In interferometric cryogenic gravitational wave detectors, there are plans to cool mirrors and their suspension systems (payloads) in order to reduce thermal noise, that is, one of the fundamental noise sources. Because of the large payload masses (several hundred kg in total) and their thermal isolation, a cooling time of several months is required. Their observation duty factor can be increased by reducing the cooling time. Our calculation shows that a high-emissivity coating (e.g., a diamond-like carbon (DLC) coating) can reduce the cooling time effectively by enhancing radiation heat transfer. Here, we have experimentally verified the effect of the DLC coating on the reduction of the cooling time.

**Abstract**

In interferometric cryogenic gravitational wave detectors, there are plans to cool mirrors and their suspension systems (payloads) in order to reduce thermal noise, that is, one of the fundamental noise sources. Because of the large payload masses (several hundred kg in total) and their thermal isolation, a cooling time of several months is required. Their observation duty factor can be increased by reducing the cooling time. Our calculation shows that a high-emissivity coating (e.g. a diamond-like carbon (DLC) coating) can reduce the cooling time effectively by enhancing radiation heat transfer. Here, we have experimentally verified the effect of the DLC coating on the reduction of the cooling time.

**1. Introduction**

- Gravitational waves (GWs)
  - Ripples of space time predicted by general relativity
  - Detection of GWs
    $\leftrightarrow$ Michelson interferometer can detect very small displacement of mirrors
- GWs change differential length of arms
- Displacement is proportional to arm length
- Mirrors suspended as test masses
- Cooling Time Reduction of KAGRA
  - Kamioka underground (small seismic motion)
  - $20\ K$ mirrors (reduce thermal noise)

**KAGRA cryostat**

**2. Method**

- Not coated
- Coated with DLC

Spheres made by S. Koike, R. Kobayashi (KEK)

- Aluminum sphere is suspended inside cryostat
- Kevlar (aramid) wires: thermal conduction negligible
- Radiation examined to verify effect of DLC coating

- New coating (duty factor increased by 5%)
- Assuming one maintenance per year

**3. Result**

\[
e = 0.06 \rightarrow 0.4 \times (T/300 \text{ K})
\]

Emissivity: 0.06 $\rightarrow$ 0.4 $\times$ (T/300 K)

Effect of DLC coating verified!

**4. Discussion**

- Time for one maintenance (days)

<table>
<thead>
<tr>
<th></th>
<th>No coating</th>
<th>With coating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling down</td>
<td>55</td>
<td>37</td>
</tr>
<tr>
<td>Heating up</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Maintenance</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>85</td>
<td>67</td>
</tr>
</tbody>
</table>

- Assuming one maintenance per year
  - Observation duty factor $77\% \rightarrow 82\%$

**5. Conclusion**

- Cooling time of KAGRA is calculated
- Experiment has verified effect of high-emissivity coating (duty factor increased by 5%)
- Another method to reduce cooling time in future
  - How to introduce heat switch being discussed

**Effect of DLC coating verified!**