Harald Lück, AEI Hannover

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EU contract #211743

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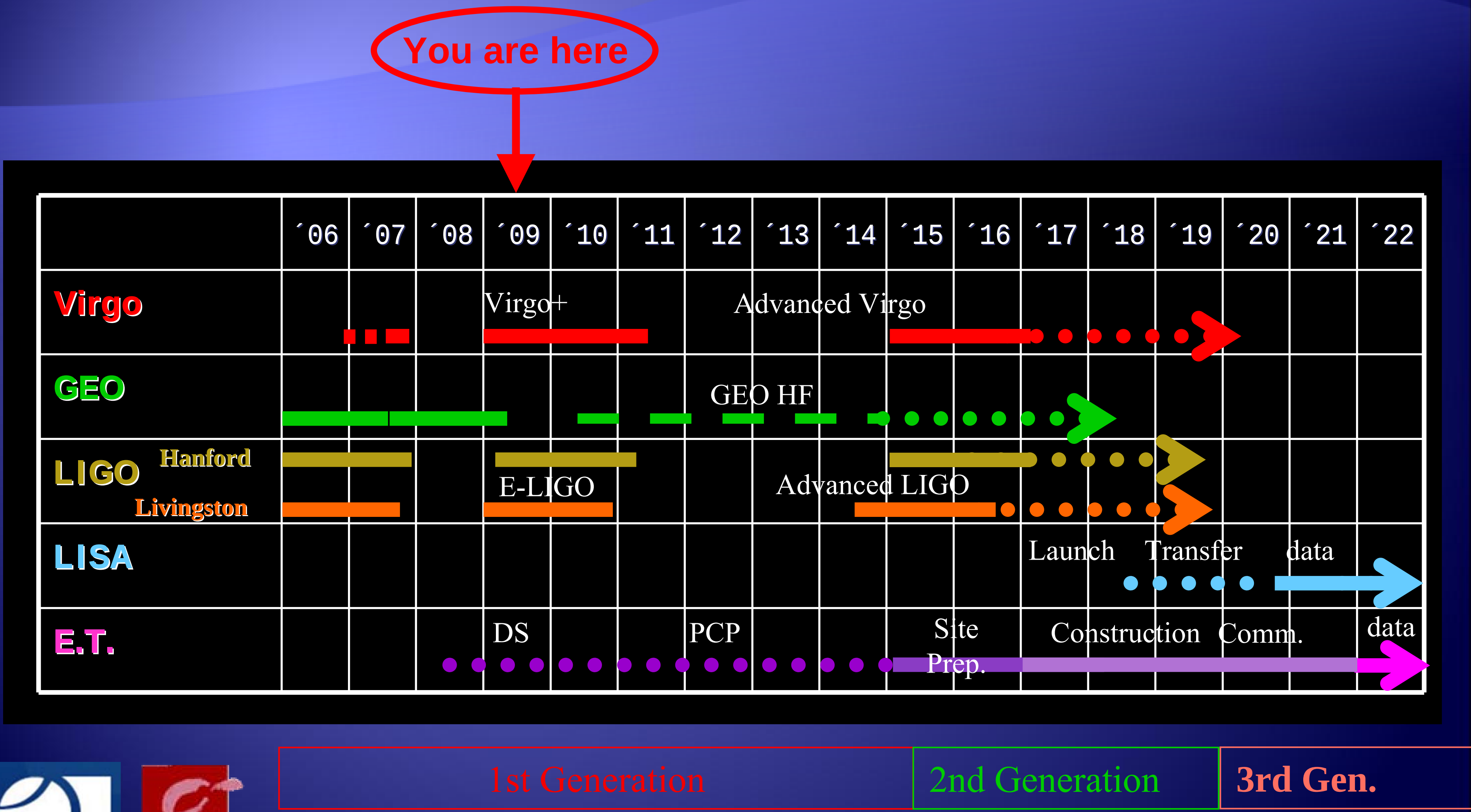
TECHNOLOGY FOR THE THIRD GENERATION

GW Timelines



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In this talk no discussion of

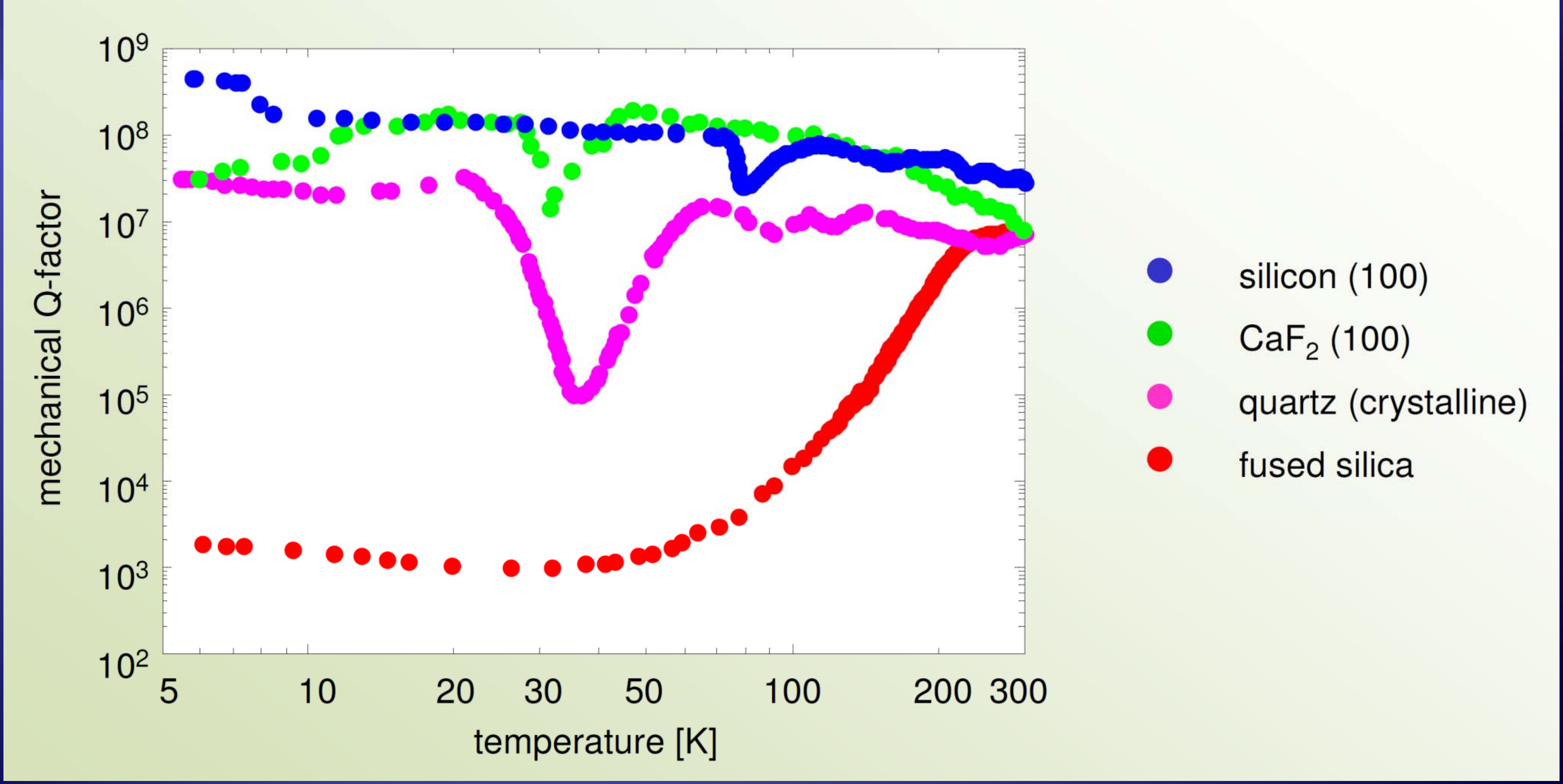
- Interferometer size
  - As big a finances allow? How big is that?
- Over-ground vs under-ground (J. Harms, Jo Van der Brand, D. Rabeling)
  - Will low frequency performance goals really require underground operation ?
- Low frequency suspensions (R. Nawrodt)
- ~~Newtonian Noise~~
- Cryogenic operation (W. Johnson, K. Kuroda)
  - Is cryogenics really needed to achieve the goals or is room temperature sufficient (at least for high frequencies) ?
- Non gaussian beams (A. Freise)
- QND tricks (H. Müller-Ebhardt)
- Xylophone: collocated multi-narrowband vs single-broadband detector (S. Hild, R. DeSalvo)

Technologies

Some (good?) candidates for the third generation

- Substrate material: Silicon
- Gratings & wave-guide coatings (H. Lück)
- Quantum noise:
  - Squeezing (A. Khalaidovski)
  - Laser (N. Man)

Mechanical Q of substrate materials

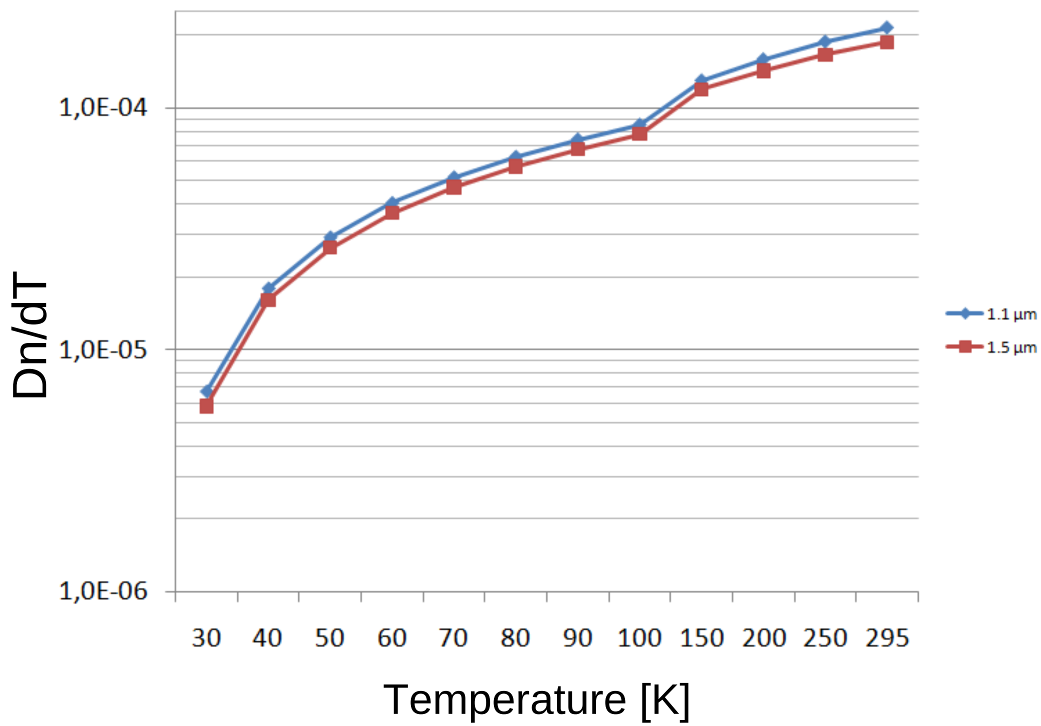


Nawrodt et al.

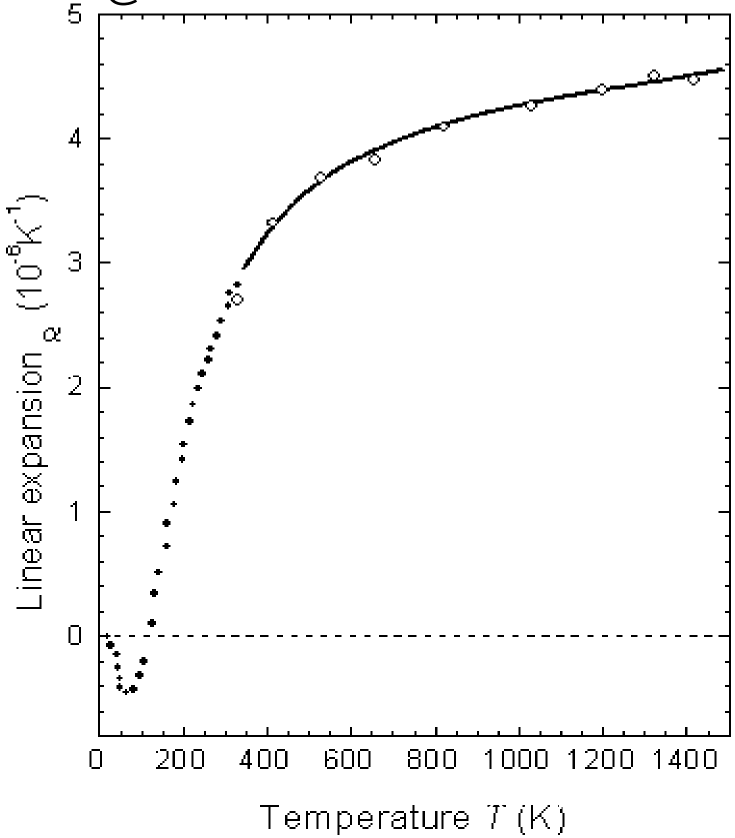
SILICON (Properties)

Low thermal lensing @ low temp.
Fused silica 2E-5 / K @ 300 K

No thermoelastic noise

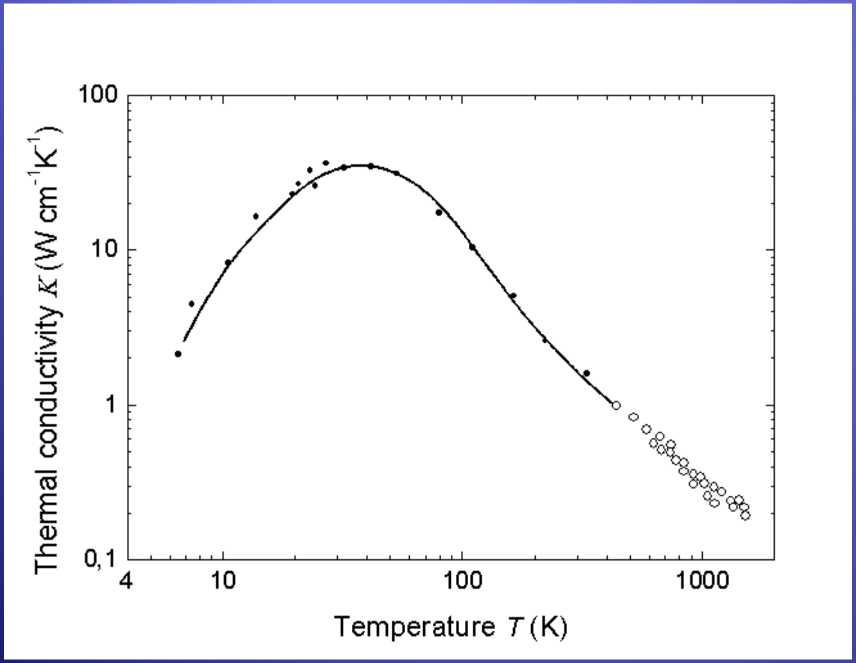


Vanishing CTE
@ 20k & 125K

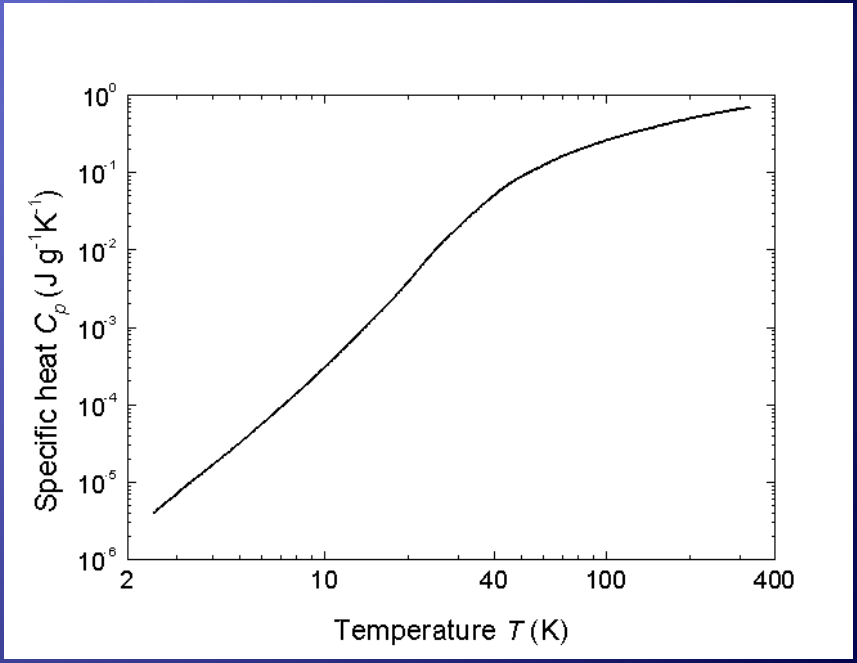


Physical properties of silicon

Thermal conductivity Silicon



Specific heat Silicon



Properties of silicon / silica

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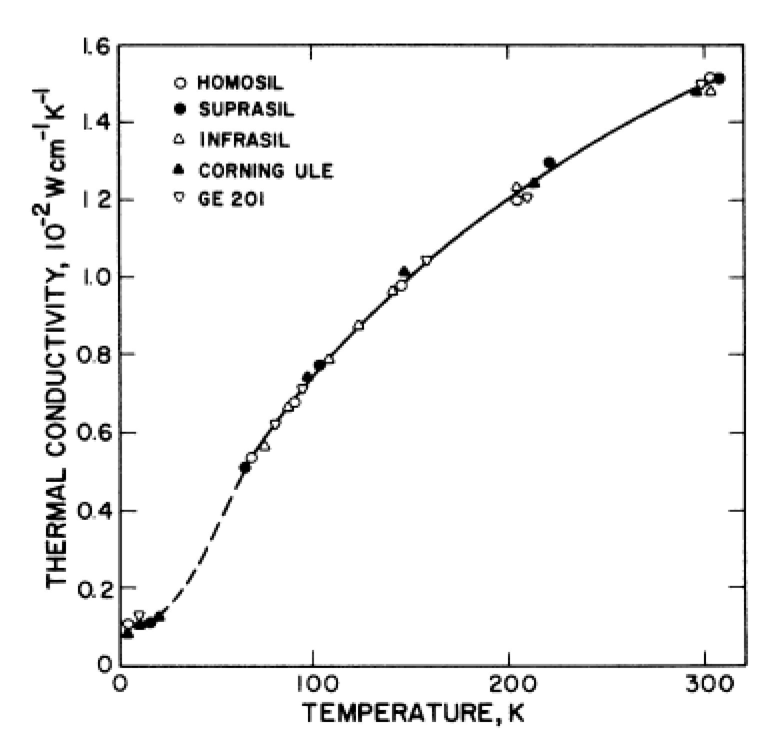
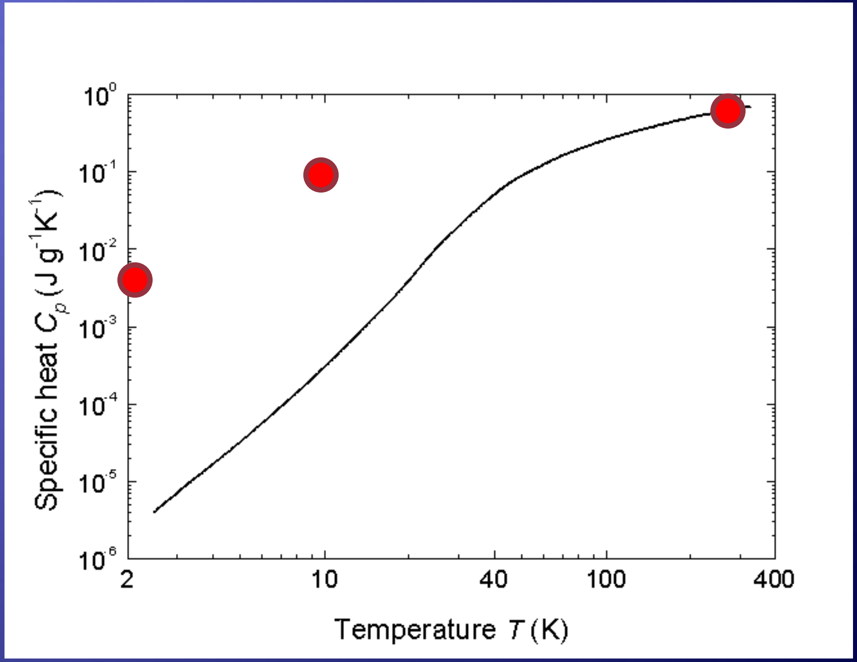
Thermal conductivity fused Silica



Specific heat Silicon / fused silica

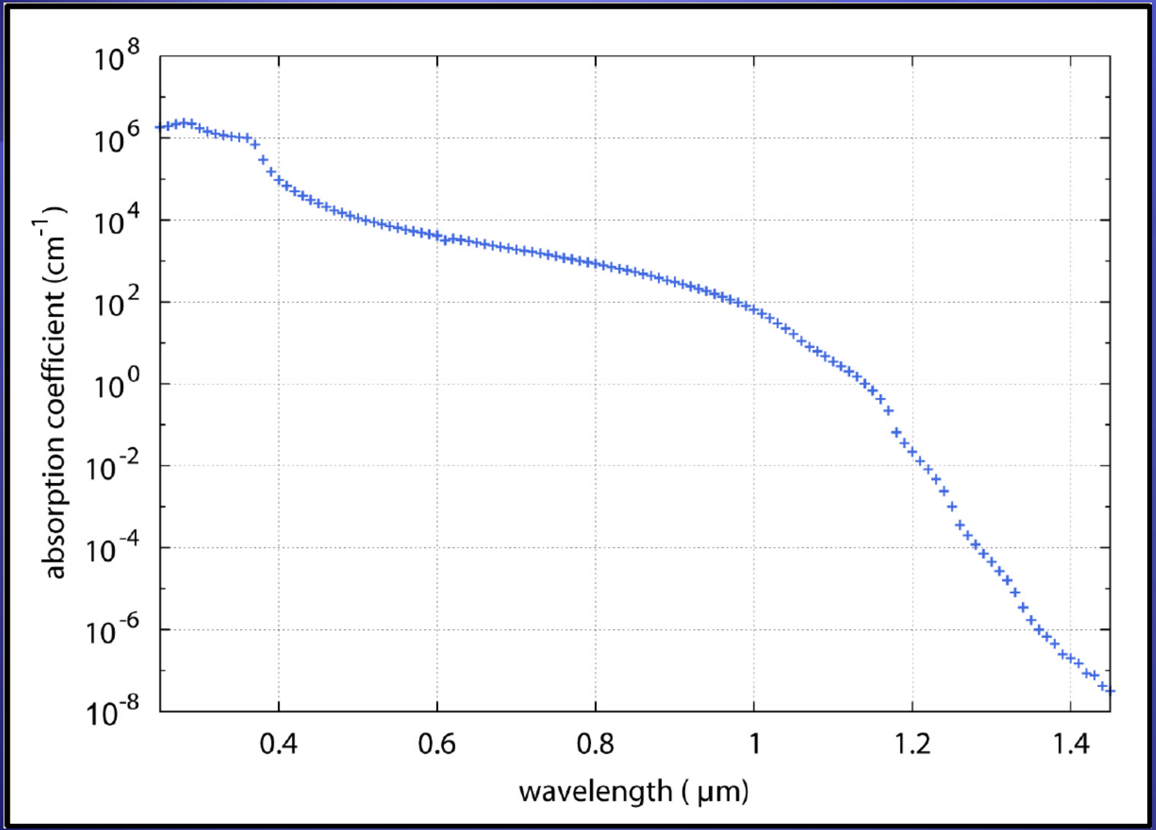


1E4

1/10

Silicon

low absorption @ 1550nm expected

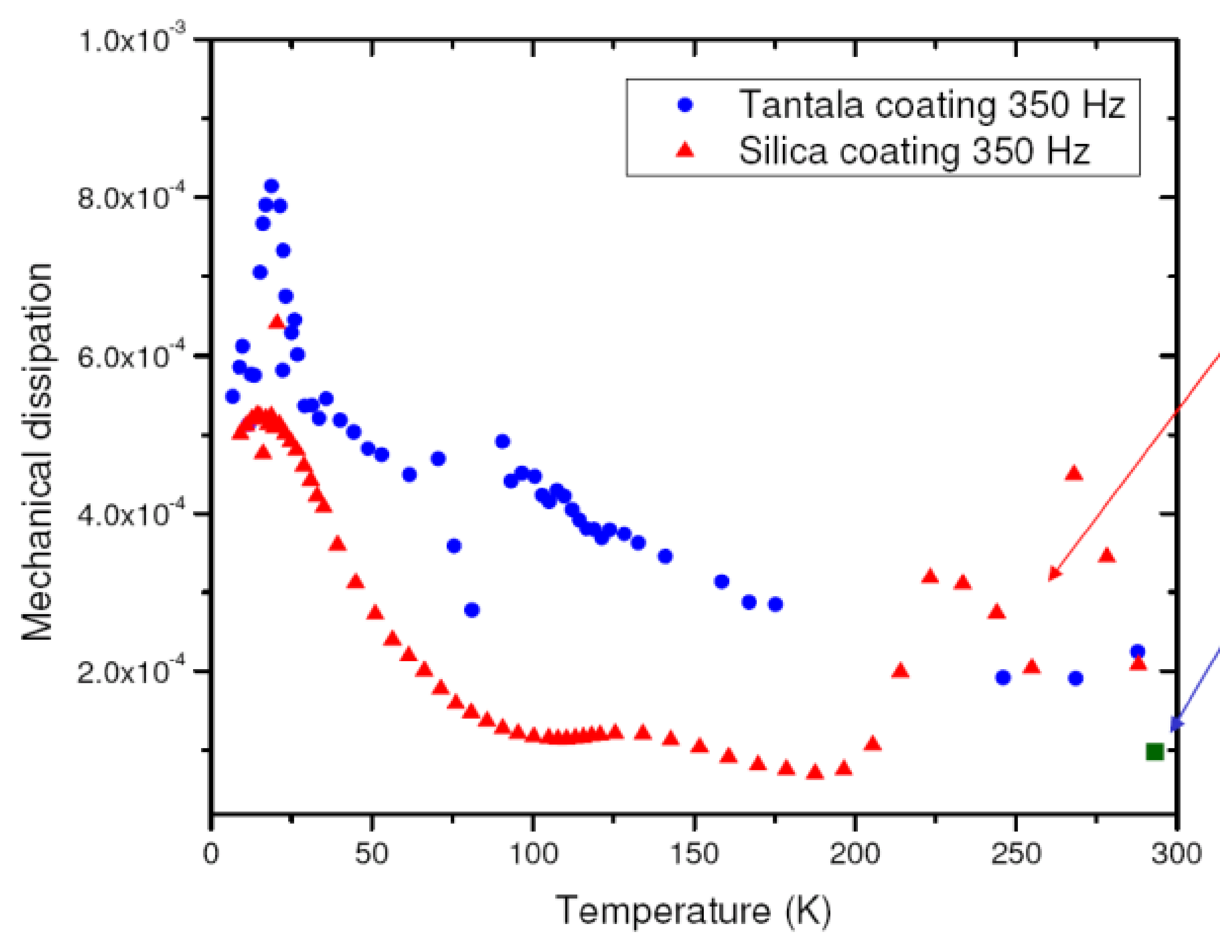


from M. Green and M. Keevers, Optical properties of intrinsic Silicon @ 300K, Progress in Photovoltaic research and Applications, Vol. 3, 189-192 (1995)

Max. Diameter currently 450mm

Wikipedia.com

Mechanical losses of the coatings

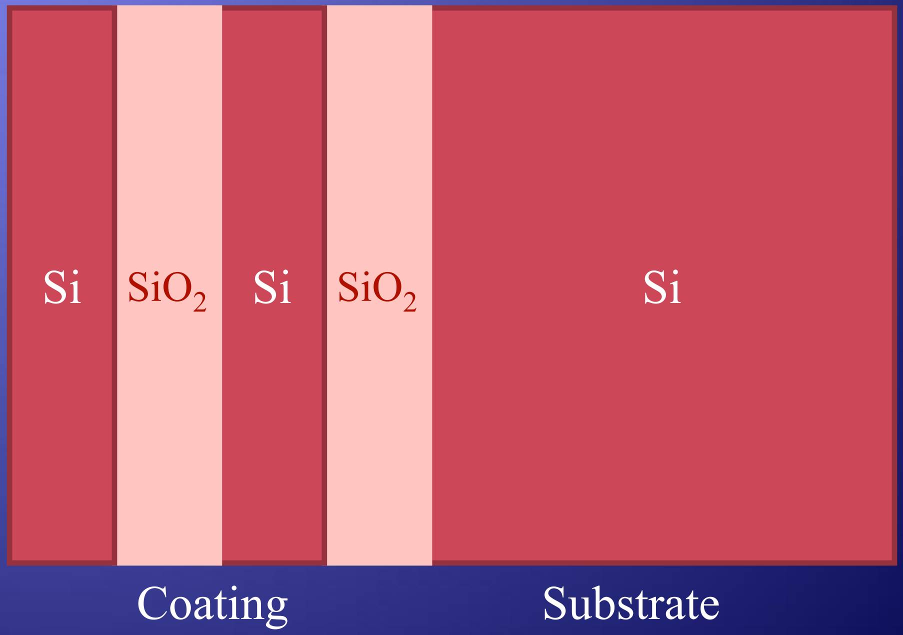


Scatter at higher temperatures, possibly due to loss into clamp.

Repeated room temperature measurement of silica coating loss.

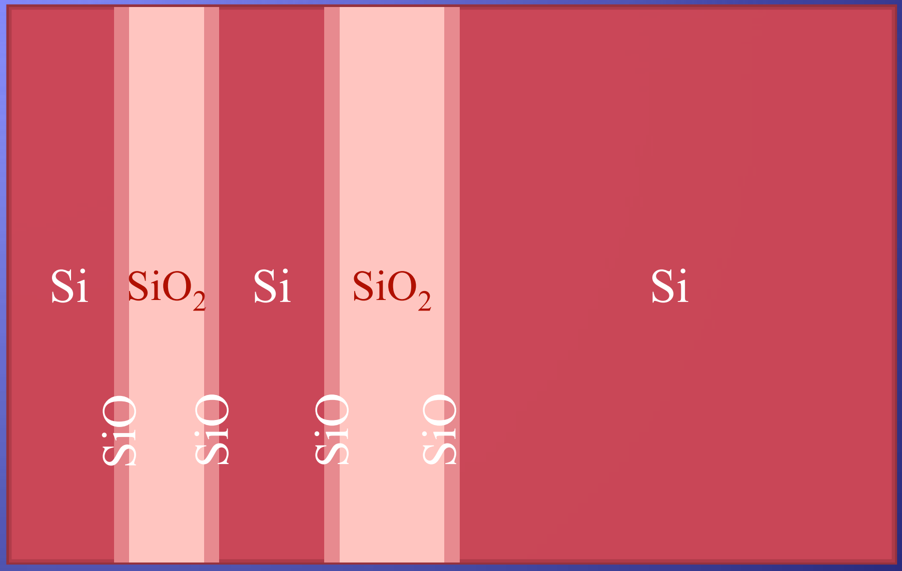
Coatings on Silicon

- Refractive index of Silicon @ 1550nm ~ 3.48 @ 300K
- Refractive Index of SiO_2 ~ 1.44
- fewer layers needed due to difference in refractive indeces



Diffusion of Oxygen

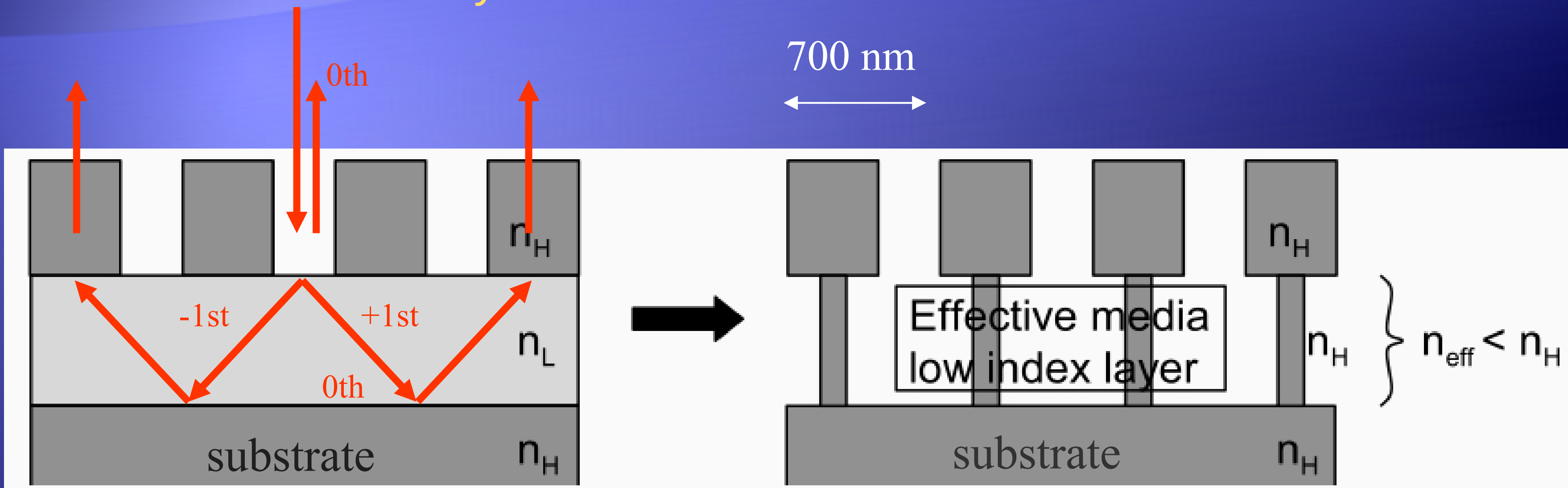
High absorption of SiO might be a problem for SiO_2 coatings on Silicon substrates



Nanostructured Surfaces

waveguide coatings

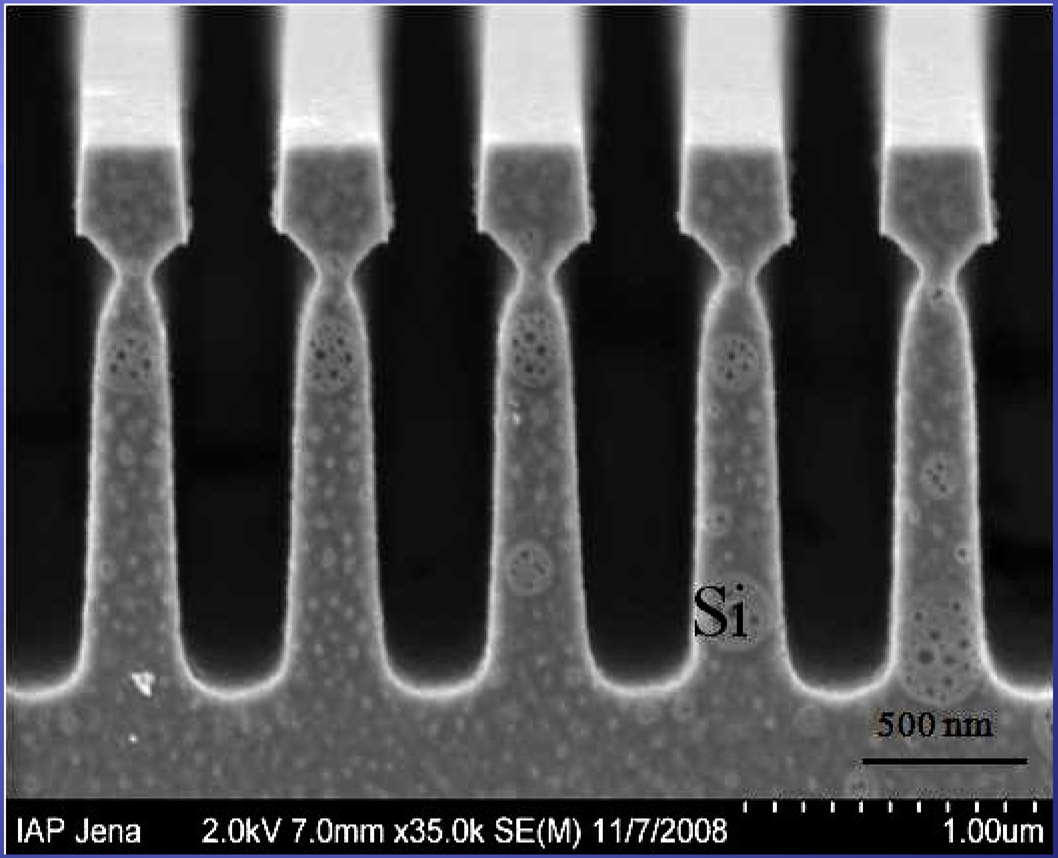
‘100%’ reflectivity



Monolithic 100% reflection “coating”

[Brückner *et al*., Opt. Lett., 33, 264 (2008)]

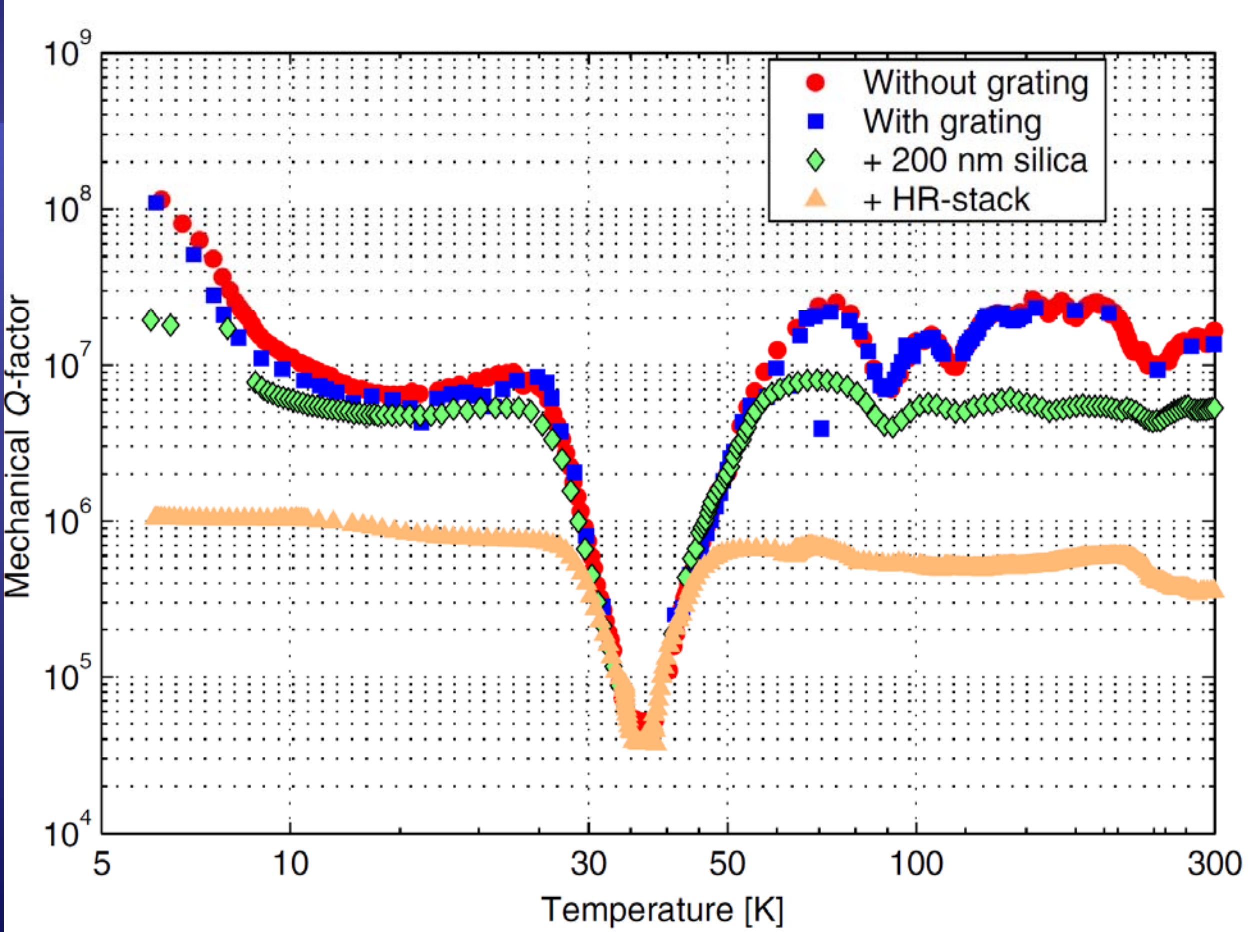
Promising new results

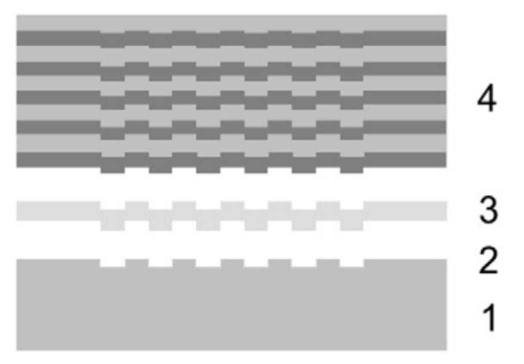


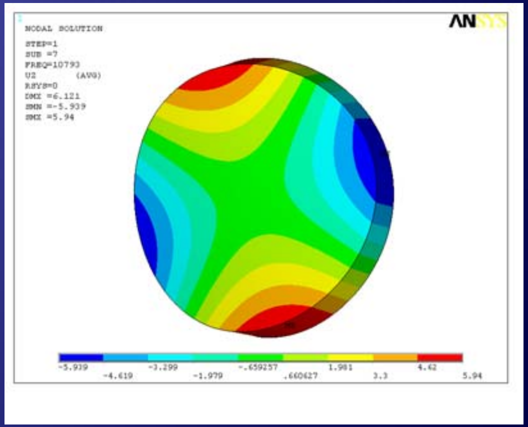
R > 99.8%, private communication, IAP Jena, R. Schnabel

Mechanical losses of gratings

Nawrodt et al., New Journal of Physics ***9 (2007) 225***







cryst. quartz, ∅ 3“ × 12 mm, 11670 Hz

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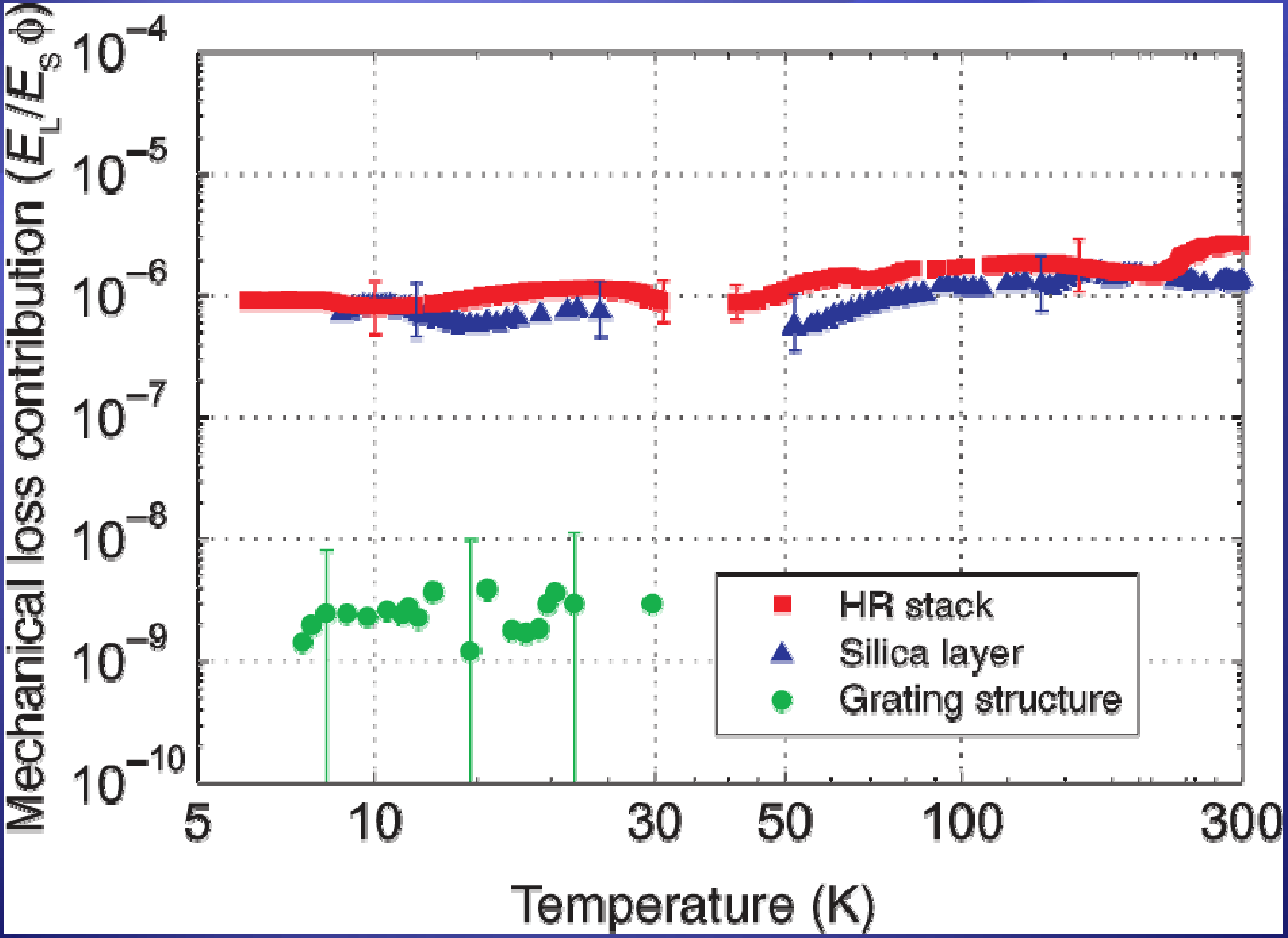
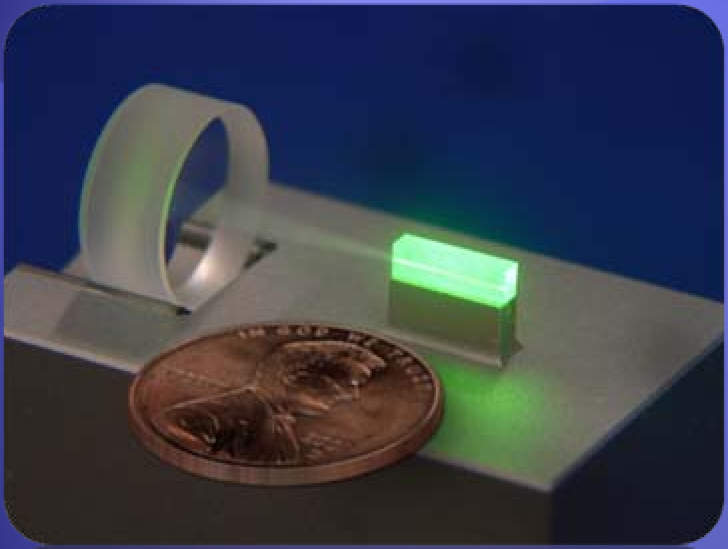
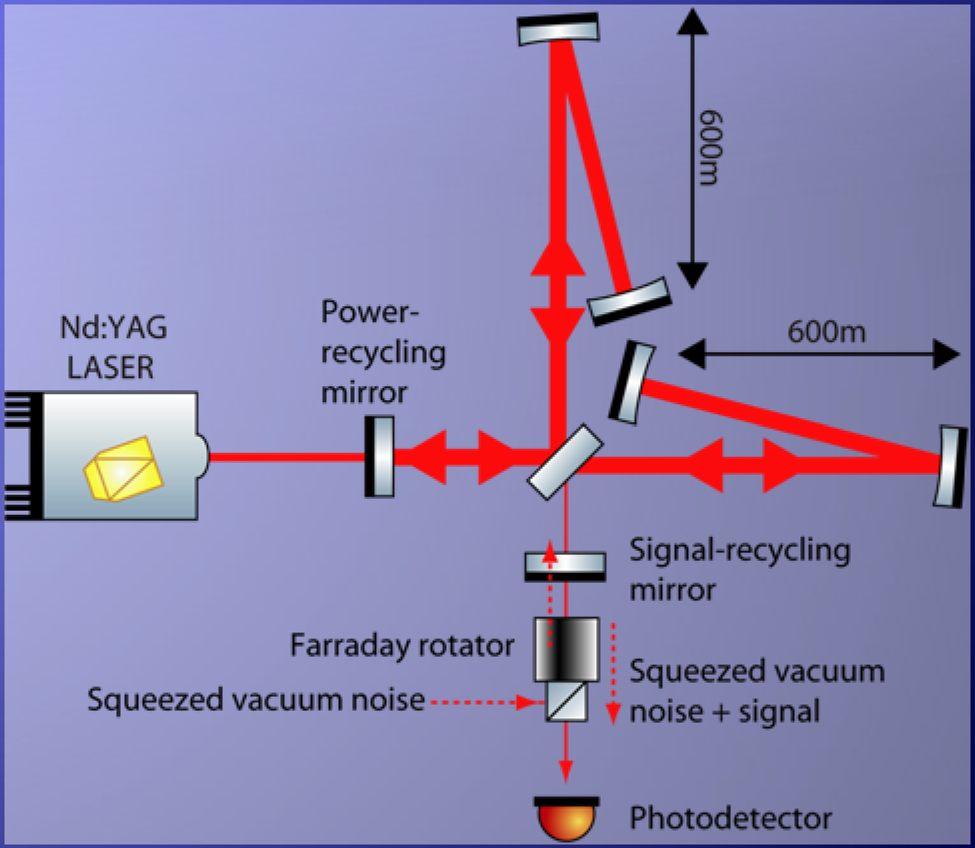
Extracted coating/grating losses



Nawrodt et al., New Journal of Physics ***9 (2007) 225***

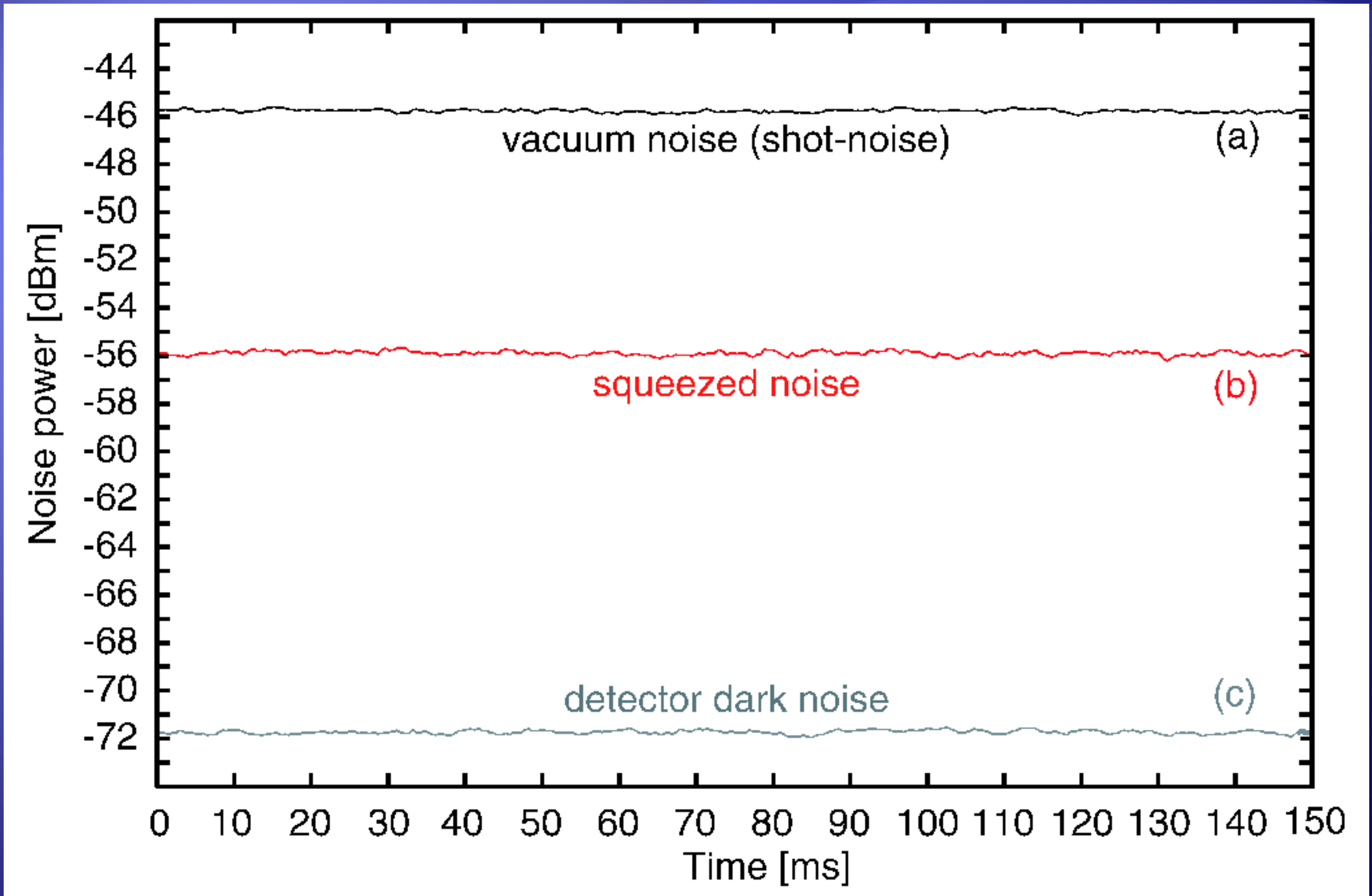
Squeezing




600m
Nd:YAG
LASER
Power-
recycling
mirror
600m
Signal-recycling
mirror
Farraday rotator
Squeezed vacuum noise
Squeezed vacuum
noise + signal
Photodetector

11.5dB @ 5MHz

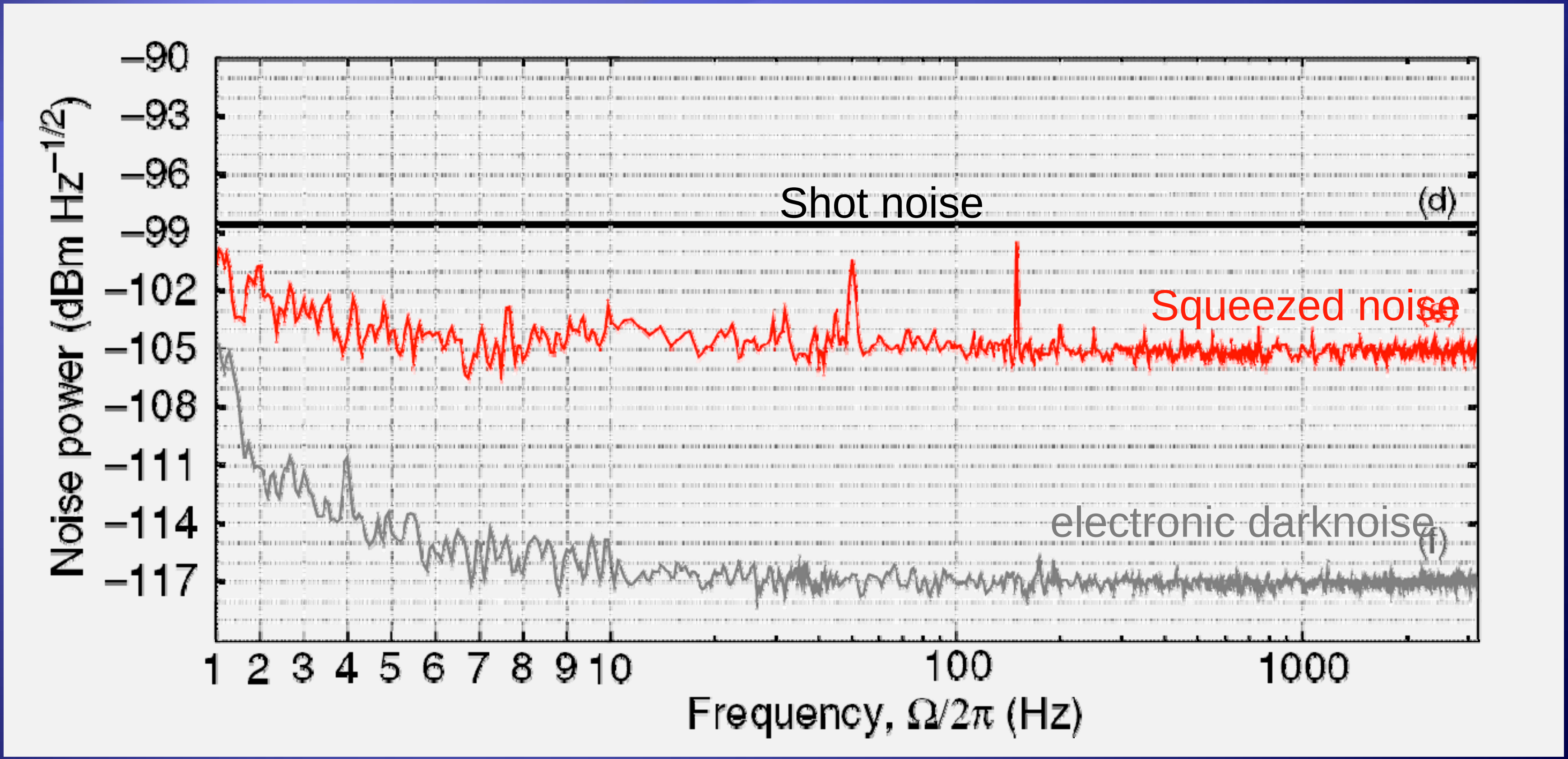
1064 nm



Vahlbruch et al. PRL 100, 033602 (2008)

Low frequency squeezing

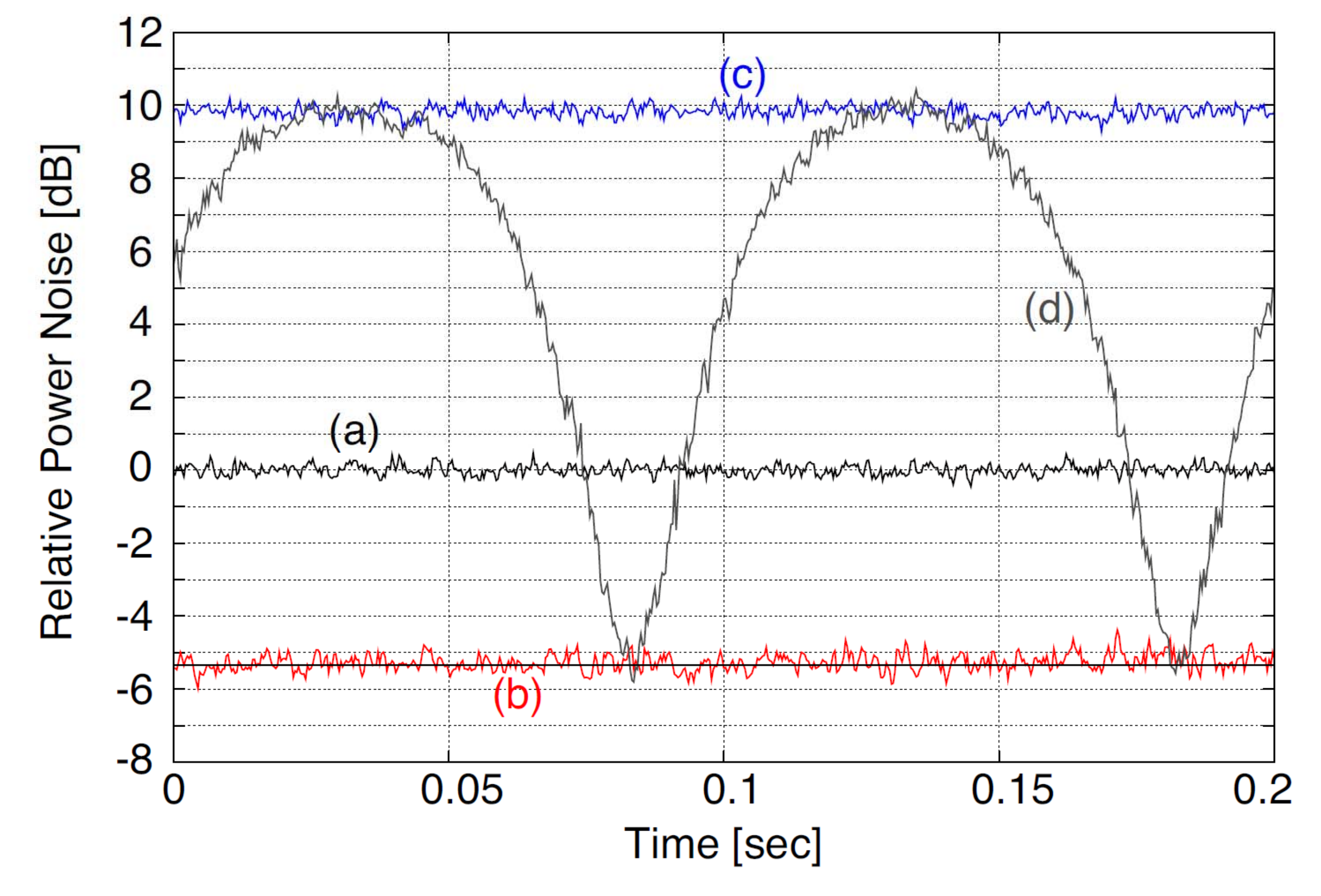
1064 nm



Chelkowski *et al.*, PRA 75, 043814 (2007)

Squeezing @ 1550 nm

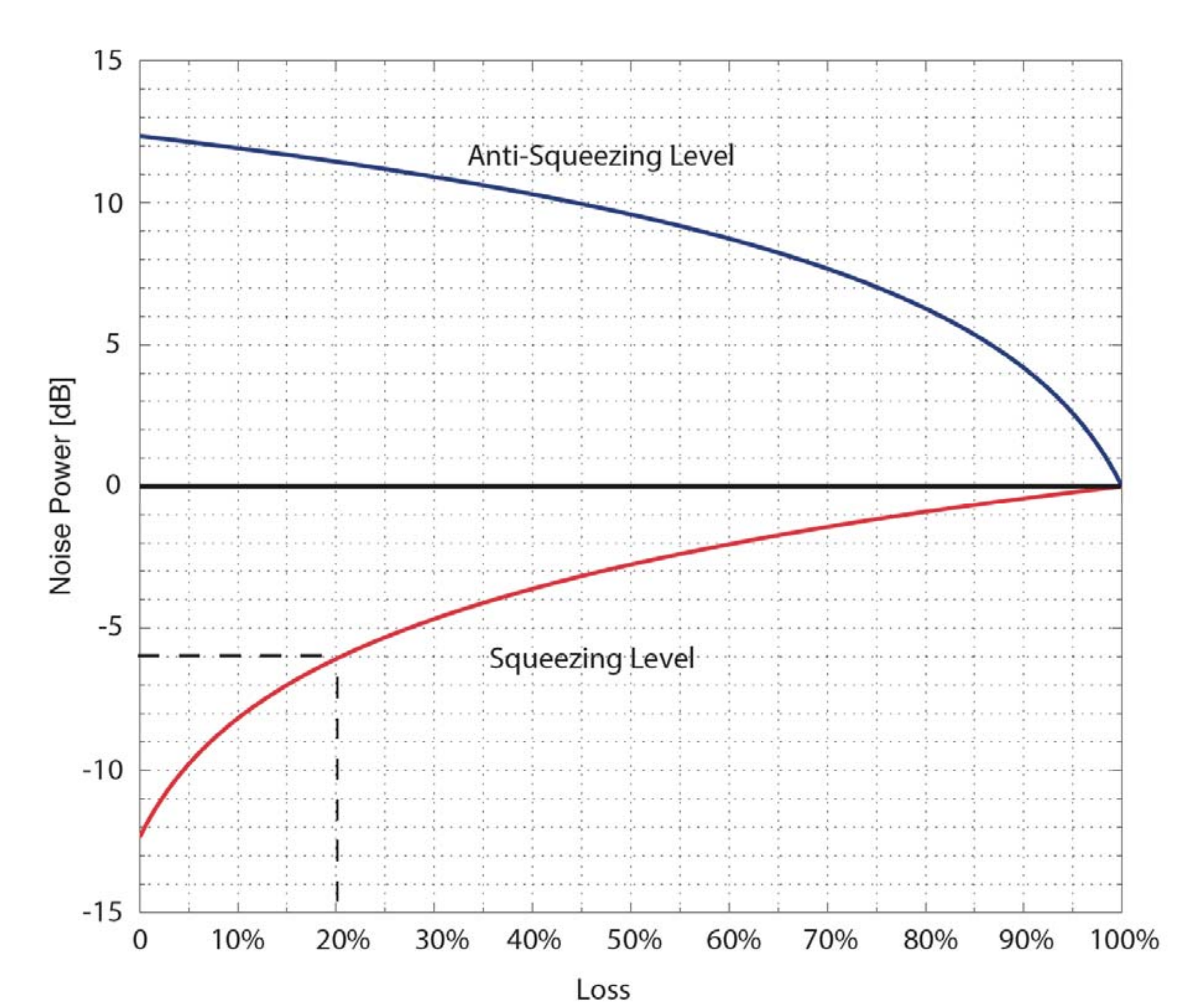
1550 nm



Mehmet et. al.: arXiv:0902.0670v1 [quant-ph]

Fragile Squeezed States

Influence of losses



Laser

available today, 1064 nm

- Solid state laser:
  - laser diode pumped solid state laser (AdvLIGO):
  - **210W** Nd:YAG, less than 12% in higher order modes, almost finished design for reliable long-term operation
  - 3 E-9 /sqrt(Hz) power stability @ 10Hz, rf noise: 1dB above SN of 100mA @ 9 MHz

- fibre laser:
  - ytterbium doped photonic crystal fiber amplifier using a single-frequency Nd:YAG non-planar ring oscillator seed source
  - **148W**, less than 8% in higher order modes
  - 13 November 2006 / Vol. 14, No. 23 / OPTICS EXPRESS 11071

Laser

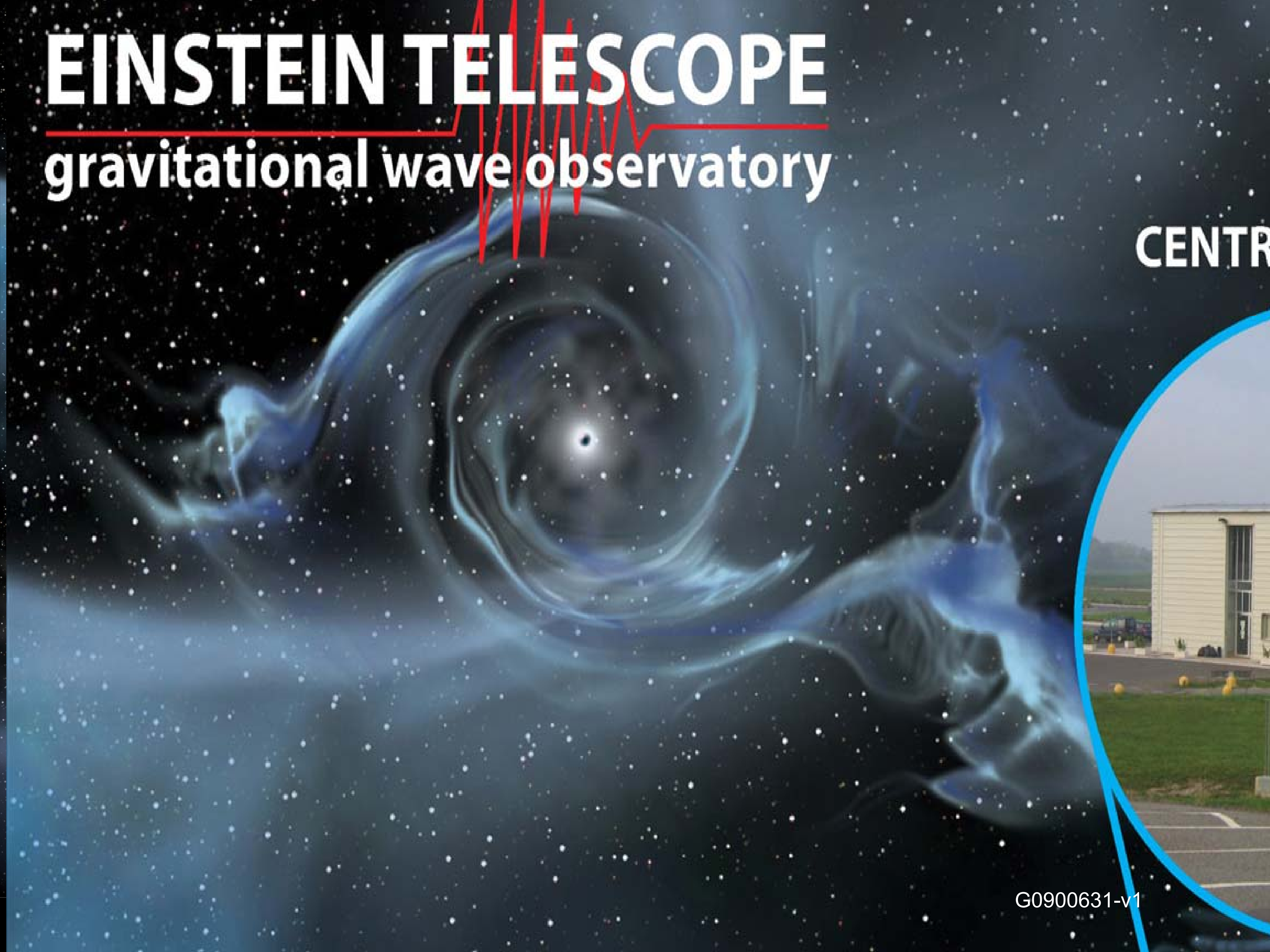
available today, 1550 nm

- Solid state laser:
  - -
- fibre laser:
  - Erbium fibre laser, ~2 W, poor reliability

Laser

plans

- 1064 nm:
  - Reach 1kW within next 5 years
  - RIN < 1 E-9 $/\sqrt{\text{Hz}}$
- 1550 nm:
  - 150 W within next few years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gravitational wave observatory
CENTR

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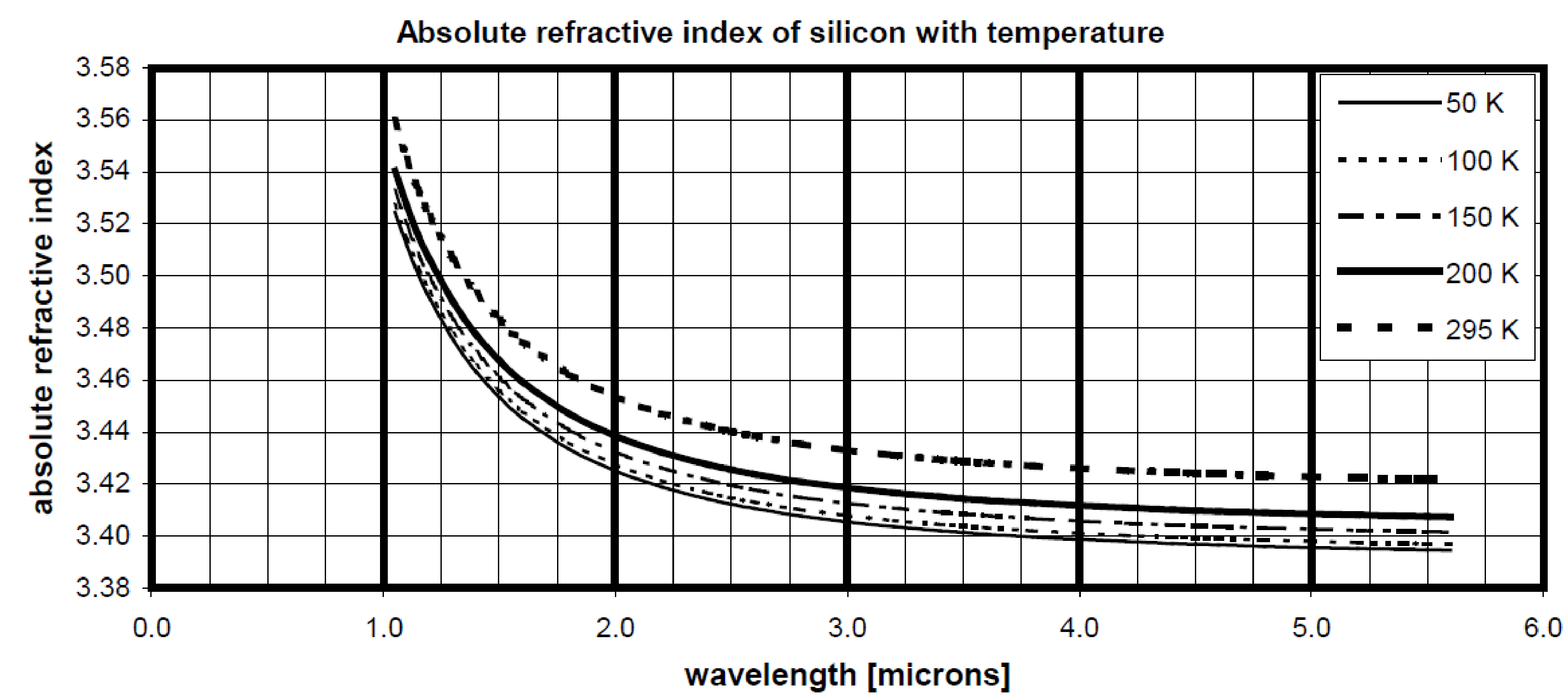
Refractive index of silicon



Temperature-dependent refractive index of silicon and germanium

Bradley J. Frey*, Douglas B. Leviton, Timothy J. Madison
NASA Goddard Space Flight Center, Greenbelt, MD 20771

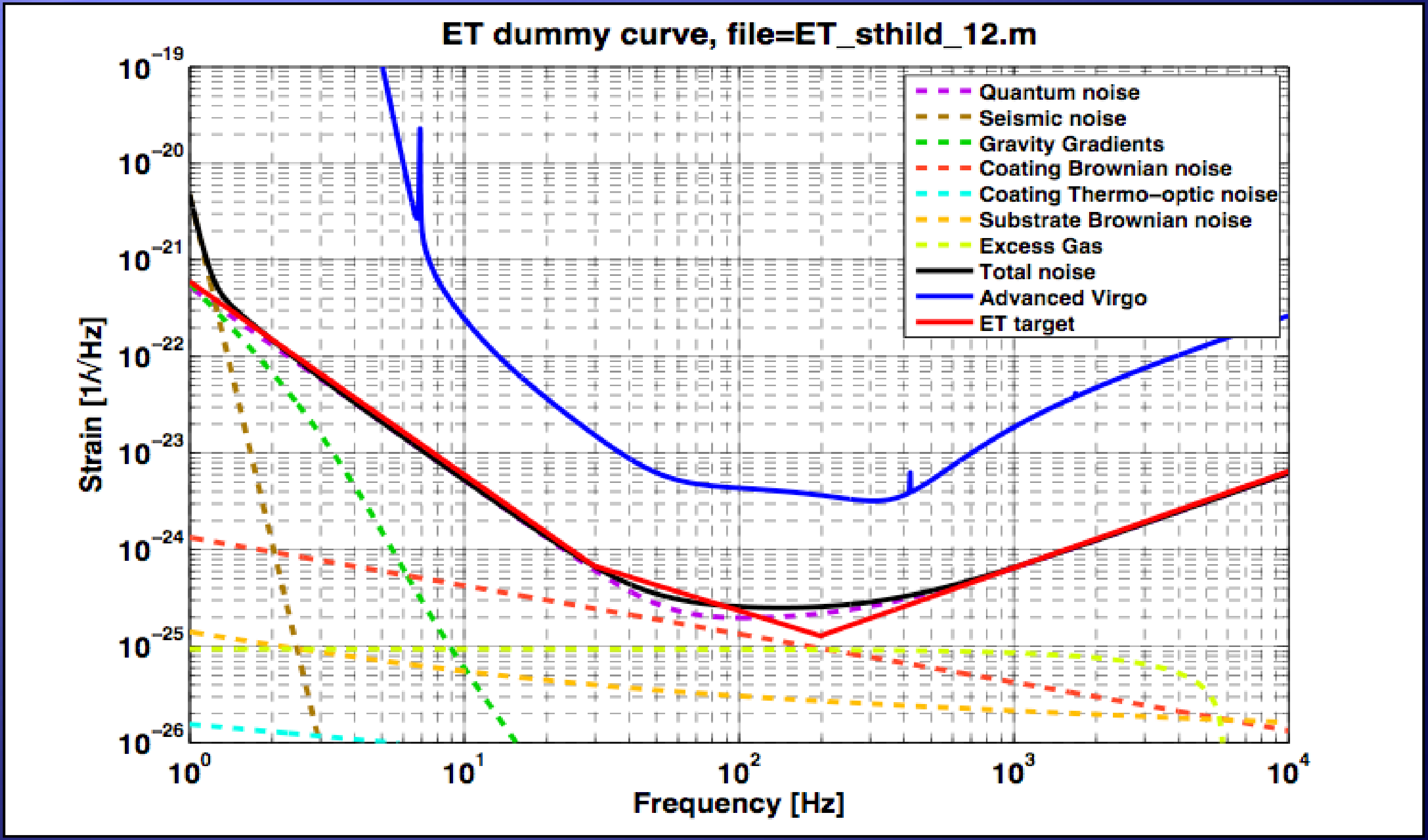
Refractive Index fused silica

http://www.sciner.com/Opticsland/FS.htm

Wavelength, µm	**0.2**	**0.22**	**0.25**	**0.3**	**0.32**	**0.36**	**0.4**	**0.45**	**0.5**	
Refractive Index	1.55051	1.52845	1.50745	1.48779	1.48274	1.47529	1.47012	1.46557	1.46233	
Wavelength, µm	0.55	0.59	0.60	0.65	0.7	0.75	0.8	0.85	0.9	
Refractive Index	1.46008	1.45846	1.45804	1.45653	1.45529	1.45424	1.45332	1.4525	1.45175	
Wavelength, µm	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0
Refractive Index	1.45042	1.4492	1.44805	1.44692	1.44462	1.44342	1.44217	1.44087	1.43951	1.43809

The brute force approach

Stefan Hild



S. Hild et al, http://arxiv.org/abs/0810.0604