DIFFRACTIVE OPTICS TOPOLOGIES

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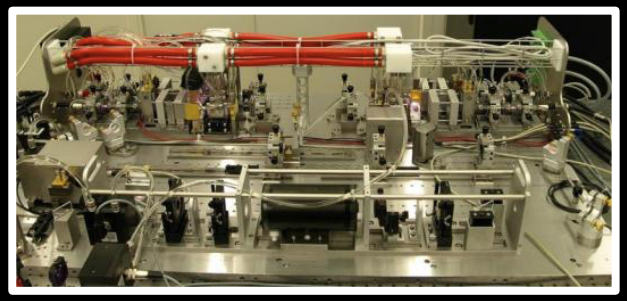
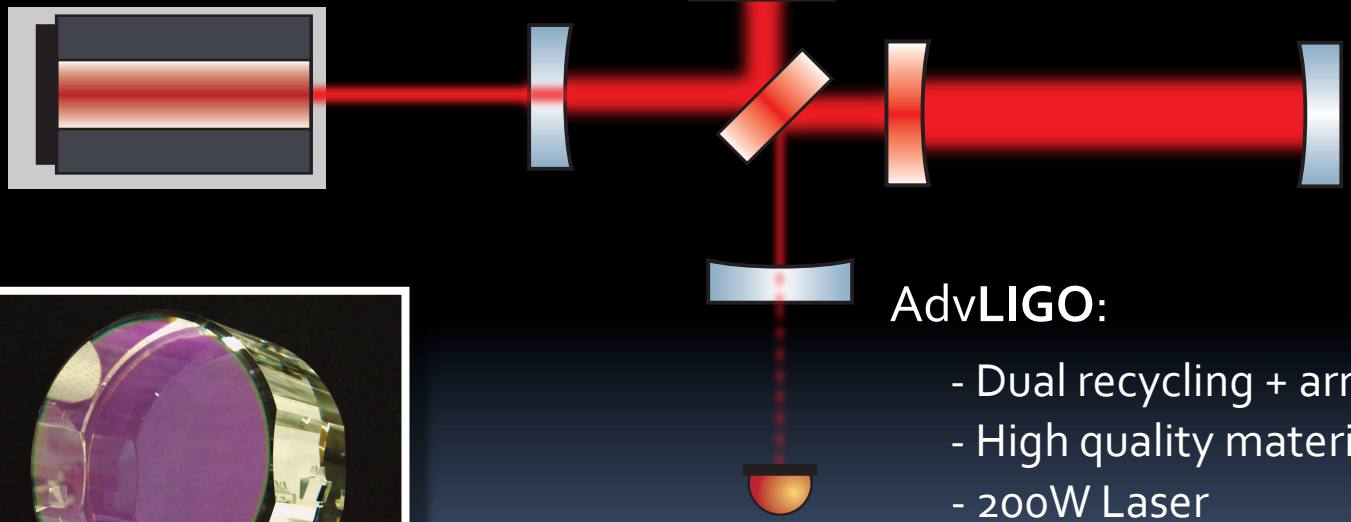
OUTLINE

- Motivation
- Interferometry with gratings
- 3-port grating cavities
- Experiments
  - 3-port grating cavity with power recycling
  - Michelson interferometer with 3PG-coupled arm cavities
- To do
- Summary

MOTIVATION





Thermal effects due to residual absorption in transmissive substrates

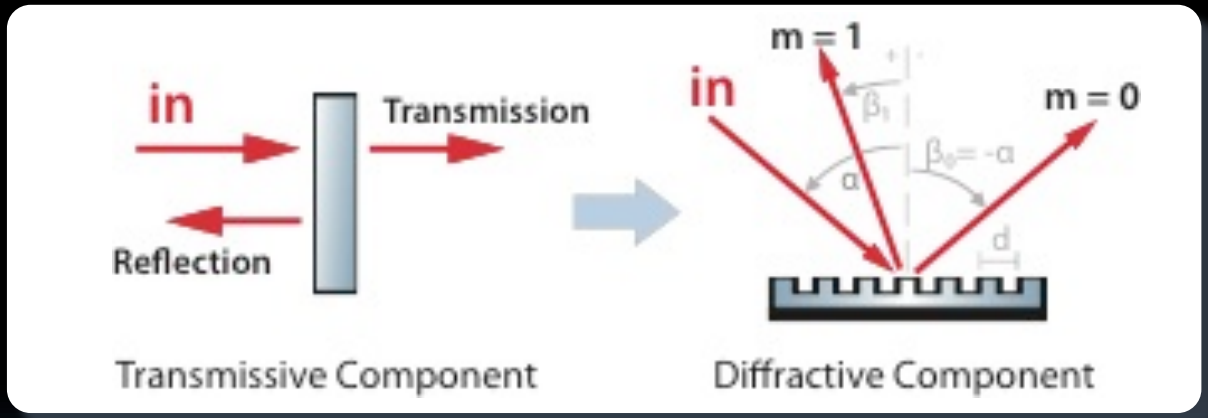
- Thermal lensing
- Photo-thermo refractive noise

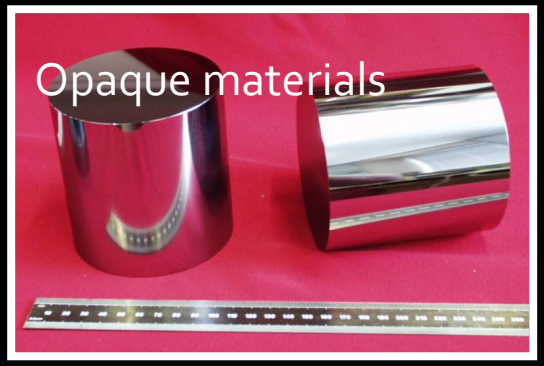
Adv**LIGO**:

- Dual recycling + arm resonators
- High quality materials
- 200W Laser

DIFFRACTIVE ALTERNATIVE

Replacing the transmissive components that are exposed to high thermal load





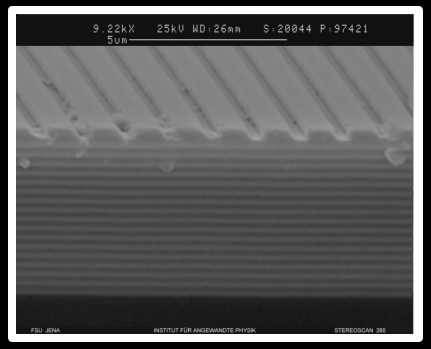
- Described by the grating equation for monochromatic light
- R, T correspond to diffraction orders with certain diffraction efficiencies

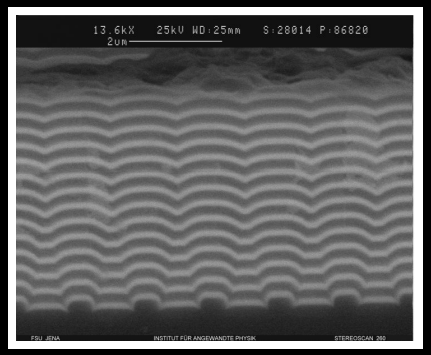
Grating Equation

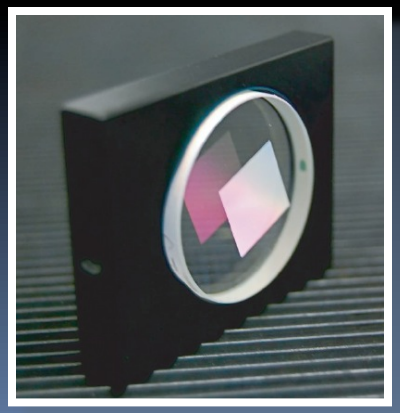
$$\sin\,\alpha + \sin\,\beta_m = \frac{m\lambda}{d}$$

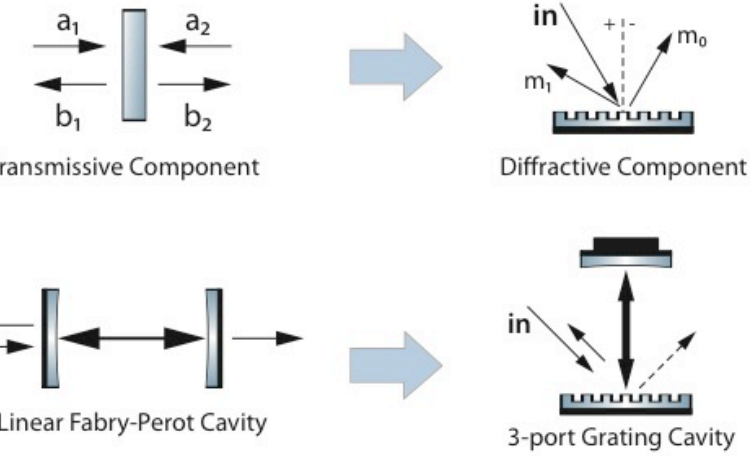
m = diffraction order
λ = wavelength
d = grating period

NEW TOPOLOGIES



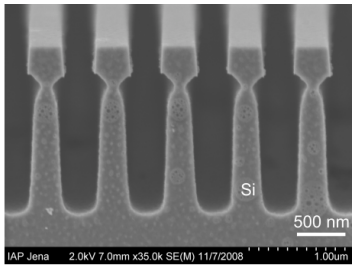






Coating still required for high reflectivity under normal incidence!

Another diffractive approach:

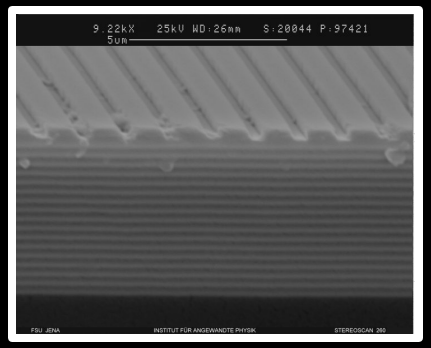


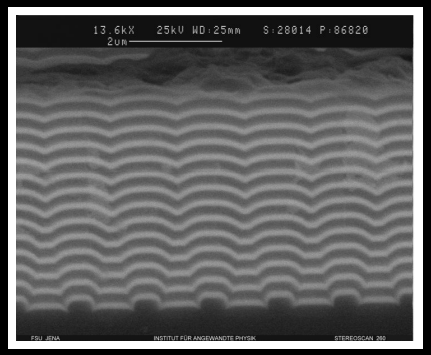
T-shaped monolithic mirror

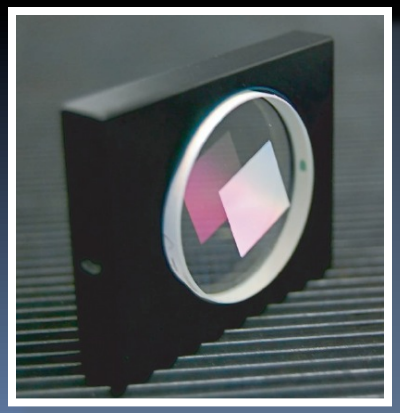
Diffractive optics for coating reduced and all-reflective interferometry

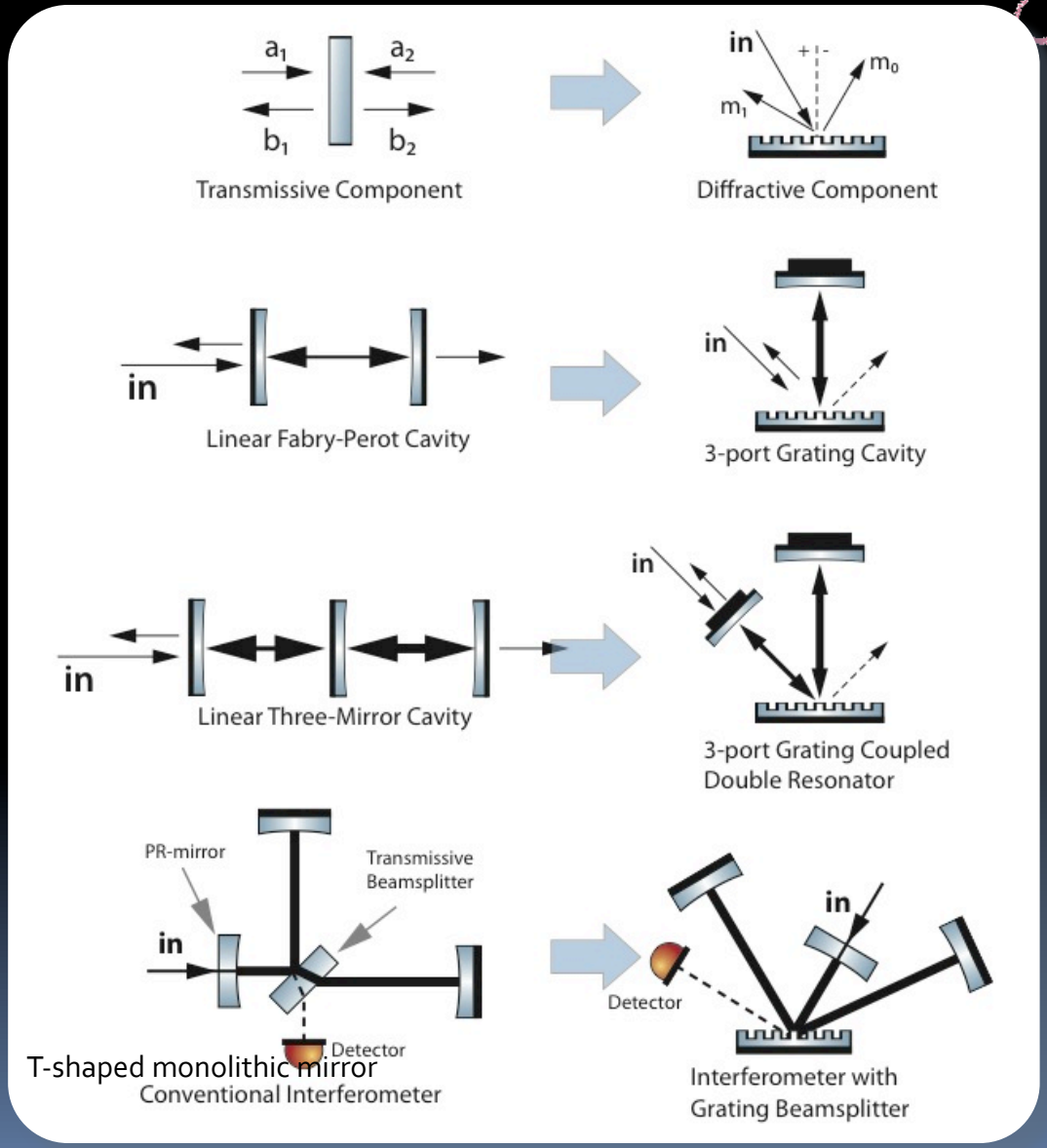
see talk of Stefanie Kroker tomorrow!

NEW TOPOLOGIES



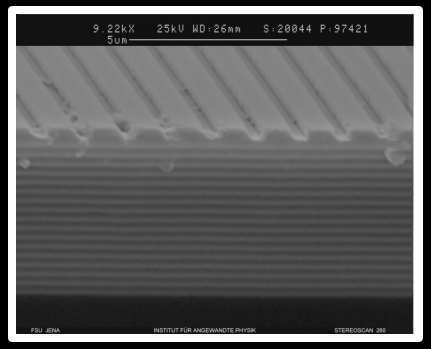


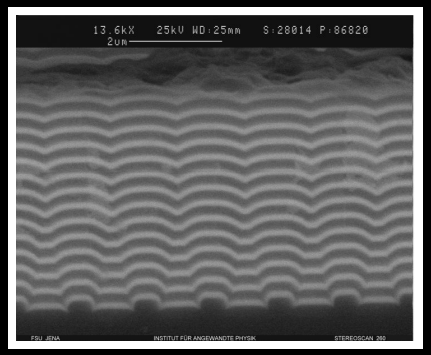


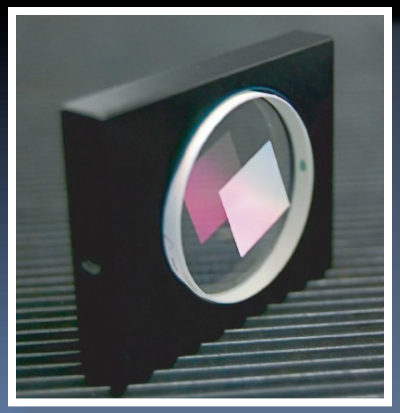


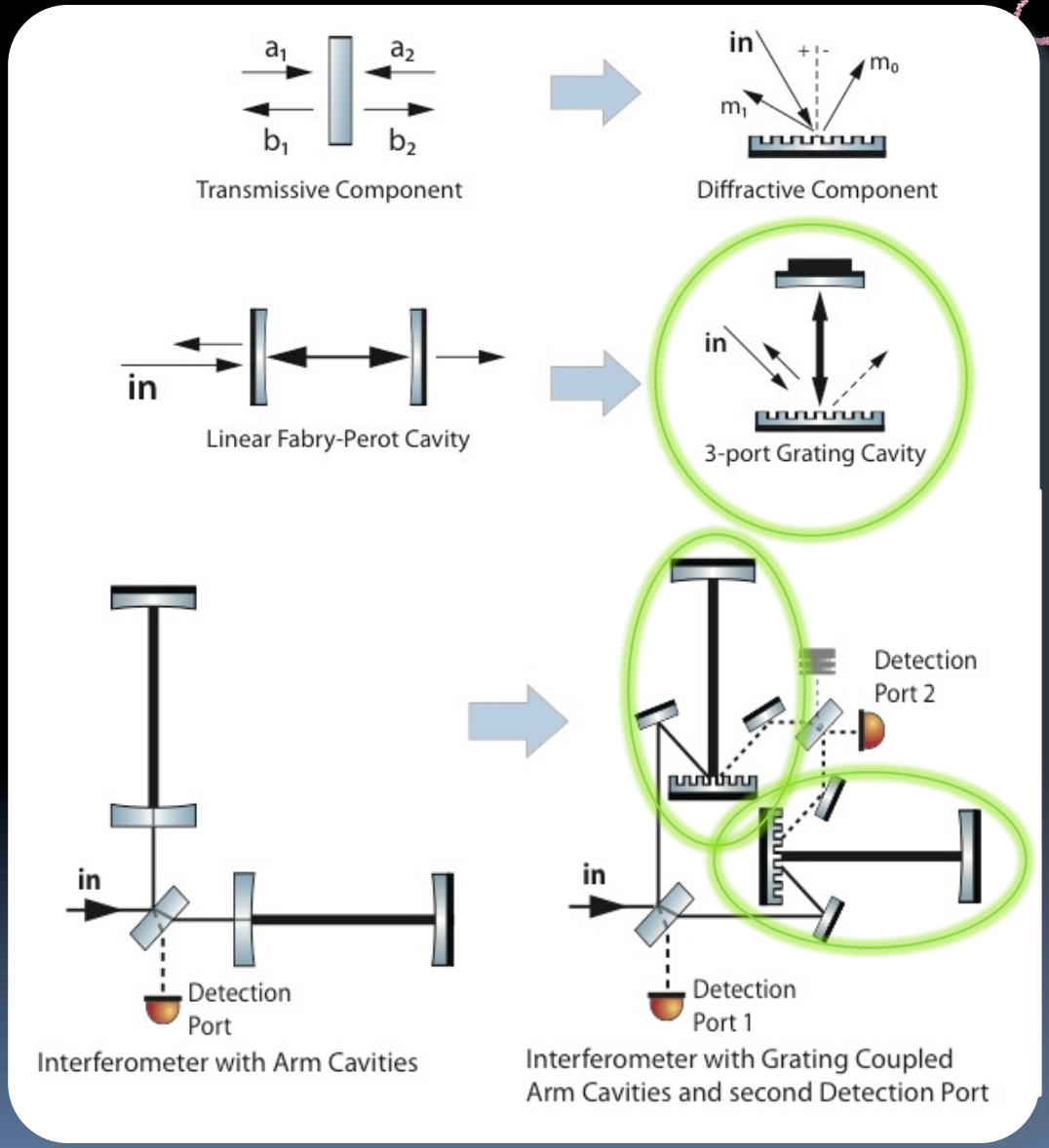
T-shaped monolithic mirror

NEW TOPOLOGIES

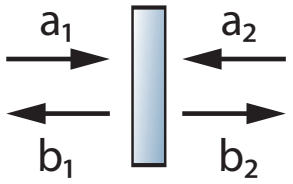








3-PORT GRATING

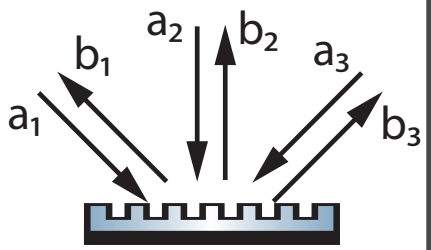


Transmissive Component

- Two light fields
- Phases are constant
- 2x2 Scattering Matrix

$$\mathbf{S}_{2p} = \begin{pmatrix} \rho & \tau \\ \tau & -\rho \end{pmatrix}$$

$$\mathbf{b} = \mathbf{S} \times \mathbf{a}$$



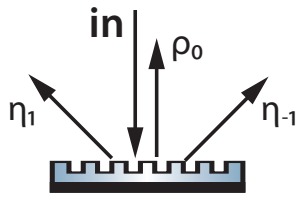
3-port Grating:

- Three light fields
- Phases: Φ(η0, η1, η2)
- 3x3 Scattering Matrix
- non-vanishing matrix elements

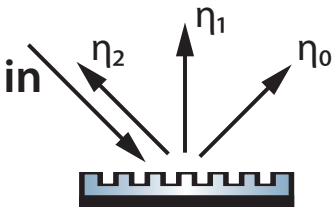
$$\mathbf{S}_{3p} = \begin{pmatrix} \eta_2 e^{i\phi_2} & \eta_1 e^{i\phi_1} & \eta_0 e^{i\phi_2} \\ \eta_1 e^{i\phi_1} & \rho_0 e^{i\phi_0} & \eta_1 e^{i\phi_1} \\ \eta_0 e^{i\phi_0} & \eta_1 e^{i\phi_1} & \eta_2 e^{i\phi_0} \end{pmatrix}$$

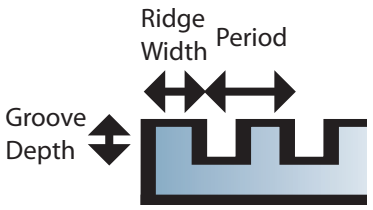
$$\eta_n \neq 0$$

Normal incidence



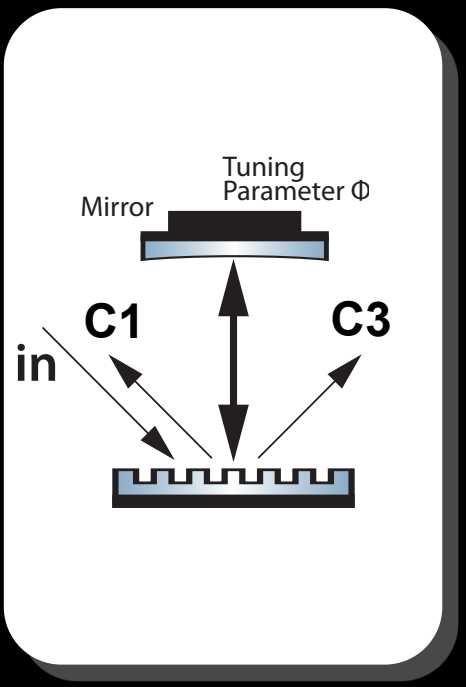
2nd order Littrow





$$\sin\alpha + \sin\beta_m = \frac{m\lambda}{d}$$

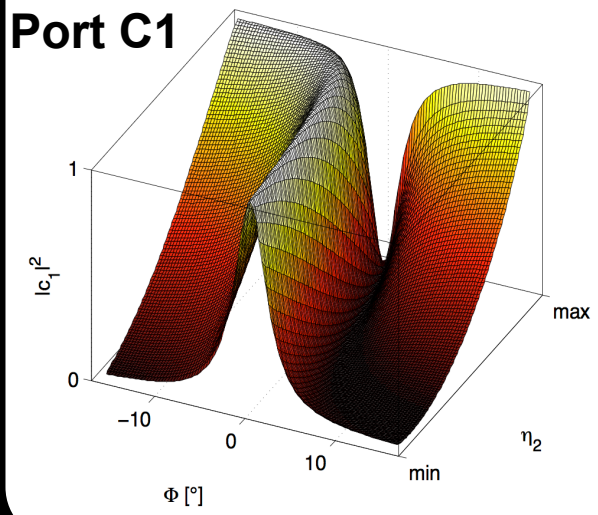
3-PORT GRATING CAVITY



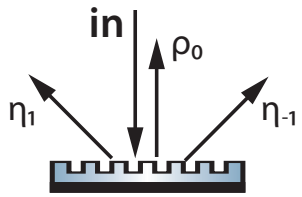
- Coupling via 1st order
- low coupling -> high finesse
- Two correlated Ports C1 and C3

Grating design defines ratio of the radiation at the two output ports

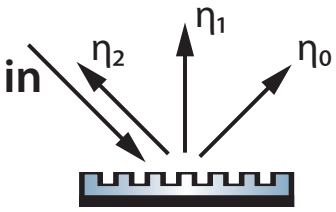
$$\eta_{0\,\mathrm{max}}^{\mathrm{min}} = \eta_{2\,\mathrm{max}}^{\mathrm{min}} = \frac{1 \mp \rho_0}{2}$$

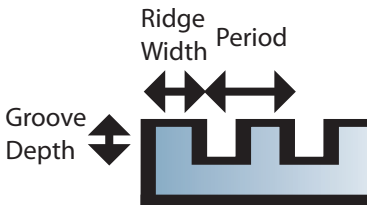


Normal incidence



2nd order Littrow

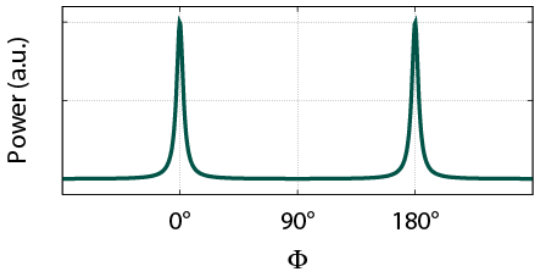




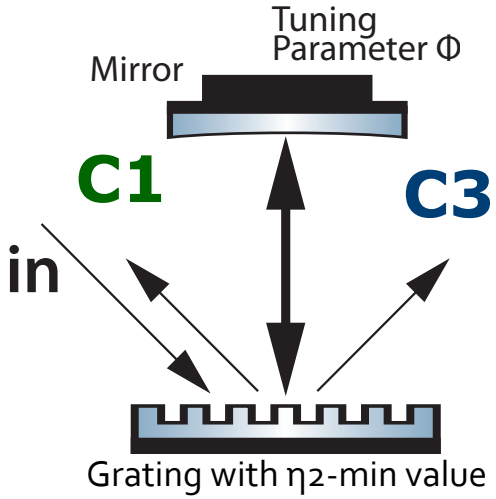
$$\sin\,\alpha + \sin\,\beta_m = \frac{m\lambda}{d}$$

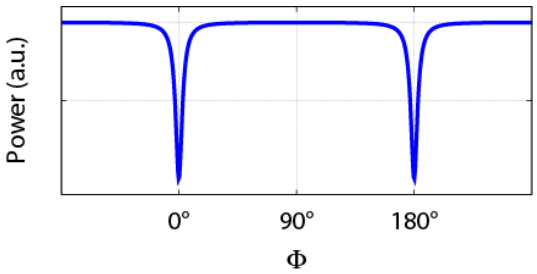
3-PORT GRATING CAVITY

Grating with minimal η2-value

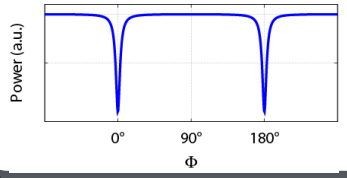


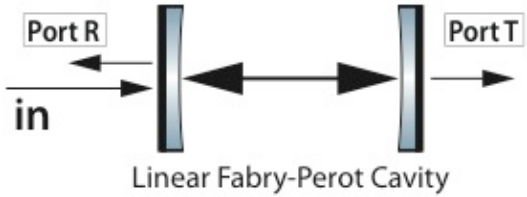
Constructive interference

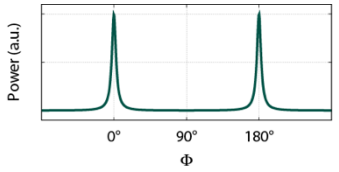




Destructive interference



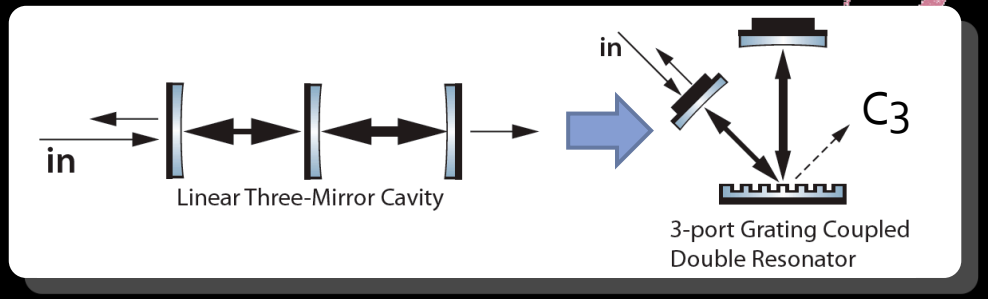




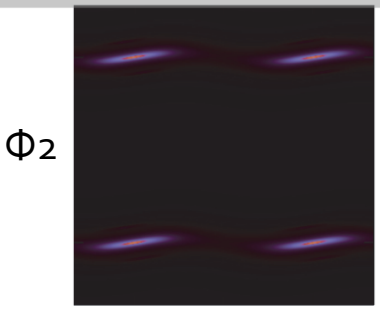
- Constructive interference at C1 and destructive interference at C3
- Light is retro reflected towards the laser source
- 'Modecleaner in reflection'

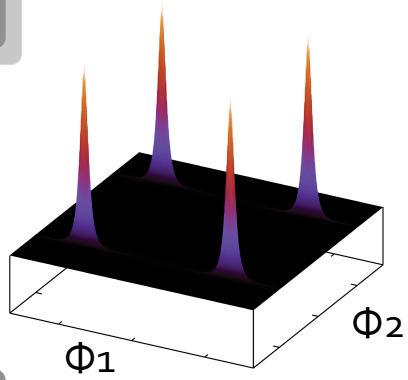
3-PORT GRATING CAVITY WITH PR

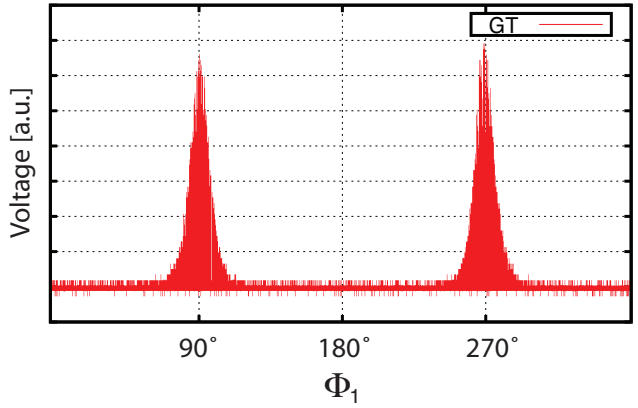
- Comparison with 'three-mirror cavity'
- Power build-up depends on two degrees of freedom (cavity tunings Φ1 and Φ2)
- Destructive interference at port C3
- No additional loss channel



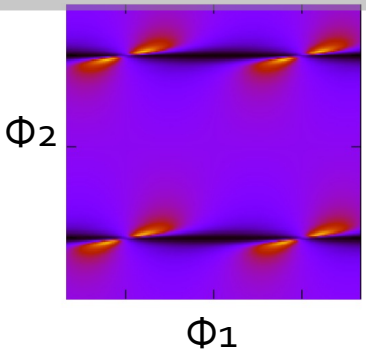
Internal power build up

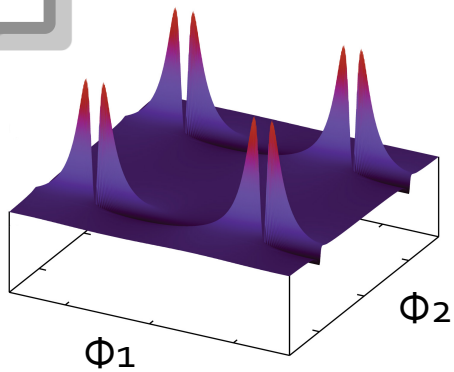


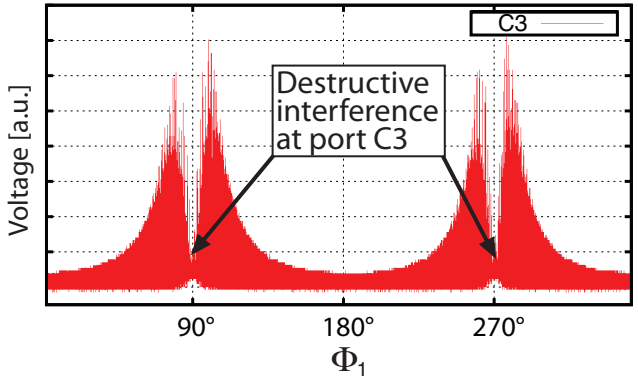




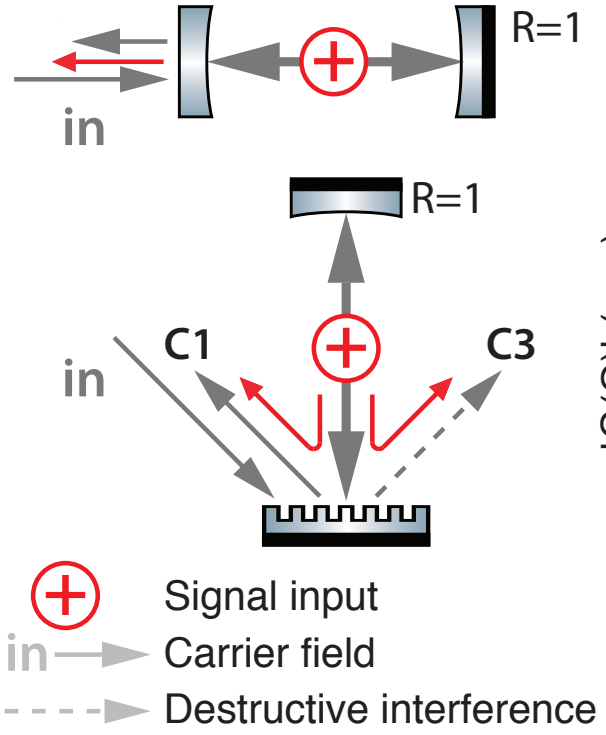
Output at additional Port C3



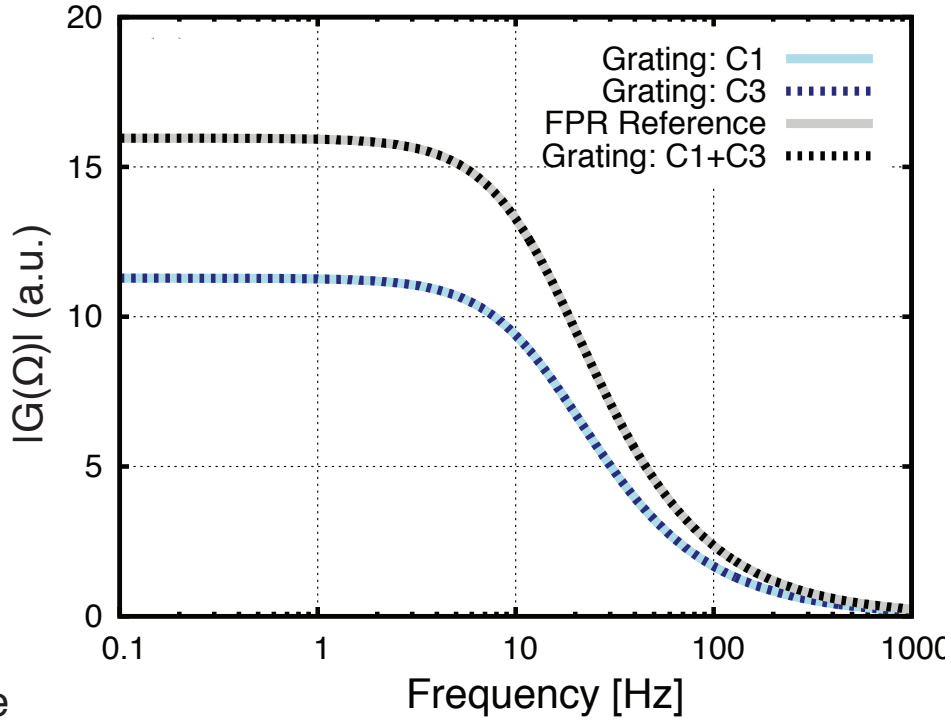




SIGNAL RESPONSE

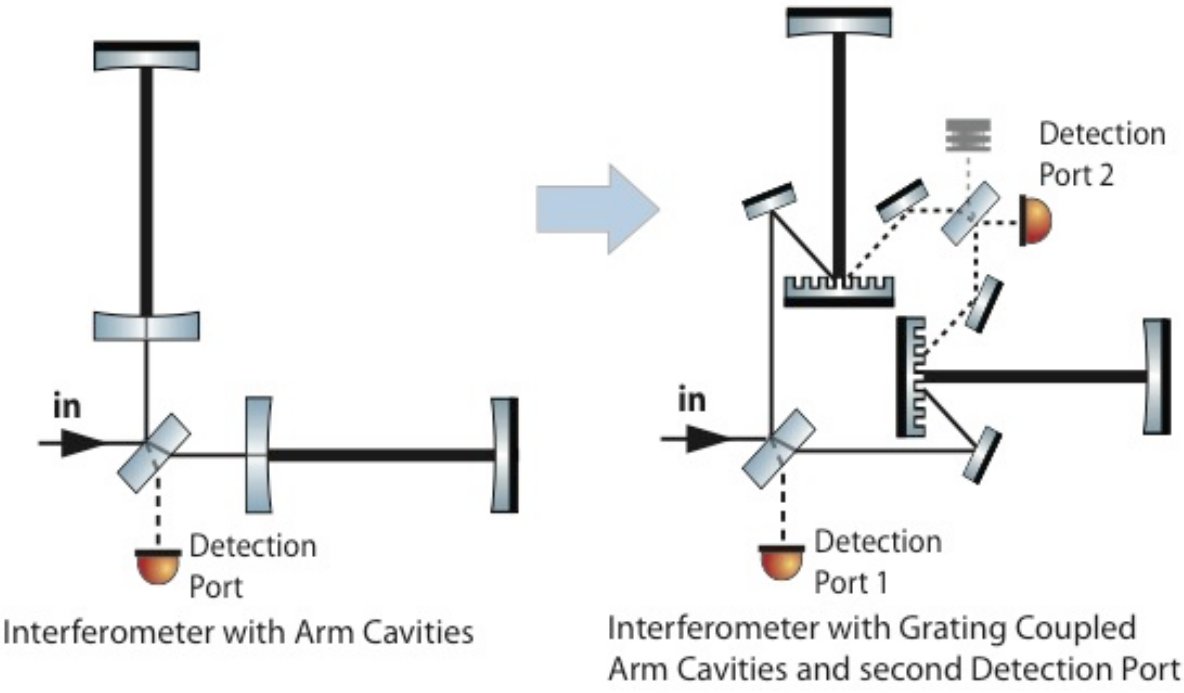


Phase quadrature readout at the detection ports for both cavities on resonance



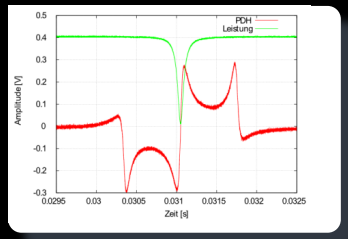
Second detection port required to gain full signal information

TWO DETECTION PORTS

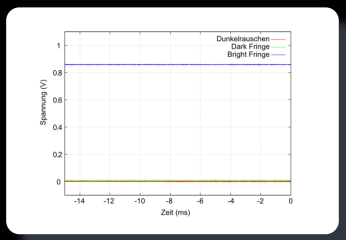


SETUP

Cavity lock with standard PDH

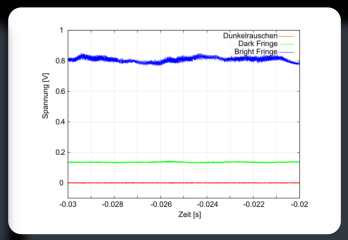


Main IFO lock with internal modulation

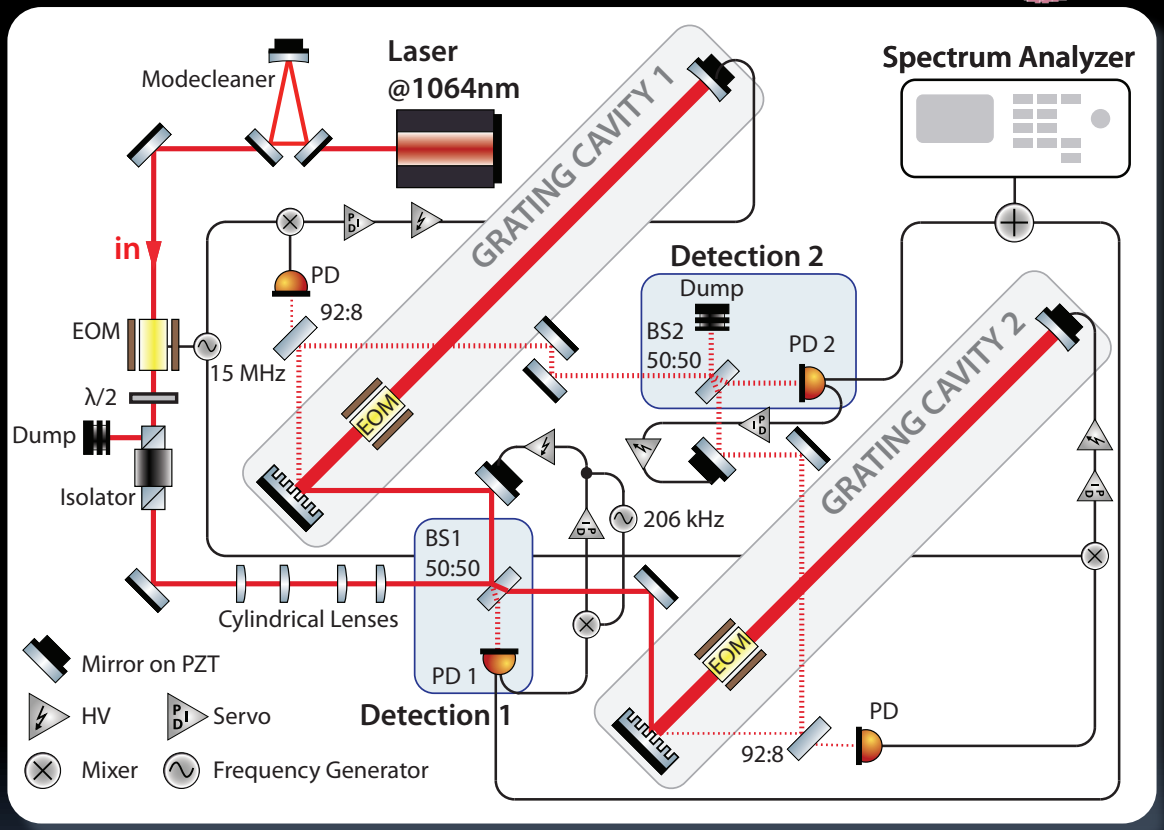


Contrast = 98%

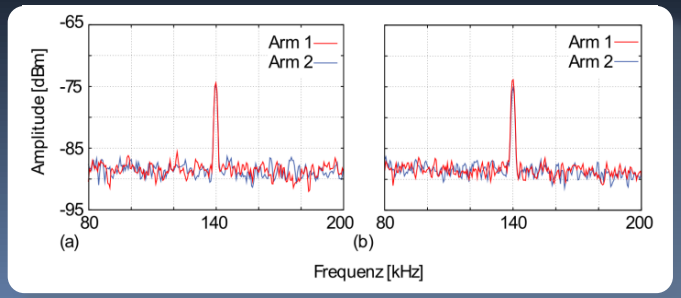
Detection 2 lock with DC lock



Contrast = 80%

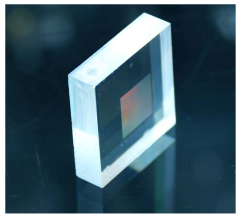


Signal adjustment for both cavities



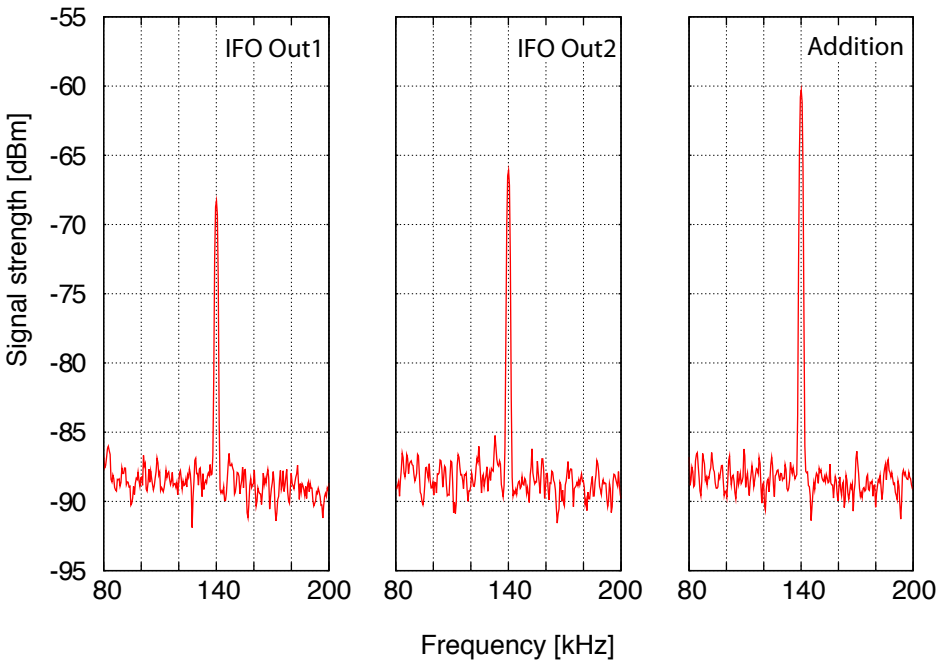
Structure-on-top grating characterized and split

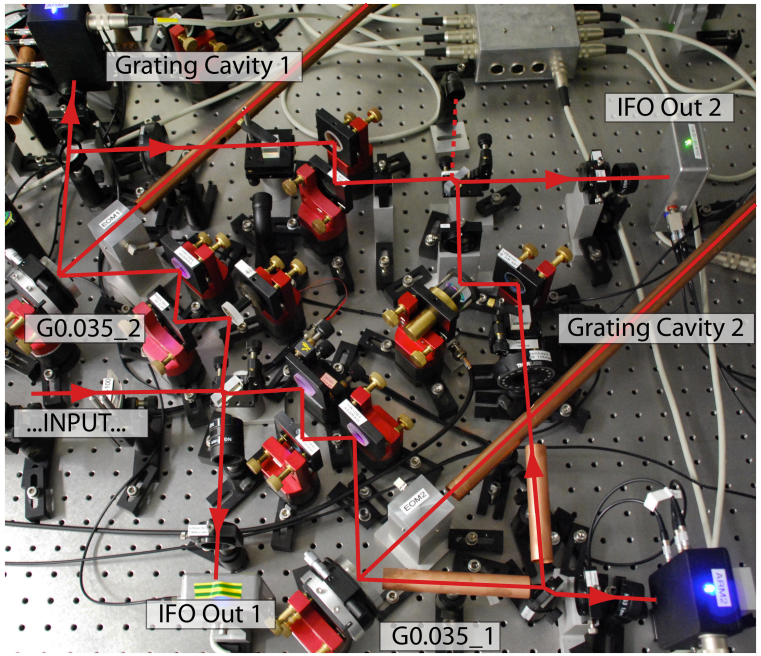
Grating	η_0^2 [%]	η_1^2 [%]	η_2^2 [%]
$G0.035_{3.1}$	96,24 (±2,3)	3,04 (±0,23)	0,04 (±0,02)
$G0.035_{3.2}$	96,01 (±2,3)	3,30 (±0,23)	0,04 (±0,02)

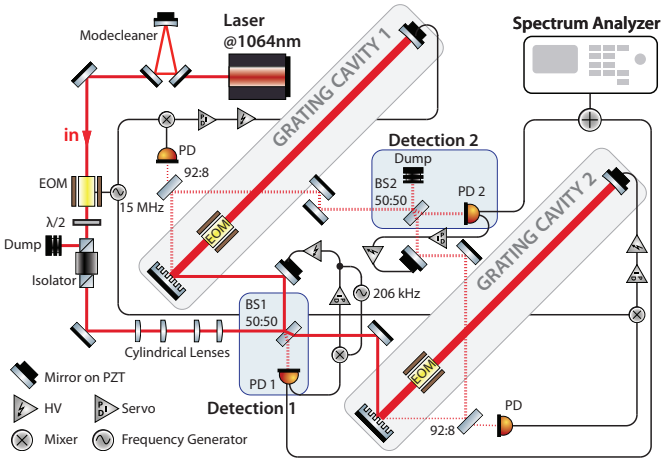


FIRST RESULTS

Signal addition:



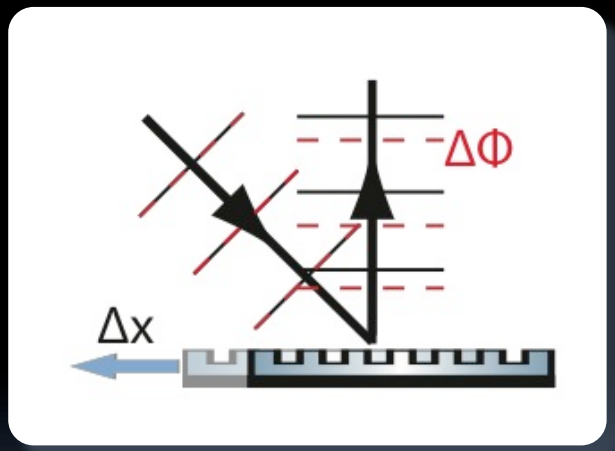




TO DO

Lateral Displacement noise

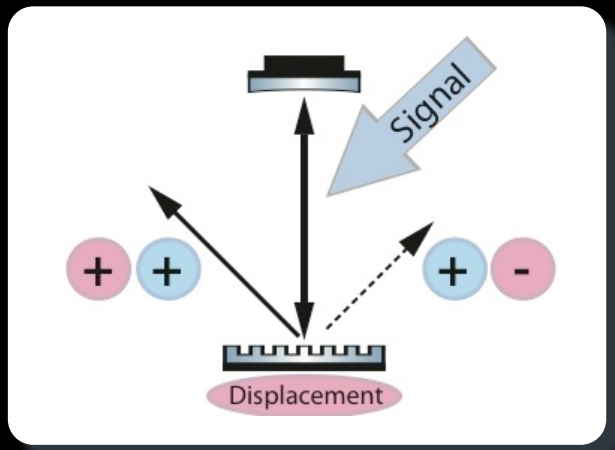
- Side motion induced phase noise
- Additional noise source
- Experimental verification in Glasgow



see following talk by Bryan Barr!

University of Glasgow

'Uninvite the uninvited guest'



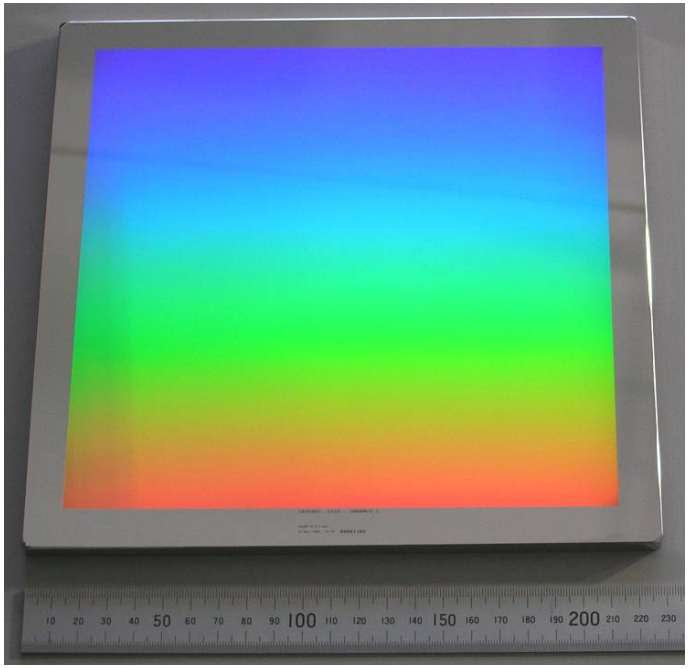
- Alternative read-out scheme at IFO
- GW signals are correlated
- Displacement induces anti-correlated signals
- Current investigations

TO DO

Reduce the scattered light and losses

- current losses ≈ 0.2%
- have to improve the fabrication process (new EBL facility in Jena)

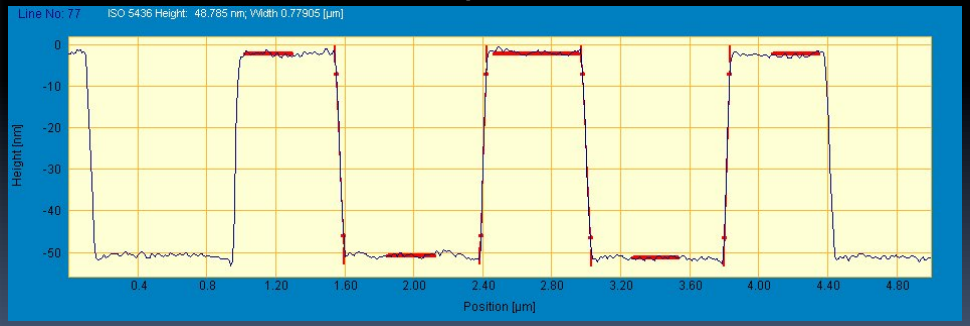
9"x 9" substrate with
3-port grating structure



Analysis of the component by means of:

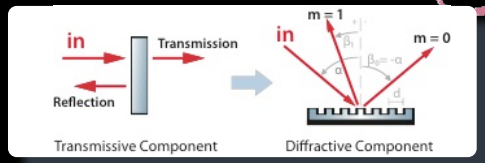
- Homogeneity
- Loss
- Wave front distortion
- Scattered light

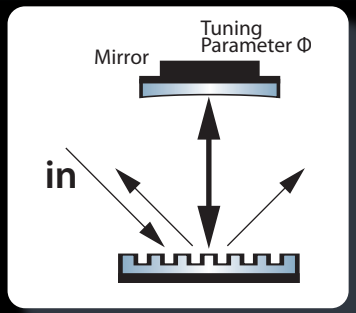
AFM measurement: depth = 45 (±5) nm

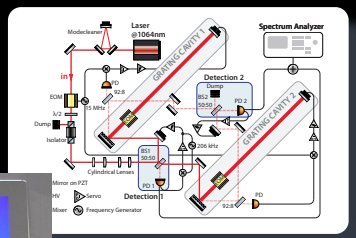


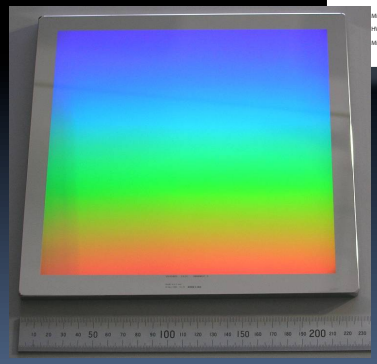
SUMMARY

- Gratings avoid transmission induced thermal effects in the substrates (and only the substrates!)
- 3-port grating cavity (η2-min) retro-reflects the light field towards the source
- 3-port arm cavities require 2nd detection port
- IFO with signal injection realized
- Challenges:
  - Lateral displacement noise
  - Improve the fabrication process





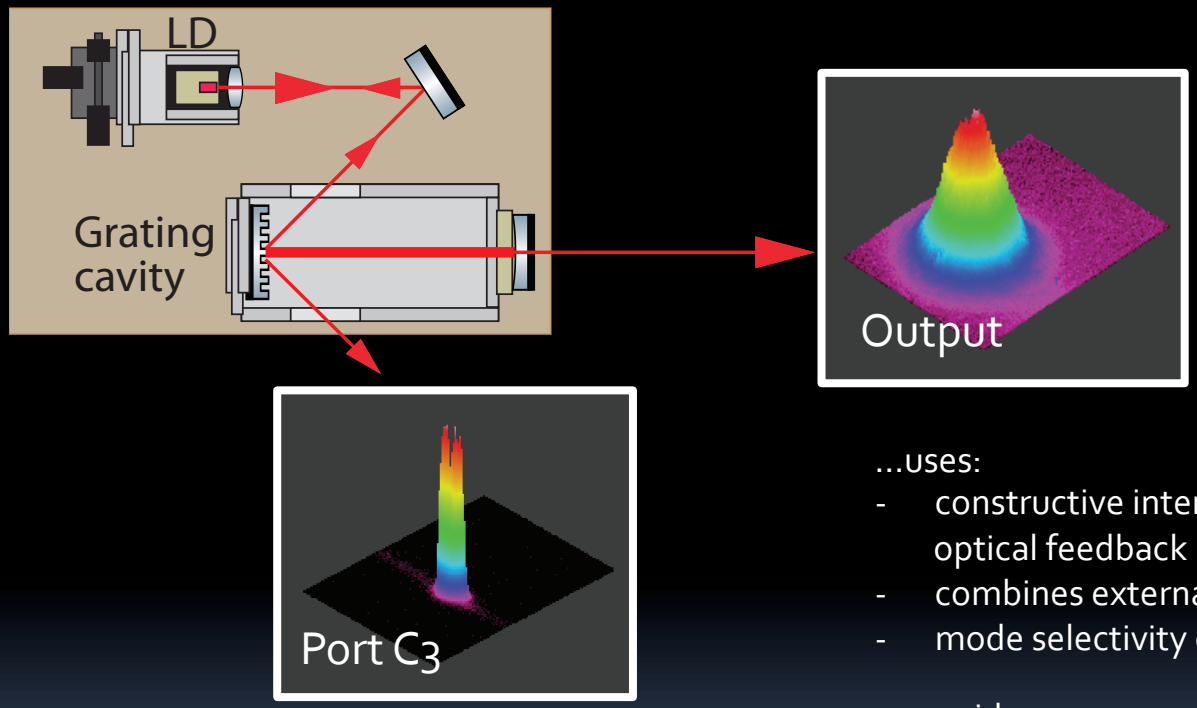




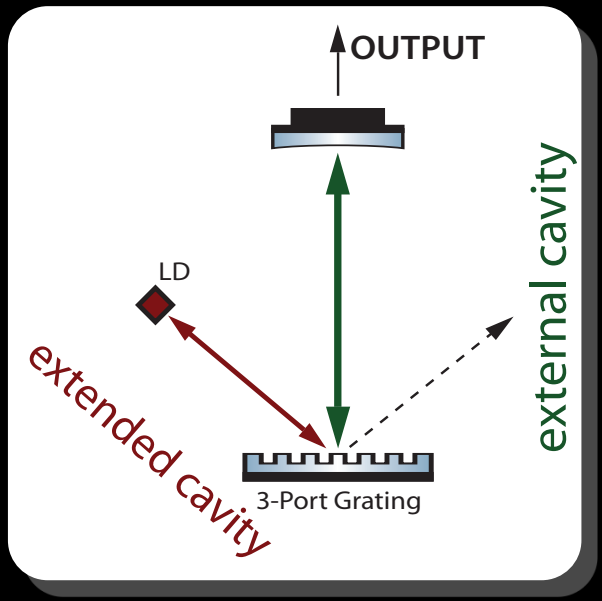
THANK YOU

3P-GRATING CAVITIES FOR OPTICAL FEEDBACK TO LASER DIODES

- Prototype set-up with alignment mirror



- elliptical profile at Port C3



...uses:

- constructive interference towards the source for optical feedback
- combines external and extended cavity
- mode selectivity of grating cavity

...provides:

- frequency selectivity of a grating
- high finesse external cavity
- high spatial mode quality
- round beam profile at output port
- low complexity