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AlGaAs as a Third Generation Coating Material

Gregg Harry

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California Institute of Technology
LIGO Project - MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW 22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

AlGaAs coatings are crystalline coatings deposited not with ion beam sputtering but with molecular beam epitaxy. It has shown good results in quantum optomechanics experiments with similar, but not identical, requirements as gravitational wave test masses, including the need for low thermal noise, see |P110001.

The high and low index layers are formed by varying the concentration of aluminum and gallium. At 1064 nm, a 10%/90% ratio gives an n=3.425 while the reverse 90%/10% ratio gives n=3.00. This is a fairly close spacing compared to the silica and tantala values of 1.45 and 2.14. This would require over 100 layers to meet the aLIGO ETM transmission spec of 5 ppm, which is routine for epitaxial coatings (note that the total thickness of the multilayer at 1064 nm would only be 8.3 um given the large index of the films). AlGaAs is transparent from 0.6-3.0 nm, but the index spread is roughly the same across this band.

The primary advantage of AlGaAs is its improved mechanical loss and thus Brownian thermal noise. A loss angle of 2.5 X 10^{-5} for the entire coating has been measured at room temperature at around 150 Hz, see G1101273. This is about the same as amorphous silica coating layers and better than an order magnitude improvement over titania-doped tantala, the aLIGO high index material. AlGaAs also improves at cryogenic temperatures, having been measured at 4.5 X 10^{-6} at 10 K. This is contrary to silica and titania-tantala, which get worse as cooled up to a peak before improving. If these loss angles and indices from above could be obtained on aLIGO test masses without any other changes, it would result in a factor of 2 improvement in coating thermal noise and a BNS reach of over 250 Mpc.

AlGaAs has three main disadvantages and challenges; the need to be deposited on a lattice matched crystal, high thermoelastic damping, and relatively high absorption.

In order to form AlGaAs coatings, the coating must be created on a crystal with a symmetry and lattice spacing matched to the AlGaAs. AlGaAs coatings have been transferred onto silicon and silica substrates of up to 150 mm diameter. The thermal noise of the resulting optics has not been tested, however. Extending this to larger substrates and making the process reproducible and routine could potentially take a significant amount of research. Understanding and possibly improving any thermal noise changes could also be a research project.

AlGaAs, like many crystals, has a relatively high thermal expansion coefficient, see http://www.ioffe.ru/SVA/NSM/Semicond/AlGaAs/index.html. This coupled to higher specific heat and thermal conductivity than silica and titania-tantala makes the thermoelastic component of thermo-optic noise about 7 times as high compared to silica/titania-tantala, with a decrease in BNS range from 200 to 185 Mpc. It may be possible to reduce thermal conductivity by 50% or more by adjusting the aluminum content, see Piprek et al, Photonics Technology Letters, IEEE, Volume 10, Issue 1 (1998). Optimization of the coating thicknesses, as has been done for the aLIGO coating, is a possibility, but individual values of thermal expansion, specific heat, thermal conductivity, and mechanical loss will be needed for the separate low and high index versions of AlGaAs. This is a research project that can begin immediately.

Finally, at 1064 nm, AlGaAs coatings have been measured to have about 10 ppm absorption, see |G1101273. Roughness, and the resulting scatter, has been shown to be low, between 1 and 2 Angstroms. Little optimization has been done on absorption, however, and there are claims that it can be made with less than 1 ppm within a year.

Note that the above information includes information that is not to be shared outside the LSC.