Cooling Time Reduction of KAGRA Using a High-Emissivity Coating

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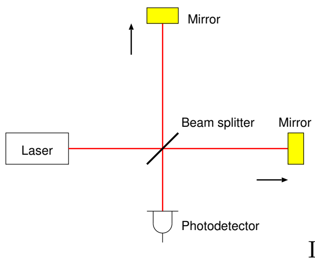
Abstract

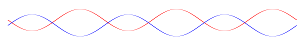
In interferometric cryogenic gravitational wave detectors, there are plans to cool mirrors and their suspension systems (payloads) in order to reduce thermal noise, that is, one of the fundamental noise sources. Because of the large payload masses (several hundred kg in total) and their thermal isolation, 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

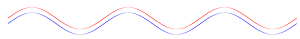
- ⋆ Gravitational waves (GWs)
  - Ripples of space time predicted by general relativity
- ⋆ Detection of GWs



← Michelson interferometer can detect very small displacement of mirrors



Light cancels.

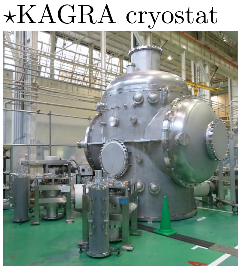


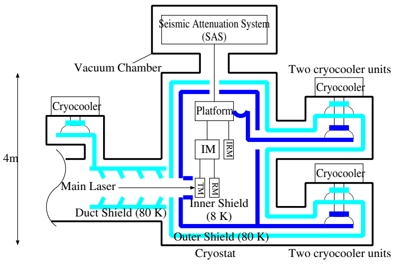
Light strengthens each other.

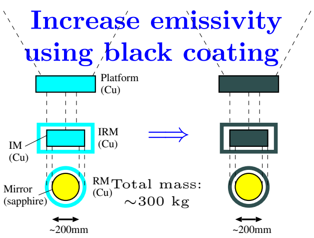
- Mirrors suspended as test masses
- GWs change differential length of arms
- Displacement is proportional to arm length

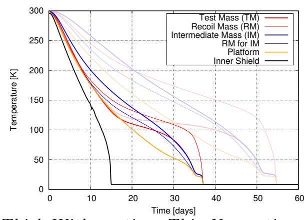
- ⋆ KAGRA:
  - Kamioka underground (small seismic motion)
  - 20 K mirrors (reduce thermal noise)

⋆KAGRA cryostat







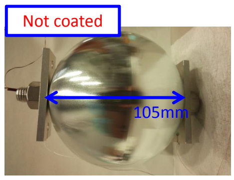


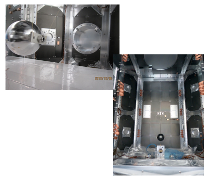
Thick:With coating, Thin:No coating

- ⋆ Cooling time reduction
  - Gas cooling
    - ∘ Mechanism to close and open holes of shields
  - Heat switch
    - ∘ Mechanism to contact and detach payloads
  - Radiation (first step) using DLC coating (Diamond Like Carbon)
    - ∘ High emissivity: $0.3 \times (T/300\ \mathrm{K})$ cf. no coating 0.03
    - ∘ Calculation of cooling 2 months → 1 month

Experimental verification necessary!

2. Method

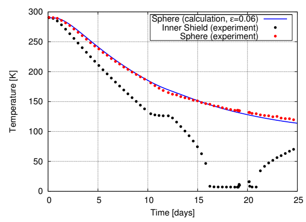


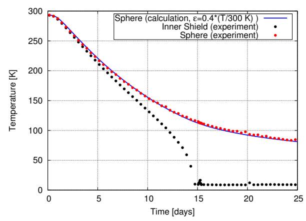


Spheres made by S.Koike, R.Kobayashi(KEK)

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

3. Result





Emissivity: 0.06 $\Longrightarrow$ $0.4 \times (T/300\ \mathrm{K})$

Effect of DLC coating verified !

4. Discussion

⋆ Time for one maintenance (days)

	No coating	With coating
Cooling down (calculation)	55	37
Heating up (using nitrogen gas, measured)	10	10
Maintenance (assumption)	20	20
Total	85	67

⋆ Assuming one maintenance per year

Observation duty factor 77 % ⟹ 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