Silica Final Lenses under HIPER Laser Fusion Reactor Operation Conditions

Introduction
We have studied the thermo-mechanical response and atomistic degradation of final lenses in HIPER project. Final silica lenses are squares of 75 × 75 cm² with a thickness of 5 cm. There are two scenarios where lenses are located at 8 m from the centre:

- HIPER 4a, bunches of 100 shots (maximum 5 DT shots <48 MJ at ≈0.1 Hz). No blanket in chamber geometry.
- HIPER 4b, continuous mode with shots ≈50 MJ at 10 Hz to generate 0.5 GW. Liquid metal blanket in chamber design.

Irradiation conditions
From the spectra of a 48 MJ shock ignition target from LASNEX [1,2], we have calculated based on our reactor designs realistic: neutron and γ-ray doses with MCNPX; ion energy deposition with SRIM; and X-ray energy deposition with appropriate absorption coefficients. Ion and X-ray deposit most of their energy density in the first 10 μm.

Experimental facility HIPER 4a (operation in bunch mode for scientific viability) [3]

Geometry
The reactor chamber is a spherical steel chamber of 5 m inner radius with 10 cm thickness and 1 mm W armor. 48 laser beam lines are used for symmetrical illumination of direct targets. Final silica transmission lenses are located at 8 m from the chamber centre. Final lens dimensions are 75 × 75 × 5 cm³. Radiation shielding are showed in the figure above.

Thermo-mechanical response
Finite element solver ASTER CODE is used to estimate temperature, stresses and deformation in final lenses. Ions must be mitigated to avoid melting. X-rays are tolerable, they lead to maximum compression stresses of 0.65 MPa, corresponding to maximum temperature increase below 15 K in one shot. Neutrons and γ-rays lead to negligible thermo-mechanical effects in bunch mode.

Absorption by colour centres [4]
ODC and E' defects increase with each pulse due to neutron and γ-ray irradiation, producing laser absorption at λ=350 nm. Even at RT absorption remains below 5% in the lifetime of HIPER 4a (<6000 shots). Anyway thermal annealing (see inset) restores lens transparency.

Demo Power Plant HIPER 4b (operation in continuous mode for commercial demonstration)

Geometry
For the power plant concept we have developed a chamber of 6.5 m inner radius provided with a metal liquid blanket (thickness 1m). Final silica transmission lenses are located at 8 m from the chamber centre, as in the previous case. Final lens dimensions are 75 × 75 × 5 cm³. Realistic radiation fluxes have been calculated making use of this geometry.

Thermo-mechanical response
In continuous mode the role of neutrons and γ-rays are of paramount importance. 3D finite element calculations show that a steady state situation is reached very fast (=25000 shots equivalent to ≈40 min at 10 Hz).

It is remarkable the appearance of a thermal gradient along both the axial and radial directions of the lens. The consequence is a varying refractive index. In addition note, that side facing the target reaches higher temperature than the back side due to direct exposure to X-rays. As in the previous case ions must be mitigated. The associated stress do not induce deleterious effects in any case.

Absorption by colour centres
In steady state the lens temperature is higher that 800 K, therefore defect annealing is very efficient resulting in low optical absorption.

Conclusions
- Silica lenses withstand irradiation conditions of HIPER 4a. Colour centre generation leads to higher absorption, however, the lens lifetime exceeds HIPER 4a operation time.
- Thermal gradients appear inside the lenses under HIPER 4b conditions with detrimental effects such as aberrations, focal length change and operation complexity.

REFERENCES:

The authors thank the Spanish Ministry of Science and Innovation for economical support via the ACI-PROMOCIA program 2003.