ASPERA Technology Forum on Mirrors and Lasers in Astroparticle Physics Infrastructures

Thursday, 20 October 2011 - Friday, 21 October 2011

EGO/Virgo Site

Scientific Programme

Mirrors & Auxiliary Optics

Coating

The dielectric coatings deposited on the core optics of gravitational waves detectors have excellent performances in term of absorption, scattering, spatial uniformity and thermal noise. Advanced detectors will have more stringent requirements, not only at 1064nm, but likely also at other wavelengths (532, 1030, 1530 or 1550nm). Multilayer-dielectric coatings for advanced detectors have to present a very low optical absorption (fractions of ppm) and minimize the mechanical dissipation with respect to the initial interferometers technology (loss angle ~10^{-4}). Particular requirements of the spatial uniformity on large surfaces (d=350mm) are dictated for advanced interferometers optics.

In VHE gamma-ray astronomy with imaging air Cherenkov telescopes (IACTs) the reflective layers are so far based on aluminium with simple protective layers such as SiO2 or Al2O3 on top. Replacing these single layer protective coatings by multilayer coatings or even using mirrors with purely dielectric coatings in the future will help to increase the reflectance in the wavelength regime of interest (300-600 nm), to suppress unwanted night-sky background and to reduce the loss of reflectance of the mirrors over time. This coatings need to be applied on large surfaces (up to $2m^2$), at low substrate temperatures, considering that many modern mirror substrates are glued sandwich structures, and at comparatively low cost.

Polishing

The micro-roughness of the mirrors is a key feature to enhance both the power in the detectors and the finesse of Fabry-Perot cavities. Complex requirements, based on spatial-frequency modelling through the simulation of the overall interferometer performances, are dictated for advanced detectors. New technologies from the industry, as Ion Beam Figuring, have demonstrated to match future expectations, but at a very high cost.

Sandwich Structures

In current IACTs, the mirrors are made from direct-figuring techniques such as full-glass polishing or Aluminum diamond milling. Considering the huge mirror area needed for the next IACT projects, the trend is to employ less labour-intensive and time-consuming replica technologies. These types of mirrors have a sandwich-like structure based on commercial float-glass sheets since the surface roughness is in general sufficiently smooth to reach the imaging properties required by IACTs. Modern technologies use thin glass sheets
cold- and/or hot- slumped on a precise mold, than glued to a backing structure such as aluminium honeycomb or glass fibre or carbon fibre composite materials.
This approach should provide also a reduction of the weight and cost while increasing the area of the individual segments. In addition, methods to form sufficiently smooth surfaces from epoxy and other materials are under investigation. In case of strong radii of curvature or very strong aspherical surfaces, the use of mirrors replicated by Nickel electroforming is investigated as an alternative method.

Flatness

The low spatial frequencies defects (below $1mm^{-1}$) of the mirrors are also important as it defines the spatial distribution of the light. It is a matter for larger and larger optics (35cm currently, 50-60 cm for next generation interferometers) used in gravitational waves detectors. New techniques as "corrective coatings" could be an asset in the future.

Deformation

Even if substrates and coatings have less than 1ppm absorption, the optics is affected by thermal-optic and thermal-elastic effects which can degrade the performance of the detectors.

Radiative heating and radiative cooling techniques, always more accurate, allow correcting the wavefront aberrations by getting more spatially uniform the temperature distribution inside the substrates. Additional R&D is required to realize, for instance, CO_2 scanning systems or other kinds of adaptive optics systems in the IR.

Aging

Even if the optics is located in a vacuum tank, with very short period in air for maintenance purpose, their performances in terms of scattering and absorption in particular can decrease over long periods. Better infrastructures and handling techniques are required to lower possible external pollution (clean room class 1 over the integration period and maintenance operations).

IACTs are usually not protected by domes, the mirrors are exposed to environmental influences all year round. As well the substrates as the reflective coatings need to maintain their optical properties under the long-term influences of temperature changes, rain, UV light, or bird faeces.

Optical metrology

Best performing optics means best performing metrology also: wavefront surface, absorption, birefringence and scattering measurements over large diameters (35cm for current detectors, and up to 60cm for future detectors).

Optical sensors

A wide range of optical sensors are used for controls and monitoring for HeNe, Nd:YAG and CO_2 lasers: photodiodes, quadrant photodiodes, PSDs, cameras, wave front sensors,... Very high quantum efficiency on large area or off-axis Hartmann sensors with accuracy better than lambda /1000 require further research and development.

Optical and thermo-optical properties

In order to cope with very faint effects that can affect the performance of the system, accurate knowledge about the optical properties (in particular thermo-optical) of the substrates/coatings is mandatory (for instance, sub-ppm absorption measurement). This is valid for Faraday and EOM crystals, fused silica glass and material used to make the dielectric coatings.

High power auxiliary optics

High laser ligth power in the future GW interferometers requires the development of active optical components (Faradays, EOMs,...) capable to sustain high intensity beams with small thermal lsensing effects. New materials and new technologies are under test.

Lasers
CO2 lasers

CO2 lasers are used to correct for thermal effects induced by absorption of the Nd:YAG. High power, better reliability, power stabilisation (RIN<10-7 Hz-1/2) and power spatial distribution (TEM00 content > 99%) are key points for such systems.

Fibre lasers

Fibre lasers offer the opportunity to further increase the power at the input of advanced interferometers while keeping the system compact and immune from environmental conditions. On the other hand, their performance in terms of Relative Intensity Noise, frequency noise and phase noise has to be improved (RIN<10-9 Hz-1/2, frequency noise < 10-3 Hz/Hz-1/2) before they can be used in place of the current solid-state lasers.

Solid State Lasers

Current state and future of Nd-Yag… lasers for GW detection.

Laser technology

Gravitational wave interferometers are run 24/7, with overall duty cycle > 80%; the laser sub-system cannot be a failure point of the detector and a duty cycle of about 100% is requested for this specific sub-system. In particular, laser diodes long term (> 2 years) performances are mandatory.

Simulation codes (FINESSE, DarkF, and Siesta)

New optical simulation softwares, based on FFT propagation, frequency domain and Hermite-Gauss modes, have been developed in the gravitational wave community to design and characterize the optics, as well as the controls of the multiple coupled optical cavities. These simulations cope with the necessity to translate control requirements in term of optical requirements, in particular mirrors flatness and roughness. Some effects as radiation pressure are not yet implemented in these codes.
No, various codes insure a better cross-check of the results. Moreover, a code as DarkF is the reference for FFT code but is not very much user friendly. Some are more user friendly (less specific to a particular optical configuration) but requires a higher computation time.