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Measurment technology of plasma emission spectroscopy with X-ray microcalorimeters

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Microcalorimeters detect a small temperature rise due to the photoelectric absorption of an incident X-ray photon. Ideally, the energy resolution is determined by the fluctuation of phonons in the X-ray absorber. The phonons have an energy of kT, so that the energy resolution is calculated to be about dE = sqrt(C k T^2), where C is the heat capacity of the absorber. Therefore, a few eV energy resolution in the X-ray range below 10 keV can be realized with a small absorber less than ~1 mm at an extreme low temperature below ~0.1 K. This value is by about 20 times better than the Si semiconductor detectors, which enables us to resolve emission lines at different ionization states of impurity elements in plasmas, or to detect a few 100 km/s motion by the Doppler line shift. Especially in the X-ray astronomy field, microcalorimeters are being developed in the world as a promising detector for X-ray spectroscopy, because there is a strong demand to observe spatially extended sources, e.g., clusters of galaxies, supernova remnants, and the X-ray photons are limited as much as 10 c/s, both of which are not suitable for the wavelength dispersive detectors, such as gratings.

For example, Japanese X-ray astronomy satellite Suzaku (launch date July 2005) carries the XRS instrument developed by NASA/GSFC, ISAS/JAXA, etc, which utilizes array of 32 microcalorimeters each of which has a 640 micron square absorber. The XRS was cooled down to 0.06 K in orbit and confirmed 7 eV resolution for 5.9 keV X-rays from Fe55 calibration isotope, although the XRS could not observe any celestial objects due to the total loss of the liquid helium only by 1 month (3 years were expected) because of malfunction of the cryocooler. However, many of astronomical future missions in Japan, US, and Europe plan to have X-ray microcalorimeters.

Microcalimeters are also known to become a good spectrometer in the gamma-ray band or particle detection with an appropriate selection of absorbers. Furthermore improvement of energy resolution or response time can be achieved by choosing more sensitive thermometer, such as transition-edge sensor (TES) or magnetic calorimeters. Development of ground-based detectors are also active in the world, and 40 eV resolution for 110 keV gamma-ray and 2.4 eV resolution for 6 keV X-ray have been attained. Our group has demonstrated similar performance in our laboratory, too. We have also conducted an experiment of measuring a plasma emission from the test device of nuclear fusion, and X-ray diffraction measurement of crystals under extreme high-pressure environment. These topics are briefly introduced in my talk.