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Simulation of a multilayer thermal regulator for an optical reference

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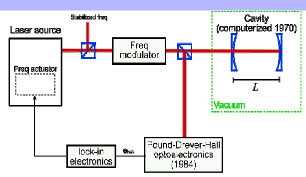
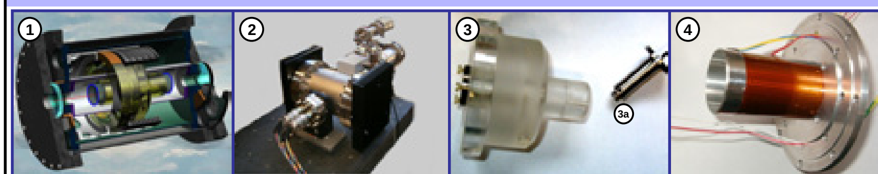
The research project under which the COMSOL simulations are performed deals with multilayer and fine thermal control of an optical reference cavity for space applications. The cavity, made of Ultra Low Expansion glass (Corning ULE), must be kept close to the zero-expansion temperature of the glass (close to room temperature). The target can only be met by active control, while leaving the cavity free of sensor and actuators. This is achieved by applying two concepts: thermal bath and reference thermal sink, the latter allowing the zero-expansion temperature to be reached by heaters in a wide range of environment temperature. Cavity thermal stability requirement is expected to lie close to 1 mK.

Principle (Interferometry)



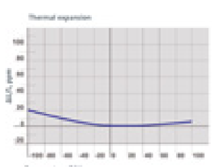
Lock in circuit keeps the laser frequency hooked to the length between cavity mirrors. Frequency stability directly depends on cavity length stability, to be guarantied by using ultra low expansion material ULE further stabilized in temperature by means of an active irradiative bath around the spacer between mirrors.

Implemented design



1. Artist view of the cavity, the cup-shaped support, the thermal bath and the vacuum chamber.
2. Current prototype used to test control system. It is equivalent to the final one except for the use of acrylic.
3. Acrylic cavity with capacitive sensor (3a) instead of mirrors to test thermal stability.
4. Inner aluminum shield with flexible heater and flexible sensor installed.

Corning ultralow expansion glass



$$CTE(\ ) = \frac{d}{d}\left(\frac{L}{L}\right)(\ )$$
$$= (\ - \_)$$

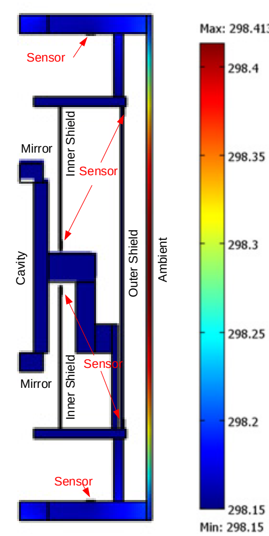
Assume coefficient of thermal expansion (CTE) of ULE to be a linear function of the temperature, crossing zero at some point called zero expansion temperature (ZET). Bounds of CTE provided by manufacturer are used to find the maximum value of .

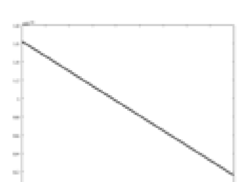
Sensitivity to disturbances

Disturbance [K]	Sensitivity [m/m/K]	Maximum disturbance for target [mK]
ThAmb	-6.3E-11	-15.873
ThExR	-4.1E-11	-24.3902
ThExL	-2.2E-09	-0.45455
ThInL	-3.6E-09	-0.27778
ThInR	-2.7E-09	-0.37037
ThoutL	-2.2E-09	-0.45455
ThoutR	-1.6E-08	-0.0625

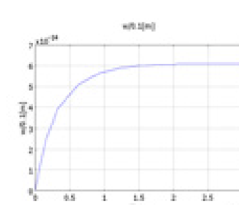
Comsol model

- The vacuum chamber exchange heat with the ambient trough convective heat exchange, and with the inner shields trough conduction and irradiation.
- The inner shields have some small portions at constant temperature, corresponding to the points in which the sensors are placed.
- The cavity is left without sensors and exchange heat by conduction and by irradiation.
- The cavity expansion is calculated from the temperature static solution by assuming the CTE depends on the temperature.





Step response of the cavity expansion for a step like variation of the ambient temperature.



Thermal expansion for errors on regulation error in sensor bottom sensor of the outer shield ranging fomr 10mK to 10mK.