Chapter 27 Cryogenic interferometry

1. Introduction

I will introduce the original idea of cryogenic interferometer and overview the reason of necessity, the obstacle to be defeated, technical challenges to be established and the overview of technical status.

1. Principle of cryogenic interferometry

Since lowering temperature of the mirror system assists to reduce thermal noise of a laser interferometer, cryogenic technique improves the sensitivity of detector. For example, the power spectrum of vibrational mode of the bulk mirror is proportional to its temperature and inversely proportional to its mechanical quality factor. If we reduce the temperature from room temperature 300K to cryogenic temperature 3K (which is not technically practical) without changing the mechnical loss, the thermal vibration amplitude simply decreases by one order. If the sensitivity of the interferometer is dictated only by this thermal noise, the adoption of cryogenic system is equivalent to increase the baseline length by one order, which is attractive to funding people. The cryogenic laser interfeorometer is assumed to cool only mirrors with leaving the vacuum tubes of laser beams in room temperature. This caused various technical problems that can be solved. The main study of cryogenic interferometry is the study of cryogenic mirror.

1. Main technical challenges

The most difficult problem is how to cool the mirror that is mechanically isolated and left quiet. Thermal radiation fails down under cryogenic temperature because the radiative power decreases in the fourth-power low. The radiative power at lower than 40 K becomes negligibly small. We take a method to cool the mirror by conduction through suspension fiber. The second problem is keeping mechanical quality factor at cryogenic temperature. The best material for mirror substrate is fused silica, which realizes homogenious best optical quality in the sense of transparency, good machining nature. However, the mechanical loss increases at cryogenic temperature. We have to find other material for cryogenic mirror. The candidates are silicon and sapphire crystal. Silicon is not transparent for 1 micron wavelength light. We take sapphire, the optical quality of which needs to be improved for our final objective. The third problem is to prevent heat from reaching the mirror system through vacuum tubes. The original idea to reduce the optical view solid angle was not the final solution. I show the current progress on this matter.

1. Prototype interferometers

We have confirmed the practicality of cryogenic interferometry by the development of the small scale Fabry-Perot interferometer in Kashiwa campus and the prototype interferometer CLIO at Kamioka underground.

1. Achievements for cryogenic mirror

Our challenge is supported by the development of cryocooler system. The presentation of the development of cryocooler is not the subject of this chapter but key technology of anti-vibration is explained. To realize the KAGRA cryogenic system, we need to develop various cryogenic elements that are under investigation. I would like to introduce some of them.

1. Future prospect

If we can realize the interferometer limited by thermal noise at cryogenic temperature, it means the sensitivity is actually quantum noise limited. And if laser power requirement is eased by quantum squeezing technique, we will be able to lower the mirror temperature more than present design. Cryogenic interferometry is compatible with quantum squeezing, which will promise more advaned interferometer in future.