All-reflective Optics for Gravitational Wave Detectors

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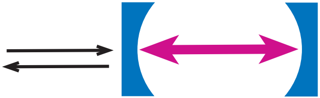
Institutions

- Universität Hannover &
  Max-Planck-Institut für
  Gravitationsphysik
  - Operation of GEO600
  - R&D for future GW Detectors: Lasers, suspension, squeezed light, all-reflective configurations...

- Universität Jena
  Institute of Applied Physics
  - Design and fabrication of dielectric reflection gratings

Motivation

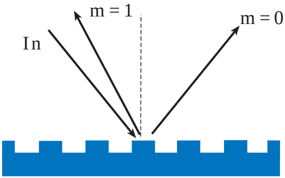


- Future detectors will use much higher laser power
- Transmission ⇒ absorption
- Thermal lensing, thermal noise

All-Reflective Interferometers

- Decrease thermal effects
- Opaque materials with superior properties

Basics



- All orders allowed by the grating eq. will contain some light power
- If only few orders wanted: $\lambda \approx d$

Grating equation

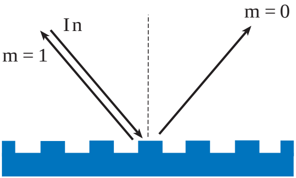
$$\sin(\theta_m) + \sin(\theta_{in}) = \frac{m \cdot \lambda}{d}$$

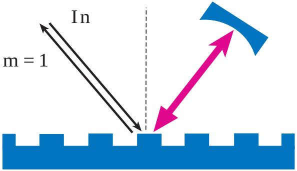
Littrow configuration

n order Littrow $\Rightarrow \theta_n = \theta_{in}$

$$m\lambda = 2d\sin(\theta)$$

Cavity in 1st order Littrow mount



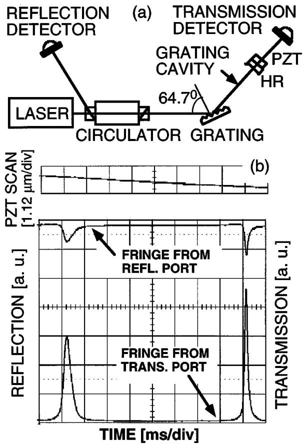


- 0th order is coupled
- Need high diffraction efficiency
- Cavity is a 2-port device (simple)

Drawbacks

- Finesse of cavity is limited by diffraction efficiency
- Hard to obtain high ($>$ 99%) efficiency

Experimental realization



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All-reflective Michelson, Sagnac, and Fabry–Perot interferometers based on grating beam splitters

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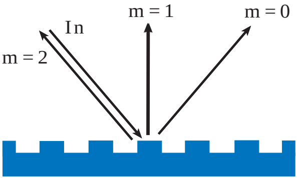
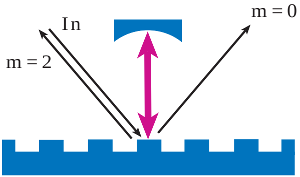
Received December 3, 1997

- Metall gratings
- 91 % diffraction efficiency
  $\Rightarrow$ low Finesse (≈ 50)
- high losses

Cavity in 2nd order Littrow mount





- Need grating with low diffraction efficiency
- 1st order is coupled to cavity
- Cavity is a 3-port device (new)

Benefits

- Need a good mirror with a small periodic pertubation
- Finesse of cavity is limited by reflectivity

Drever's proposal

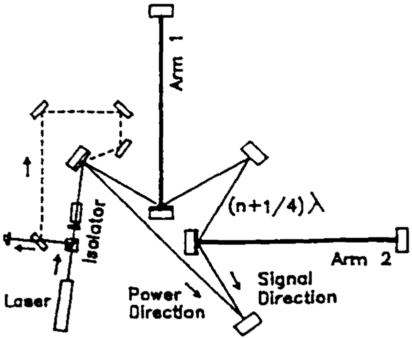


Fig. 4. Interferometer without beamsplitter

Seventh Marcel Grossman Meeting on GR (1995): 1401

Concepts for Extending the Ultimate Sensitivity of Interferometric Gravitational Wave Detectors Using Non-Transmissive Optics with Diffractive or Holographic Coupling

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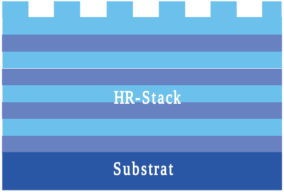
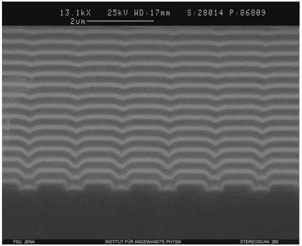
- All reflective topology
- Only low diffraction efficiency gratings
- Interesting configuration

Two approaches for gratings

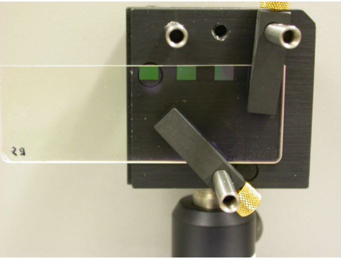


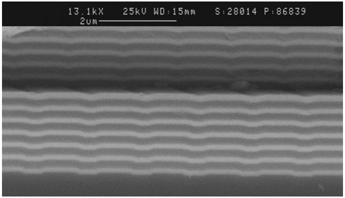
- Grating on top of HR stack
- Conventionally used for high diffraction efficiency gratings



- Overcoated grating
- Effectively a volume grating
- Harder to calculate

Low-Efficiency Cavity Coupler





Design:

- $d = 1450\,\text{nm},\ f \approx 690\text{mm}^{-1}$
- $\eta_0 > 98\,\%$
- $\eta_1 < 2\,\%$

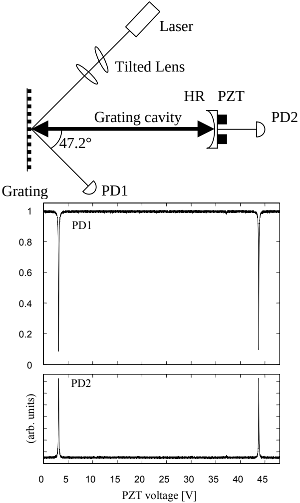
Achieved values:

- $\eta_0 = 98.5\,\%$
- $\eta_1 = 0.58\,\%$

Properties:

- Shallow periodic structure $\approx 40 - 50\,\text{nm}$
- Weak distortion of HR-stack

Cavity built



Cavity parameter:

- $\alpha = \arcsin\left(\frac{m\lambda}{d}\right) \approx 47°$
- End mirror: HR
- Finesse: 400
- Losses at grating $< 0.4\%$

Difficulties:

- Need elliptical beam profile
- Coupler has 3 ports

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Summary/Outlook

- Low diffraction efficiency gratings can replace all transmissive elements in IFO
- Phase relations are understood
- Losses of first test gratings $< 0.4\%$

- Theoretical and experimental investigation of new IFO topologies
- Influence of the grating on Q of mirrors
- Gratings on silicon substrates
- Scalability