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Study and development of silicon carbide stray light optical components for third generation gravitational wave detectors

Rudy Nahed, Olivier Dalverny, Antonino Chiummo, Marc Ferrato

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Problematic and research objectives

Problematic

Stray light is the light that does not follow the intended path reaching the detector [1]. Subsequently, stray light was considered as an issue because scattered light from surfaces other than the mirrors surface, such as the walls of the cavity, will carry information about the displacement of the wall that will recouple back with the main beam adding a stray light field to the unperturbed field inside the interferometer:

$$E_{total} = E_{in} + E_s = E_{in} + \sqrt{f_{sc}} E_{out} e^{i\theta_s(t)} \quad E_{total} = E_{in} \exp\left[\sqrt{f_{sc}} \frac{P_{out}}{P_{in}} (\cos \theta_s(t) + i \sin \theta_s(t))\right]$$

This final profile of the equation contains a real part and an imaginary part. In this sense, the real part represents the amplitude modulation induced $\frac{dP(t)}{P}$ and the imaginary part represents the phase modulation $n_\theta(t)$ [1]:

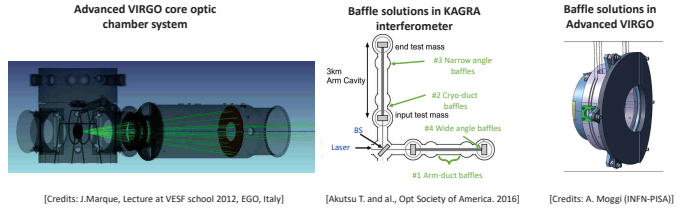
$$\frac{dP(t)}{P} = \sqrt{f_{sc}} \frac{P_{out}}{P_{in}} \cos \theta_s(t) \quad n_\theta(t) = \sqrt{f_{sc}} \frac{P_{out}}{P_{in}} \sin \theta_s(t)$$

Where E_s is the stray light field, E_{out} is the output field and θ_s is the phase angle that carries information about the scattered light.

Stray light in the current detectors is being reduced using light shades called « baffles ». In fact, the third generation detector will be using a very high power laser and the test masses will be subjected to a different temperature condition « cryogenic temperature ». Hence, we had to find a new material that can be a replacement for the current baffles and that can bear these conditions.

[1] Casuel B., and al., Opt Express. 2013 May 6; 21(9):10546-62

The chamber and the core optics with stray light



Research objectives

- Studying and analysing the thermal and mechanical behavior of SIC under interferometer conditions
- Studying the possibility of stray light reduction or elimination by using SIC as baffles

Methodology

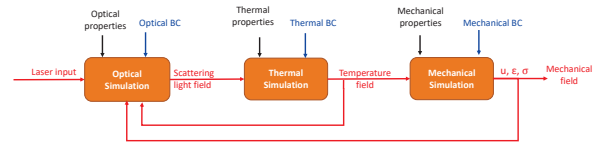
Multiple actions combining

- Optical characterization of the most promising materials (SiC, coated SiC...),
- Analysis of the thermal and thermomechanical changes induced by scattering light flux,
- Analysis of the influence of this changes on the scattering light process (if needed).

All the methodology could be applied to advanced virgo and/or third generation interferometer.

Key points : cryogenic temperature, high laser power density

Methodology of simulation



Optical Work

Optical work

- Material Requirement (SiC is a very promising candidate)
- Optical Characterization
 - Measuring the scattering at room temperature (Advanced VIRGO) and at cryogenic temperature (Einstein Telescope ET)
 - Same conditions for measuring the reflectivity of SiC

	Candidate			
Requirements	SS 304	Al-NiPW	SiC-CVD	SiC
Low Scattering	*(RT)	**	***	*
High Laser Induced Damage Threshold LIDT	*(RT)	**	***	***
High Thermal Conductivity	*	***	***	***
Low Thermal Expansion	**	*	***	***
High Stiffness	**	*	***	***
High Absorption Coefficient	*	***	***	**

*** Most promising candidate

Physical characterization of BOOSTEC® SiC

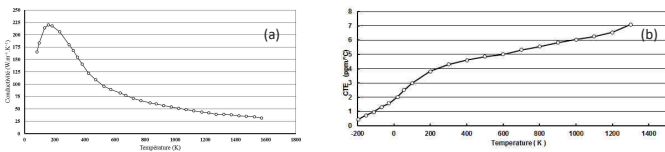


Fig: BOOSTEC® SiC experimental data as a function of the temperature, (a) thermal conductivity, (b) thermal expansion.

Optical characterization of 3 samples of MERSEN SiC

- TIS is calculated as the ratio between scattered output light and input light source
 - TIS measured as a function of the root mean square roughness
- $$TIS^* = \frac{P_{out}}{P_{in}} \quad TIS^{**} = 1 - \exp\left[-\left(\frac{4\pi\cos\theta_i\sigma}{\lambda}\right)^2\right]$$
- λ is the wavelength of the laser
σ is the surface roughness of the sample
θ_i is the incident angle (2°-3°)
(Bennett and Porteus)

Polished Sample	Process	Surface Roughness (nm)	TIS** (ppm)	TIS* (ppm)	Reflectivity at Brewster angle (%)	Reflectivity at 3 deg (%)
HIP BOOSTEC® SiC	Hot Isostatic Pressing	5	3487	2120	0.2	21
BOOSTEC® SiC polished (no HIP)	Pressureless sintering	2	558	4360	0.2	19
MERSEN SiC-CVD	Chemical Vapor Deposition	< 1	<<<	50	0.1	19

[V. Bavigadde, and A. Magazzu, EGO, Cascina (Italy)]

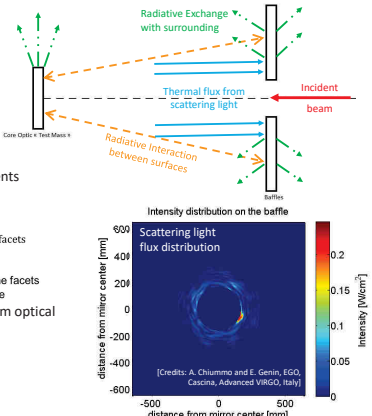
Conclusion & Next Steps

Conclusion

- BOOSTEC® SiC could be a good candidate for baffles for the third generation gravitational wave detectors regarding its thermal and mechanical properties.
- MERSEN SiC-CVD is a very promising material for this purpose due to its agreement with the optical requirements desired.
- Preliminary results of FE modeling interaction between the test mass and the baffle allowing us to study and analyze their temperature variation.

Thermal analysis

- Steady state thermal analysis
- Open cavity radiation
- View factor interaction
- Radiative interaction with surrounding
- Radiative interaction between the optical components
- Thermal flux distribution on the baffle obtained from optical simulations



Results

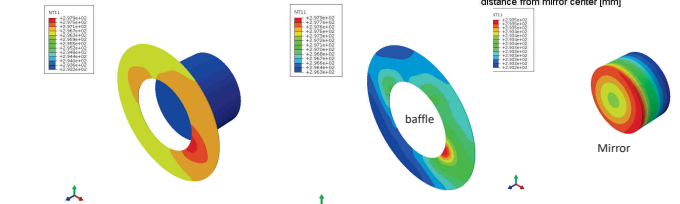


Fig: Temperature field over the baffle and the mirror with room temperature as surrounding one (K)

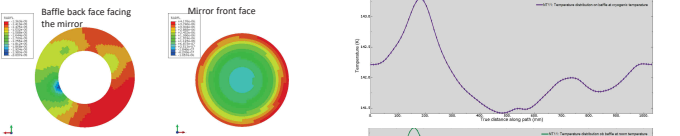


Fig: Radiation flux per unit area on baffle and mirror (W/mm²)

- Maximum temperature attained by SiC at room temperature is T = 297.8 K
- Maximum temperature attained by SiC at cryogenic temperature is T = 141.2 K
- Temperature variation at room temperature and cryogenic temperature is ΔT = 2 K

Fig: Baffle temperature distribution at room and cryogenic temperatures (K)