Damage testing of reflective coatings in Astra TA2

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Introduction

The maximum power of a CPA laser pulse for a given beam size is limited by the laser-induced damage thresholds of the reflective surfaces of optical components used after pulse compression. When developing a laser system it is always desirable to keep the beam size as small as possible in order to minimise the costs associated with using larger optics. Therefore, it is important to quantify the damage threshold of various reflective coatings so that the beam size can be minimised while keeping the risk of damaging optics as low as possible.

There are two main causes of laser-induced damage to optical coatings. One is the thermal effects caused by absorption of laser energy, raising the temperature of the coating and the other is direct ionisation by the intense pulse [1,2]. The thermal mechanism requires a significant energy transfer between the laser and the coating/substrate and hence it is dominant for long pulse (> ps), high energy lasers. In this regime the damage threshold is best expressed in terms of the fluence. For shorter pulse (<100 fs) lasers which contain less energy for the same peak power, the influence of ionization dominates which is dependant on peak intensity.

Very little work has been published on damage testing of reflective coatings with femtosecond laser sources. This study aims to provide data on the damage thresholds of coatings commonly used for optics on the Astra Gemini laser system.

Experimental setup

The schematic of the experimental setup is shown in figure 1. We used a Ti-Sapphire laser beam with a central wavelength of 800 nm and pulse duration of 50 fs. The beam was focussed in vacuum onto the samples with an angle of incidence of 45° to create an elliptical spot with minor and major axes of 5 mm and 7 mm respectively. The reflected beam was split onto two diagnostics one of which measured the reflected energy and the other imaged the near field at the point of interaction with the target. An earlier split off of the beam was used to image a near field at the same point as seen by the target to allow comparison of the incident and reflected beams. This also allowed the intensity of hotspots in the beam to be calculated. The energy in the pulse was variable in the range 4-400 mJ to control the mean intensity on target between 3×10^{11} and 3×10^{13} W/cm^2.

The target was illuminated with a local white light source as well as the 532 nm alignment beam and a camera was viewed the target in real time to show any visible damage caused by shots.

Targets

The following coatings were tested in this study:

- Protected Silver
- Protected Gold
- Dielectric coating with >99% reflection for 45° interactions over 750-850 nm
- Gold gratings with 900, 1000 and 1100 rulings/mm

In the first instance the mirror targets were irradiated at 45° with a p-polarized laser. The gratings were placed with the rulings in the horizontal plane and angled at 24° horizontally from normal and 5° out of the plane to match the beam layout they are intended for. A second test was conducted for the dielectric and grating samples using a half-waveplate to achieve s-polarization.

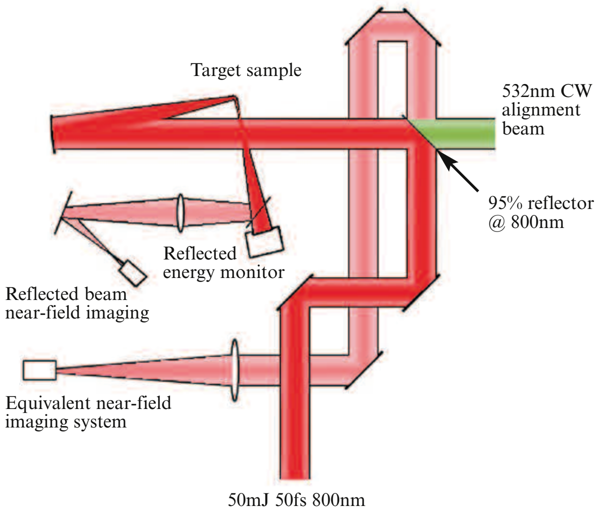

Figure 1. Schematic representation of the experimental layout. Note that the target is positioned about 33 mm before focus in order to make an ellipse with minor and major axes of 5 mm and 7 mm respectively.

Damage threshold measurements

The mean intensity of the pulse at the interaction point is readily calculated from the pulse length, the geometry and the measured incident energy. However, due to the incident angle of the focussing beam there is an intensity gradient across the sample and there are also inhomogeneities in the beam, which cause damage to occur non-uniformly across the irradiated sample. These were mapped using the equivalent near field images and the actual intensities of the hotspots where damage first occurs were calculated.

As a relatively large spot on the target was illuminated any small defects on the surface that start to damage at a lower intensity can be identified and eliminated. It is necessary to move to a new location if any damage spots occur as damage can lower the threshold in the surrounding area.

Starting off with the highest intensity on each target, we fired the laser onto a region of the target until it showed signs of damage. Then the target was moved to a new position and this was repeated at a lower intensity. We repeated this until there were no signs of damage after 500 shots, starting with an undamaged area every time. The highest intensity at which no damage occurred even after 500 shots was considered as the multi-shot damage threshold.

Areas of coating damage could easily be observed in the reflected near field which was recorded after 1, 2, 10, 100 and 500 shots on each location. When this diagnostic no longer showed any damage to the optic the chamber was let up for a visual examination to make sure there were no subtle signs of damage such as discolouration.

The reflected energy from targets and the reflected near field indicate the damage on the irradiated surface. For determining damage thresholds, the input laser energy is monitored by a leakage through a mirror onto a Gentec energy monitor.

Results

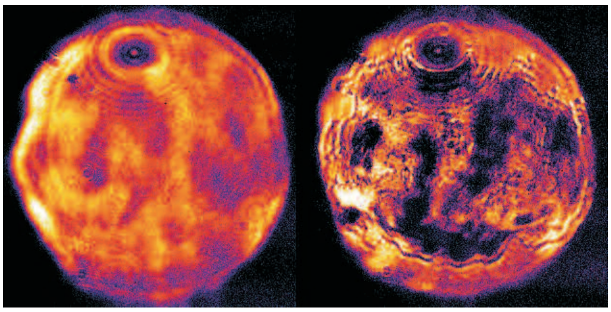

Figure 2. The reflected beam imaged at the target surface showing damage to the coating.

Figure 2 shows the reflected near field as seen before and after surface damage to the coating. Due to non-uniformity in the beam profile, the damage induced on the target is not uniform across the spot. It was noticed that damage initiates at the hotspots of the beam and then spread outwards. Due to incubation effects, damage thresholds can be lowered at already damaged areas. Since the local intensity levels at the hot spots can be higher than the average intensity across the spot, only energy levels where no damage was observed were used to calculate the damage thresholds.

Figure 3 shows the damage thresholds calculated from the results of the experiment. The results indicate that the dielectric coating TLMB has the highest damage threshold, followed by the protected sliver. For comparison, the current mean fluence and intensity of the unfocused Gemini beam are also plotted. The results suggest that dielectric and protected silver coatings are the best to use

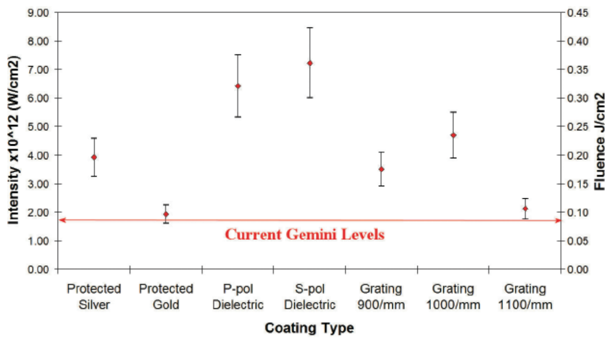

Figure 3. This graph shows the highest observed intensities and fluences at which the coatings did not damage. Also indicated is the levels at which Astra Gemini is currently operating.

for optics in Gemini laser system, although protected silver may damage if there are any significant hotspots in the beam and also the gold gratings may be at risk.

Figure 4 shows how the reflectivity of the samples deteriorated with number of shots for a protected silver coated optic. From this graph the reflectivity is seen to drop after about 8 shots whereas damage to the coating was seen in the reflected near field after the first shot. This was true of all the coatings tested in this experiment.

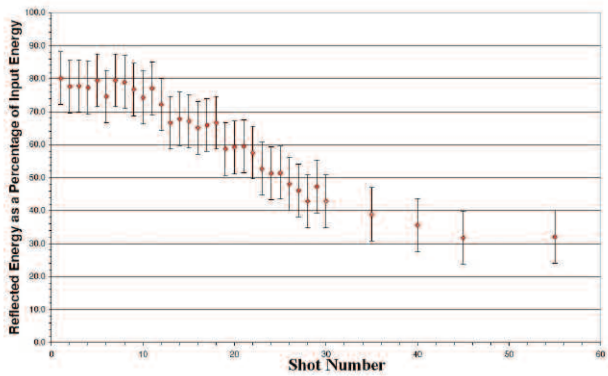

Figure 4. A graph showing how the reflected laser energy decreases as the coating becomes damaged.

Conclusions

Multishot damage thresholds for several coated optics commonly used in high power laser systems are examined in the femtosecond regime. Dielectric coatings are found to be the most robust under repeated high power laser irradiation, making them ideal candidates for most optics in the system. Multishot thresholds are more relevant than the single shot thresholds in such laser systems because repeated exposure reduces the damage threshold due to incubation effects [2]. We indeed observe this in our studies, as illustrated in the last figure.

Damage in this regime is thought to be initiated by direct multiphoton ionization, followed by avalanche effects. Incubation effects are likely to be caused by changes in the molecular structure [3] due to ionization, resulting in a reduction in ionization threshold [4]. Though damage by ionization is prominent for femtosecond pulses, it is possible that the thermal conductivity properties of the coating also play a role. Change in conductivity due to earlier damage can also induce incubation effects. More studies are required to identify the exact mechanism of damage and its dynamics in such cases and these are underway.

References

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