Materials for Advanced Detectors

Coatings for Future Gravitational Wave Detectors

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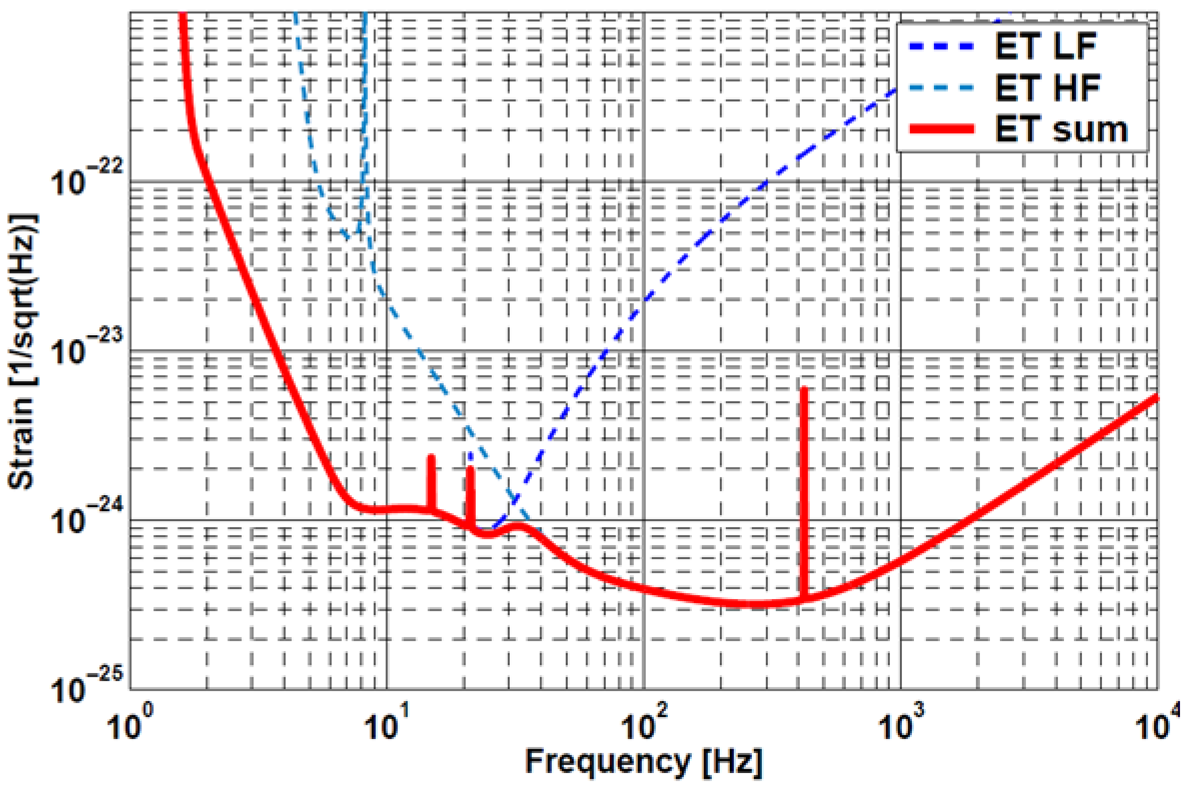
Maastricht University and Nikhef

ET Design Report Update 2020



ET Design Report 2020: https://apps.et-gw.eu/tds/ql/?c=15418

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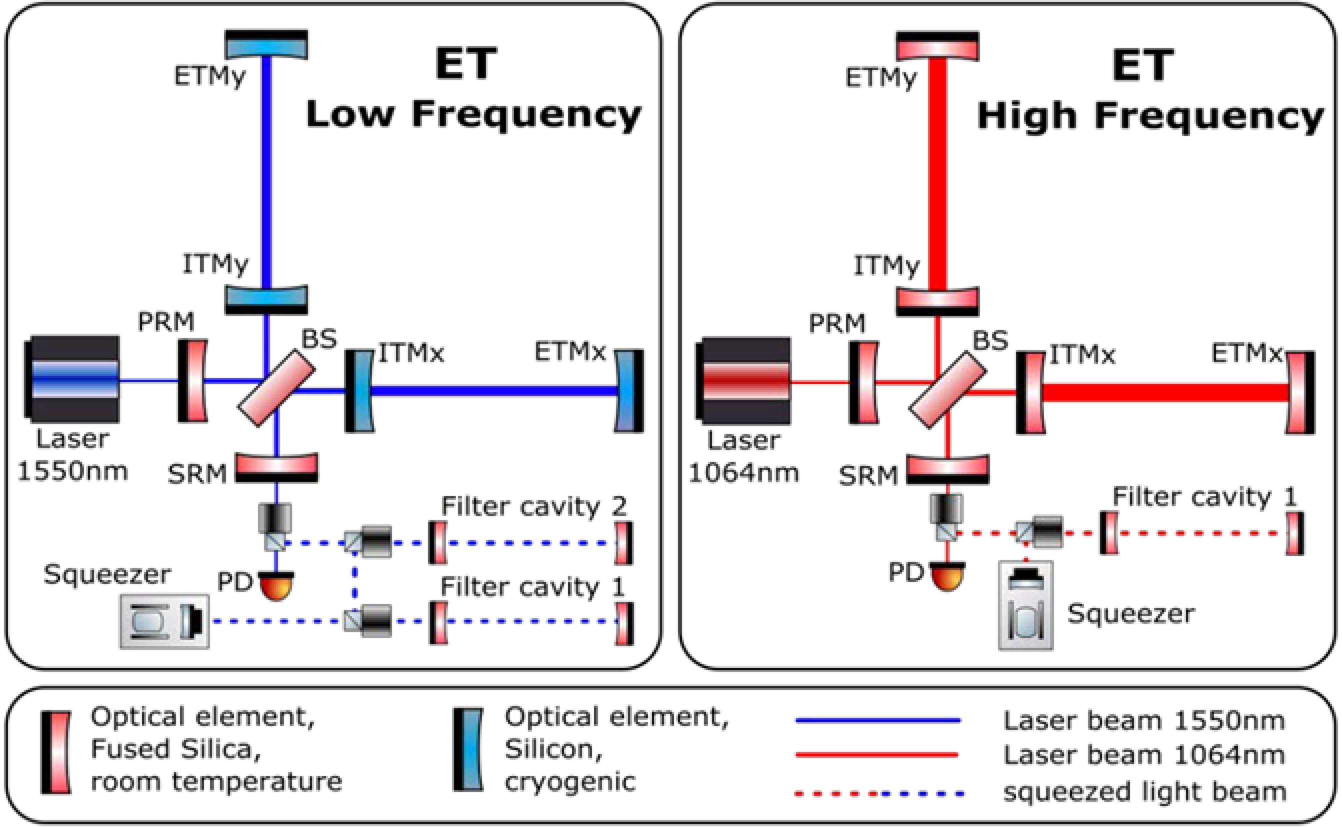

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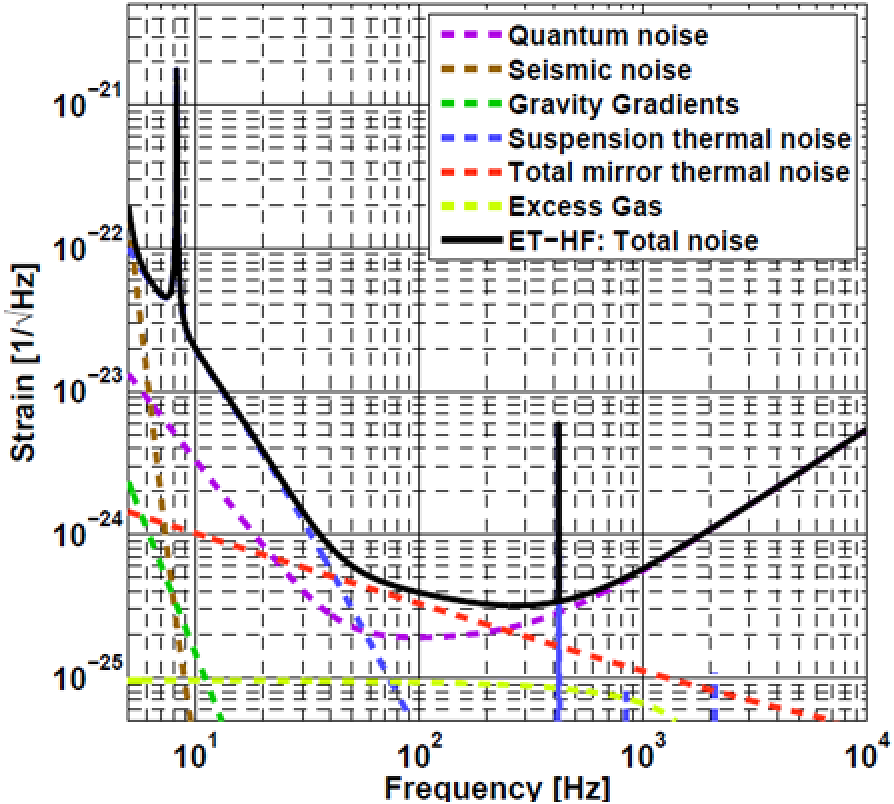
Mirror Requirements



mirror temperature

Coating thickness (Reflectivity and refractive indices)

$$\mathrm{CTN} = \sqrt{\frac{4k_{\mathrm{B}}T}{\pi^2 f w^2 Y_{\mathrm{sub}}}\, d\phi \left[\frac{Y_{\mathrm{coat}}}{Y_{\mathrm{sub}}} + \frac{Y_{\mathrm{sub}}}{Y_{\mathrm{coat}}}\right]}$$

beam radius (on mirror)

coating mechanical loss

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Mirror Requirements

Material Properties (T-dependent)

low mechanical loss

high reflectivity
ETM: $R \approx 99.999x\%$,
ITM: $R \approx 99.x\%$

low optical absorption

tolerates heat treatment required for low absorption and mech. loss

high laser damage threshold

homogeneous layer thickness

low scattering

low number of defects, point absorber etc.

large diameters

Production Technology

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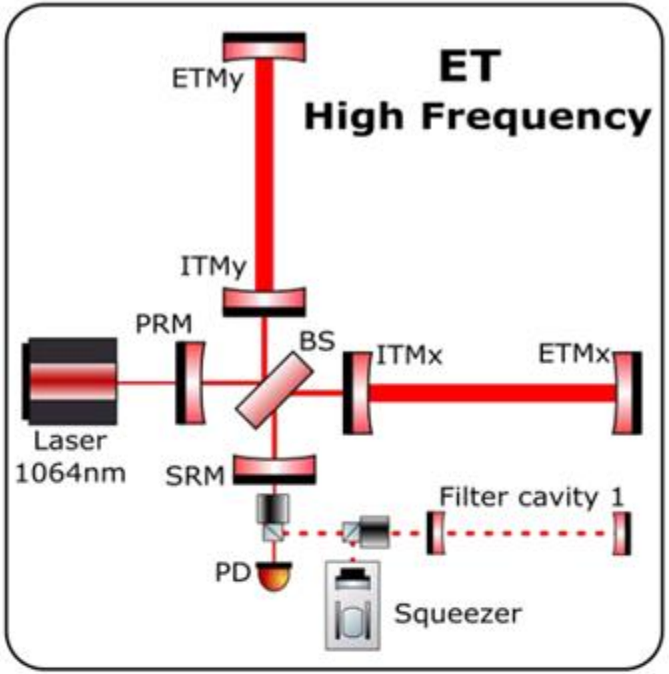

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AdvVirgo - ET Design Report Update 2020

Parameters	Adv Virgo	ET-HF
Arm power	100 - 150 kW (O4)	3 MW
Mirror mass	42 kg	200 kg
Temperature	290 K	290 K
Laser Wavelength	1064 nm	1064 nm
Mirror diameter	35 cm	62 cm
Beam radius	5 - 6 cm	12 cm
Bulk absorption	Suprasil 3001/3002 0.2 ppm cm^{-1}	Fused silica
Coating absorption	0.3-0.4 ppm	

Better for shot noise
Worse for point absorbers
Worse for thermal lens

Better for radiation pressure
Better for fibres thermal noise

Better: 2x CTN reduction from a 2x larger beam
Aiming at a x10 reduction @100Hz (arm length x beam size x better coatings)

Advanced Virgo: DOI 10.1088/0264-9381/32/2/024001
ET Design Report 2020: https://apps.et-gw.eu/tds/ql/?c=15418

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Coating being worked on for A+, i.e. should be ready for ET

Main work on:

- Scaling up to large size (Production Technology)
- Better coating (lower CTN)
- High-power laser related problems

SiO_2 and mixed oxides [1][2]
(likely) TiO_2: GeO_2
(or TiO_2: SiO_2 or SiN_x [3])

[1] See talk by Mariana Fazio
[2] See talk by Shima Samandari
[3] See talk by Simone Marchetti

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ET Design Report 2020: https://apps.et-gw.eu/tds/ql/?c=15418

See more about research ongoing on coatings: https://doi.org/10.1002/adpr.202400117

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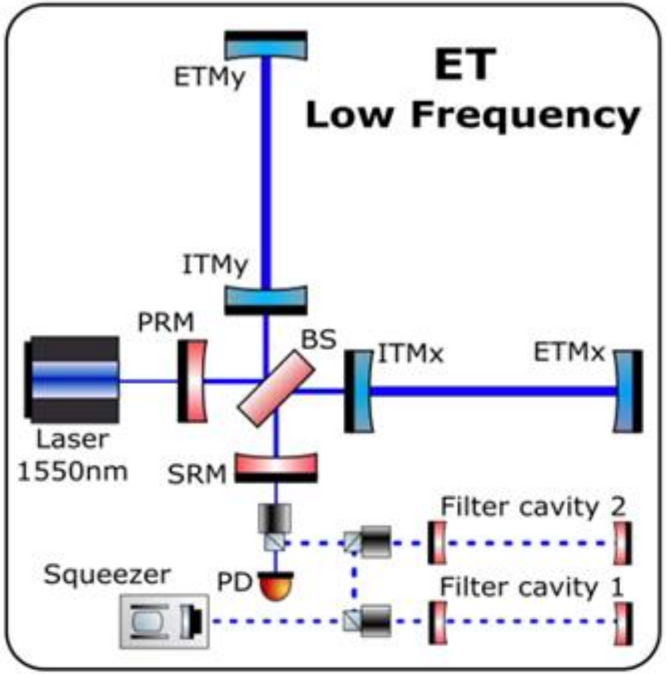

ET Design Report 2020: https://apps.et-gw.eu/tds/ql/?c=15418

AdvVirgo - ET Design Report Update 2020

Parameters	Adv Virgo	ET-LF
Arm power	100 - 150 kW (O4)	18 kW
Mirror mass	42 kg	211 kg
Temperature	290 K	10-20 K
Laser Wavelength	1064 nm	1550 nm
Mirror diameter	35 cm	45 cm
Beam radius	5 - 6 cm	9 cm
Bulk absorption	Suprasil 3001/3002 0.2 ppm cm^{-1}	
Coating absorption	0.3-0.4 ppm	

Better for radiation pressure
Worse for shot noise

Better for radiation pressure
Better for fibres thermal noise

Better for CTN
Increase complexity of detector
(how to cool it down? Frosting? …)

Better for absorption

Better for CTN
Aiming at a x10 reduction @10Hz
(arm length x temperature x beam size x better coatings)

?

Advanced Virgo: DOI 10.1088/0264-9381/32/2/024001
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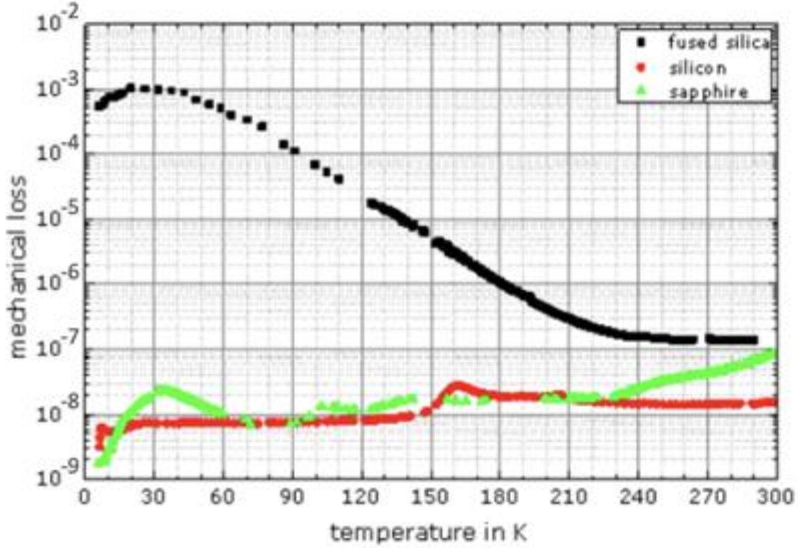
Oxides at Low Temperatures

Mechanical loss of (currently used) fused silica increases at low T

Mechanical loss can be strongly temperature dependent

- ➢ Increases significantly on cooling for fused silica.
- ➢ Slightly decreases for silicon.
- ➢ (Similar for Sapphire)

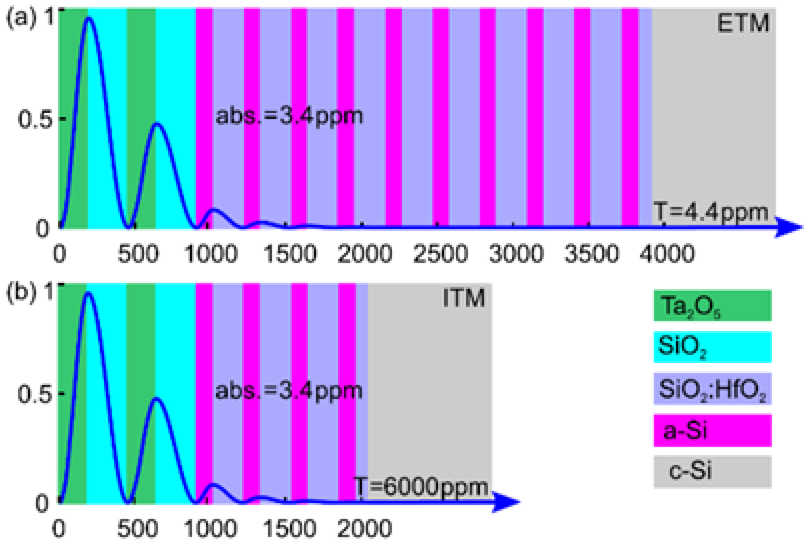
→ Motivation for investigating silicon



[R. Nawrodt et al.: *Cryogenic Setup for Q-factor measurements on bulk materials for future gravitational wave detectors*, in Proceedings of ICEC22-ICMC2008 (2009)]

Possible Activities for ET-LF Coatings

- **Longer wavelength (1550nm instead of 1064nm) opens up new material options:**
  - a-Si - low mechanical loss as low temp., but requires absorption reduction.
  - SiN - low mechanical loss at low temp., combination with a-Si being explored.
  - SiO_2:HfO_2 - can potentially meet ET-LF requirements in multimaterial design (see below).
  - TiO_2 - low mechanical loss at low temp., low absorption, but crystallizes easily during heat treatment (may be no issue).
  - …
- **Other coating concepts**
  - Monocrystalline multilayers (e.g. AlGaAs, oxides)
  - Crystalline/amorphous hybrid coatings. (e.g. crystalline toplayer)
  - Multimaterial coatings: more than two materials in a multilayer stack.
  - Nanolayers (to suppress crystallisation).
  - Ion implantation of reflective layers [1]
  - …



[1] See talks of Luca Massaro and Ismail El Ouedghiri-Idrissi

Possible Activities for ET-LF Coatings

- **Identify final materials for low temperature and 1550 nm**
- **Set a clear absorption limit**
- **Verify multimaterial coatings:**
  - investigate deposition conditions and heat treatment
  - avoid cracks and blisters after heat treatment, due to stress
- **Coating production:**
  - increase size (mainly problematic for crystalline coatings)
  - Point-like defects reduction
  - …
- **Combination of different coatings for ITM and ETM:**
  - Different substrates for ITM and ETM
  - Different sizes for ITM and ETM
  - …

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