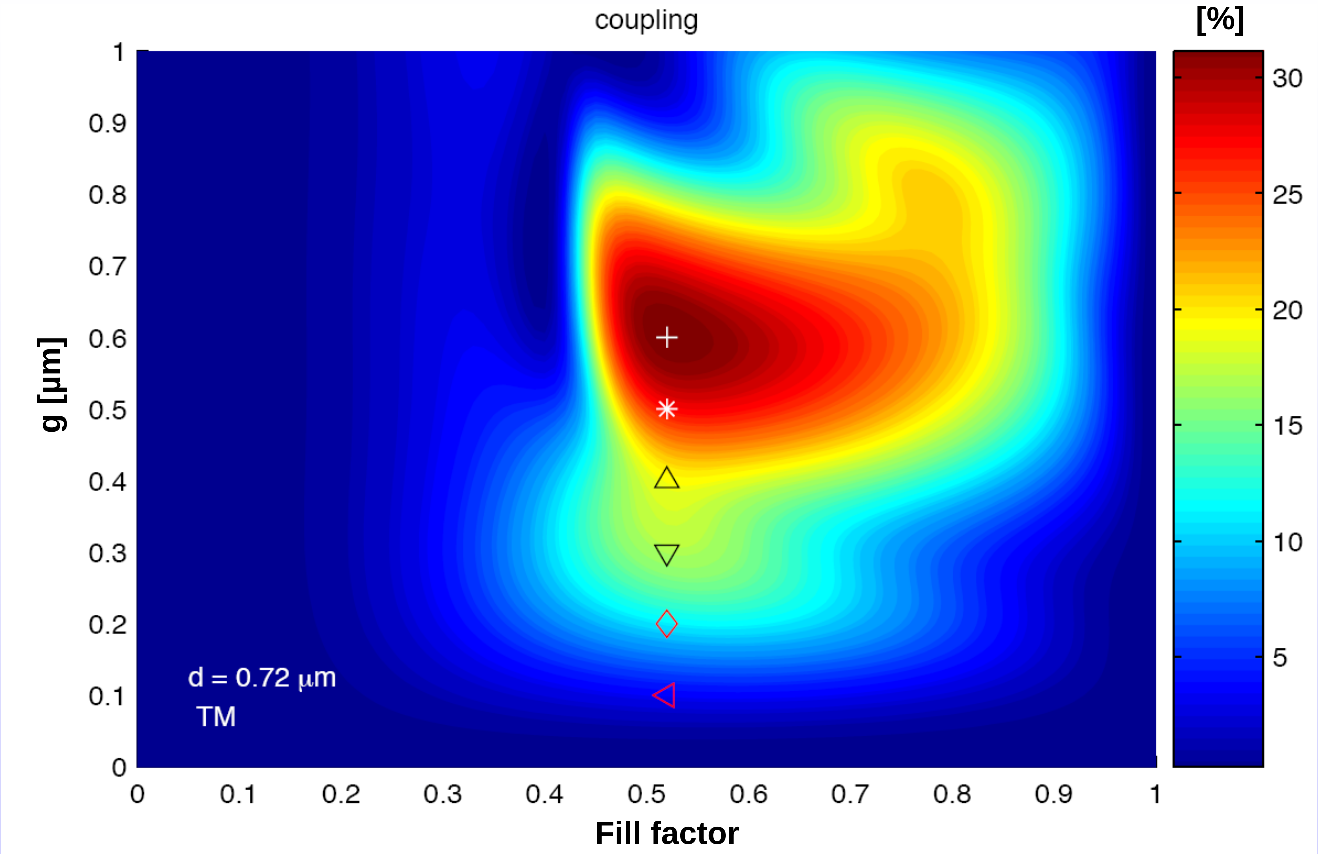
Narrow reflection peak



Liu *et al*, Opt. Lett. **23**, 1556 (1998)

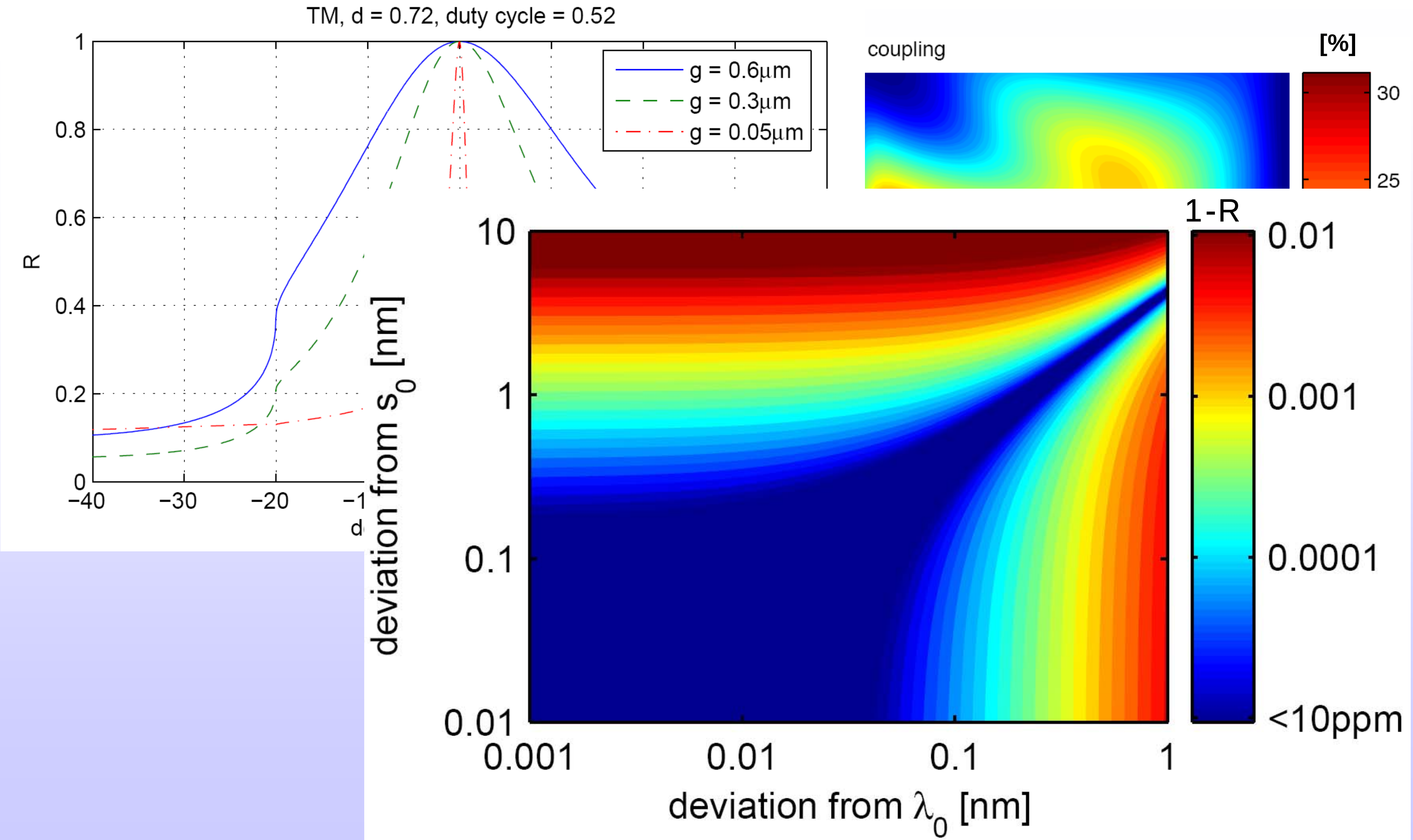
Design width of reflection peak



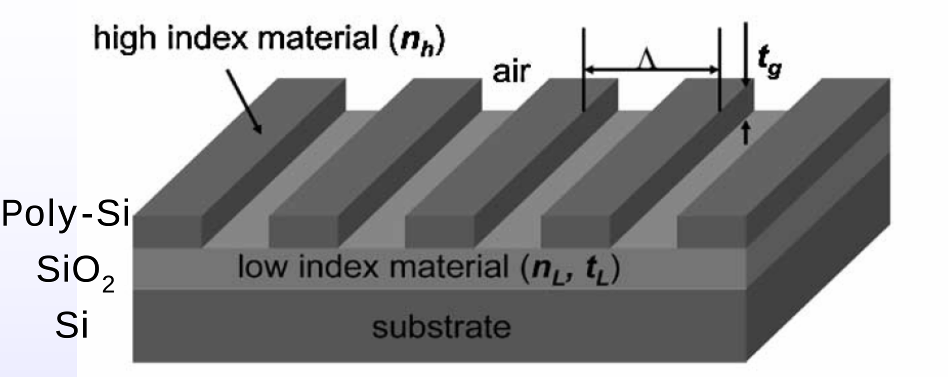


d: period
g: groove depth
r: ridge width
s: film thickness
r/d: fill factor

Design width of reflection peak



Broadband mirror for 1550nm



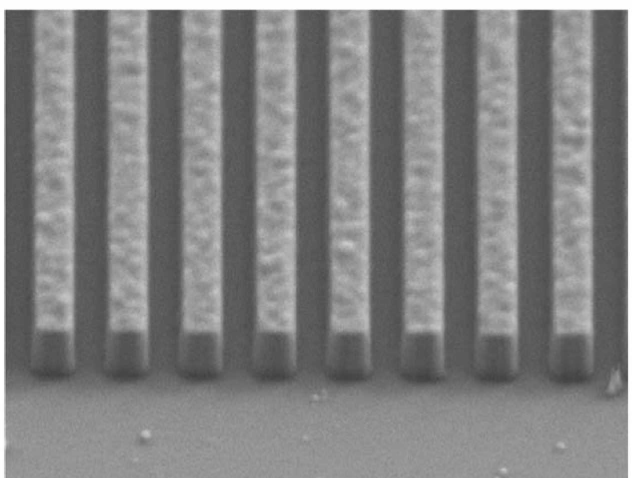
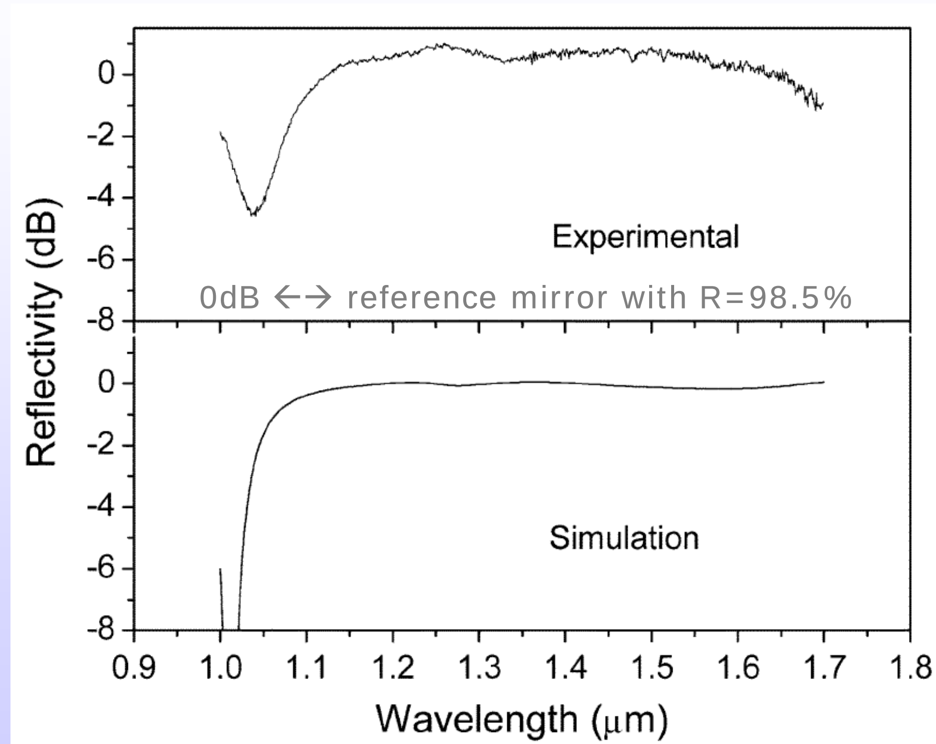


Fig. 3. SEM picture of the fabricated SWG. Grating is formed by polysilicon and air on top of silicon oxide.



Mateus et al,
IEEE PHOTONICS TECHNOLOGY LETTERS,
VOL. 16, NO. 7, JULY 2004

Conclusion #2

Summary:

- High reflectivity is possible with single layer

Outlook:

- Check fabrication tolerances, finite size effects...
- Design, build and test gratings
- Think of better suited wave guide structures


great, greater, grating