論文の内容の要旨

Development of an optical absorption measurement system to characterize KAGRA sapphire mirrors and new high-reflectivity crystalline coatings.

(KAGRA サファイア鏡及び新たな高反射性結晶コーティングの評価のための光吸収測定システムの開発)

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KAGRA is the Japanese interferometric gravitational wave detector. It employs sapphire test masses and operates at cryogenic temperatures to reduce mirror thermal noise. Sapphire substrates optical absorption needs to be minimized to reduce the heat deposited in the mirrors and to make the cryogenic operation possible.

We developed and tested an optical absorption measurement system based on the so-called Photo-thermal Common-path Interferometer (PCI) technique: a high-power laser at 1064 nm periodically heats up the sample that we want to test; then a probe laser at 633 nm crosses the sample, and it is used to measure the absorption rate inside and on the surface of the sample.

For a better understanding of the system, its calibration, and alignment, we made some numerical simulations that reproduce the absorption signal readout. The simulations results are in good agreement with the measurements and can predict the absorption signal behavior when changing the experimental parameters.

We further improved the setup by designing, assembling and testing an upgraded version of the system. We set a large translation stage to measure KAGRA sapphire mirrors (22 cm in diameter and 15 cm in thickness). We made maps and studied the absorption structures inside the sapphire substrates. The sensitivity on sapphire bulks is better than 2 ppm/cm and the calibration is compliant with other laboratories. We are now able to measure the absorption continuously along the depth of the sample and to make 3D absorption maps. We found interesting absorption structures inside the crystal. This new information will help the maker to improve the quality of future sapphire crystals.

For future upgrades of KAGRA, high-reflectivity substrate-transferred AlGaAs crystalline coatings have been proposed. This new type of coatings will contribute to

reducing the coating thermal noise, which is currently a limitation at mid frequencies in the sensitivity curve.

In order to investigate the possibility to apply this new material to KAGRA, we characterized the optical performances of new large-area (2 inches-diameter) AlGaAs crystalline coatings. To measure the absorption map of the coating, we assembled and tested an additional infrared probe (1310 nm) in our PCI system, reaching a sensitivity better than 0.2 ppm. We found that the crystalline coating absorption is very uniform except some point defects. In collaboration with CNRS/LMA, we measured absorption, transmission, defects number, scattering maps, and surface roughness. We measured 2 samples, one is AlGaAs transferred on a fused silica substrate, and the other is AlGaAs transferred on a sapphire substrate. The coatings show excellent optical performances, in particular, the absorption (below 1 ppm) and the scattering (below 10 ppm) fulfill the requirements for KAGRA, but the defects number is higher than current amorphous coatings. In collaboration with MIT, we did a direct thermal noise measurement at room temperature. The result is that the crystalline coating thermal noise is a factor of 2 lower than the amorphous coatings used in present gravitational wave detectors.