R&D for a new concept of acoustic gravitational wave detector

Francesco Marin for the DUAL collaboration
Reading the differential response of two oscillators

- Both resonators are driven below resonance
- Both resonators are driven above resonance
- Intermediate GW broadband

DUAL working principle 2 – back-action reduction

\[ \omega_S \approx 0 \quad \omega_M \]

\[ \delta D = -\frac{F}{M}\omega^2 \quad \delta L = \frac{F}{M}(\omega_M^2 - \omega^2) \]

\[ \delta d = \frac{F}{M} \left[ -\frac{1}{\omega^2} + \frac{1}{\omega_M^2 - \omega^2} \right] \]

Experiment in the \(10^5-10^6\)Hz range:
T. Briant, GWADW, Elba, 2006

\[ \delta d = 0 \quad \text{for} \quad \omega = \omega_M/\sqrt{2} \]
- **Large area readout**

‘Local’ deformations due to Brownian noise and back-action must be avoided (i.e., avoid the effect of high order mechanical modes) → average over a large area readout

- **Mode selection**

A proper symmetric choice of the readout surface shape reduce the number of noisy acoustic modes within the frequency band of interest
Possible configurations - 1

Dual sphere
antenna pattern
isotropic

Dual cylinder
Antenna pattern:
like 2 IFOs rotated by 45°
the deformation of the inner surface has “opposite sign” for the first and the second quadrupolar mode
- configurations
- materials
- suspensions
- readout:  - optical
  - capacitive + SQUID
- cosmic rays effect (→ underground?)
- laser stabilization
- Demonstrator of  - large area readout
  - back-action reduction
  - mode selectivity
R&D program

- configurations
- materials
- suspensions
- readout: - optical
  - capacitive + SQUID
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- Demonstrator of - large area readout
  - back-action reduction
  - mode selectivity
Material requirements:

1. High cross section (i.e. maximize $Y^2/\rho$)
2. High quality factor ($Q/T > 10^8$)
3. High thermal conductivity (ultracryogenic operation?)
4. Availability low cost

Materials presently under investigation:

- Silicon
- Silicon Carbide
- Molybdenum

Main activity

- Measurement of Bonding losses
- Measurement of mechanical losses
- Bonding and Q measurements
Materials - 2

- Capacitive readout
- Nodal suspension
Infiltrated silicon carbide C-SiC: results

- Measured sample: disk
- Capacitive readout
Sintered silicon carbide: results

- **Cantilevers** of different thickness (0.3-0.5 mm) and length (5-10 cm)
- Both optical lever and capacitive readout
Si disk achieved results for $h=0.5$ mm

Thermoelastic damping dominated
Measurement of the Si bonding loss angle $\Phi_{bond}$

Aim of the experiment is to measure $\phi_{bond}(\omega)$ at low temperature.

Sample (in preparation, March '07) $h=0.9$ mm $<100>$ pure Si
Folded Fabry-Perot: FFP

relative shot noise limited displacement sensitivity: constant
relative freq. noise due to Brownian noise \( \propto \frac{1}{N} \)
relative freq. noise due to rad pressure noise \( \propto \frac{1}{N^2} \)

+ spatial correlation effects

Experimental prototype also as demonstrator of large area readout (based on photothermal effect reduction) and back-action reduction
Experimental Realization

- 2 oscillating slabs derived from two aluminum blocks with different thickness, different resonance frequencies
- 9 total mirrors disposed on the two faces of the oscillators
- Folded cavity built by attaching the two blocks
- Phase modulated Nd-YAG laser
- Laser frequency locked to the FFP cavity
- Input optical power modulated by an AOM used on the 0 order
  - light frequency insensitive to AM
- Light transmitted through a PM optical fiber
  - spatial mode unaffected by AOM)

- Extraction of the cavity frequency response to the AM of the light power by
demodulation of the error signal at the modulation frequency
9 mirror configuration:
- input mirror with $T_{\text{in}} = 130 \text{ ppm}$
- 8 mirrors with $T = T_{\text{out}} = 10 \text{ ppm}$
- Mode-Matching $= 93\%$
- coupling constant : $\zeta = + 0.8$
- Finesse: $F = 6000 \ (\Delta \nu = 120 \text{ kHz})$

$P_c = 1.5 \text{ W}$ for $P_{\text{in}} = 10 \text{ mW}$

Measured Optical Properties consistent with theoretical model
Thermal noise spectra evidence the mechanical modes coupled to the optical cavity:

- Three quasi-degenerate modes close to the second translation mode
- All modes add incoherently to the noise spectrum
Response to intensity modulation shows
- the mechanical resonances excited by
  radiation pressure, on top of
- the photothermal background

Photothermal background is reduced by the
wide-area readout scheme

Destructive interference in the response to
intensity modulation gives a proof of
principle demonstration of the reduction
of back-action
- R&D in progress to define the achievable sensitivity

- 2009: in case of positive R&D, begin of technical design study
Infiltrated silicon carbide C-SiC: results - 1

- Measured samples: two cantilevers of different thickness and length from Cesic (Germany)
- Different Carbon matrices
- Capacitive readout

![Graphs showing loss angle vs temperature for different thicknesses and annealing conditions]
- Response to mechanical excitation presents a large number of resonant frequencies for both oscillators.

- Comparison with simplified FEM model shows the properties of the resonant modes.

<table>
<thead>
<tr>
<th>Torsion Mode</th>
<th>Translation Mode</th>
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</thead>
<tbody>
<tr>
<td>Mass 1</td>
<td>Mass 2</td>
</tr>
<tr>
<td>316 Hz</td>
<td>795 Hz</td>
</tr>
<tr>
<td>743 Hz</td>
<td>1190 Hz</td>
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