High-Laser-Damage Coatings on YAG

Using Ion-Beam-Sputtering Deposition

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IBS coating technology experienced a rapid advancement during the telecom boom in the end of the 90's because it provided coatings with near bulk material density and very predictable and repeatable optical properties—even for designs involving hundreds of coating layers. This was necessary to produce Dense Wavelength Division Multiplexing (DWDM) filters which require coatings with nearly no sensitivity to environmental factors such as humidity. After the crash in the telecom industry, IBS coatings have found other uses such as filters for fluorescence detection applications and coatings for high-power laser applications. In addition to being environmentally stable, IBS coatings also have very low scattering and absorption losses, both advantages for many laser optics applications. However, IBS coatings have not traditionally been viewed as competitive with traditional e-beam coatings when it comes to high laser damage performance[1], although good results have been reported with proper process optimization [2].

One promising application of IBS coatings is coatings on YAG structures for high power applications. We have investigated the laser damage properties of different types of IBS coatings on YAG substrates at 1064 nm, showing results comparable to those usually obtained by e-beam deposition. For an overview of different coating technologies see [3].

All the coatings tested for this paper were deposited on 1-inch diameter by 1-mm thick undoped laser-grade random-axis YAG substrates. The substrates were polished to a less than 10 Angstrom rms roughness. All the substrates were cleaned with a mechanical cleaning process using DI water, acetone and iso-propanol. The coatings where deposited using an automated IBS coating chamber. Ion assist was not used during the deposition. The laser damage testing was performed by a commercial testing service, Big Sky Laser, using 20-ns FWHM pulses at 1064 nm with a 20 Hz repetition rate and a 0.5 mm 1/e^2 beam diameter.

Sample	1	2	3	4	5	6
Coating type	AR-AR	AR-AR	HR	HR	Dichroic	Dichroic
Incident side	Air side	Air side	Air side	Substrate side	Air side	Substrate side
Damage threshold	19.2 J/cm^2	24.0 J/cm^2	48.1 J/cm^2	33.7 J/cm^2	9.6 J/cm^2	9.6 J/cm^2

Table 1. *Results of damage testing. Damage threshold is highest power density without any observed damage.*

Three types of coatings were tested: Anti Reflective (AR), High Reflective (HR) and Dichroic coatings. We also tested the uncoated YAG substrate. The HR coating was tested with light incident from both the air side as well as the substrate side of the coating. The testing results are summarized in table 1.

AR coatings: The AR coated samples were coated on both sides with the same AR coating. The coating design consisted of three layers where the first and last layers were SiO_2 while the middle layer was Ta_2O_5. The layer thicknesses were non-quarterwave thicknesses optimized using Essential Macleod thin film design software. The reflectivity was below 0.1% at 1064 nm.

We tested two samples coated in the same coating run. The results are shown in figure 1. The damage testing resulted in damage on both sides of the 1-mm thick substrate. This was expected since a 0.5-mm beam diameter results in almost the same light intensity on each side of the substrate. The highest fluence without observed damage was 19.2 J/cm^2 and 24.J/cm^2

for the two substrates. However, the frequency of damaged sites remained at only 10% all the way up to over 50 J/cm^2. This mean that the damage occurred in only some sites and is an indication that the damage is defect driven and not limited by the coating itself.

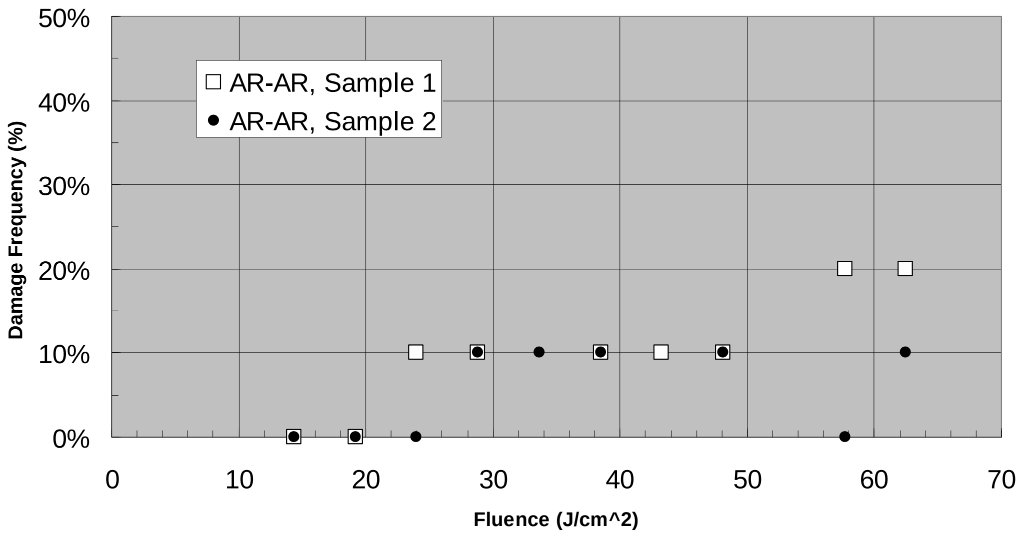

Figure 1. Damage site frequency as function of laser fluence for YAG samples AR coated on both sides. 10 sites tested for each fluence.

HR coating: The two HR coated samples were coated using SiO_2 as the low index material (L) and Ta_2O_5 as the high index material (H). The design was a simple (L H)^12 2L quarter wave design.

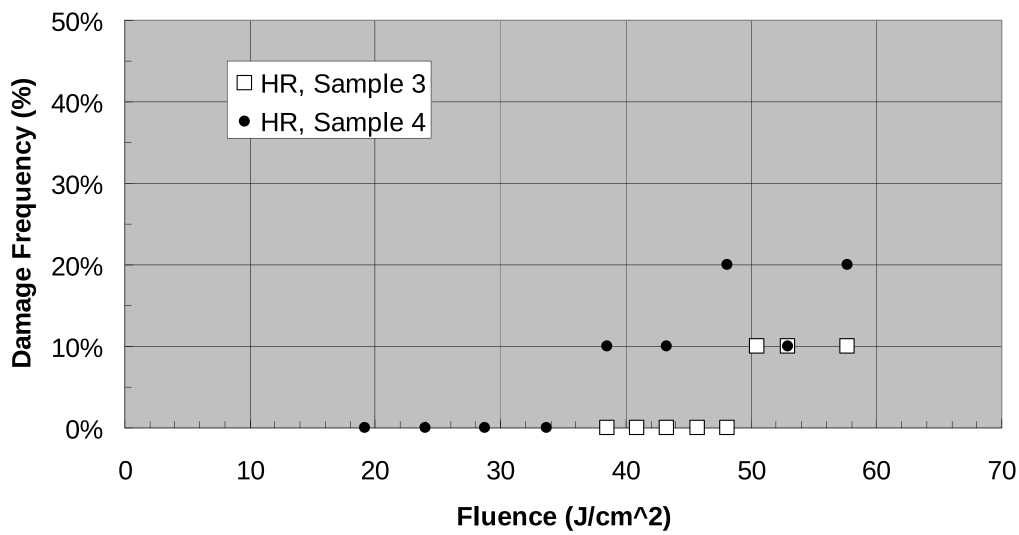

Figure 2. Damage site frequency as function of laser fluence for HR coated YAG samples. 10 sites for each fluence.

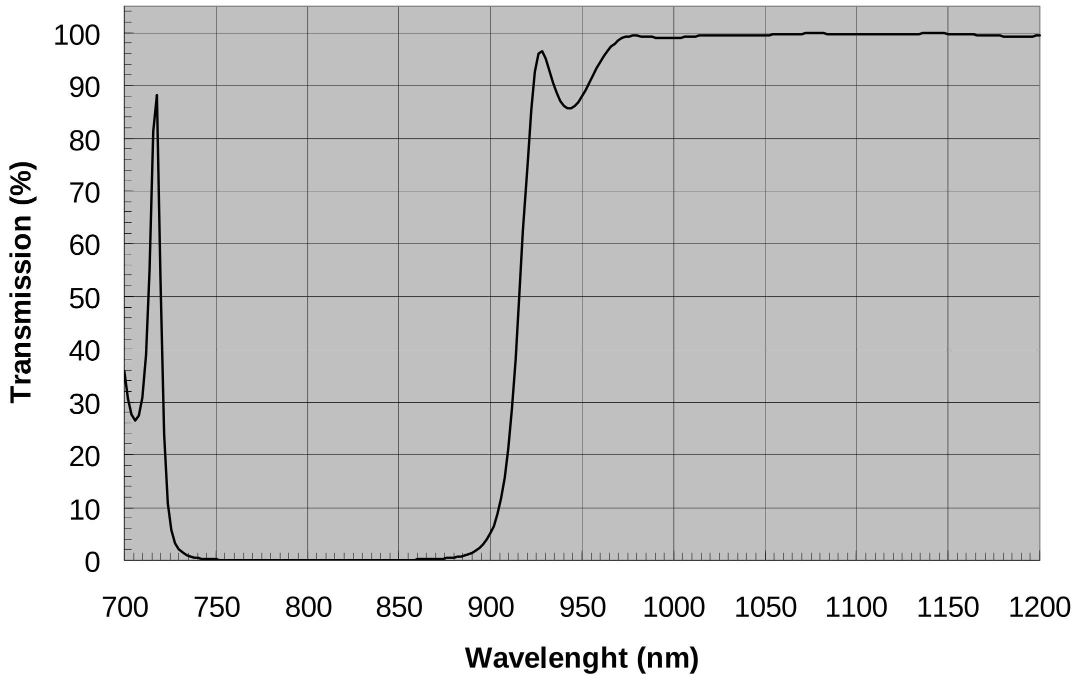

Figure 3. Transmission spectrum of dichroic coating on YAG. Reflection losses in the uncoated backside have been normalized out.

We tested two samples coated in the same run. Sample 3 was tested with the light incident from the coating side of the substrate and Sample 4 was tested with the light incident from the uncoated back side of the substrate. The results are shown in figure 2. The damage threshold of Sample 3 was measured to be 48.1 J/cm^2 while Sample 4 was measured to 33.7 J/cm^2. The lower threshold of Sample 4 compared to Sample 3 is as expected since the light is reflecting off the coating/ YAG interface when the light is incident from the back side, making it sensitive to defects and contaminations on the substrate surface.

Dichroic coating: The dichroic coating was also coated using SiO_2 and Ta_2O_5. The design consisted of a 30 layers where the center layers were quarter-wave layers at 808 nm while the bottom three and top four layers were non-quarter wave layers optimized for high transmission at 1064 nm. The measured transmission spectra, with the reflection loss of the uncoated backside normalized out, is shown in figure 3.

Two samples were tested similarly to the HR samples where Sample 5 was tested with the light incident from the coating side and Sample 6 was tested with the light incident from the back side. The results are shown in figure 4. Both samples yielded a laser damage threshold of only 9.6 J/cm^2. The low damage threshold is explained by all the light at the test wavelength passing through the whole coating and the coating-substrate interface. This is the case with the light incident from either side, resulting in the same damage threshold for both Sample 5 and Sample 6.

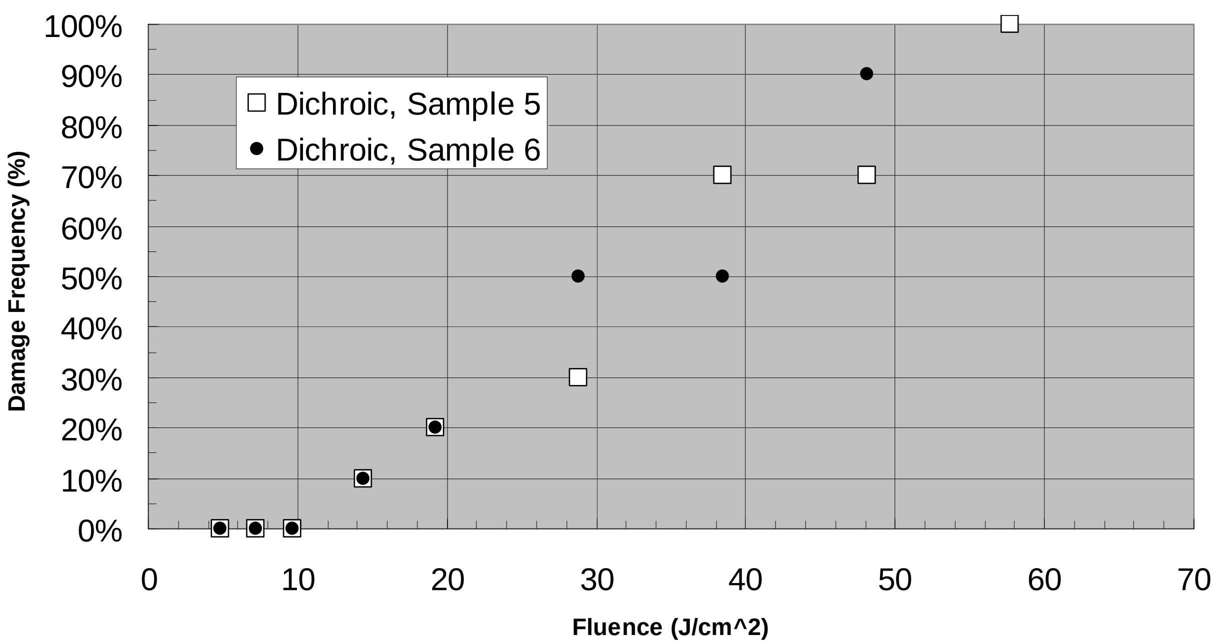

Figure 4. Damage site frequency as function of laser fluence for YAG samples coated with a dichroic. 10 sites tested for each fluence.

Conclusion: The damage testing of the different coating types reveal that the different coating designs have very different damage threshold. The HR coating tested with the light incident from the coating side has the highest damage threshold, 48 J/cm^2. In this case, all the light is reflected from the top layers of the coating and only a negligible amount of light reaches the YAG substrate. The dichroic coating tested the lowest with only a 9.6 J/cm^2 damage threshold. In this case, all the light is passing through the whole coating, coating-substrate interface, and YAG substrate. The coating is therefore sensitive to both defects and contamination in all these regions. Since the HR coating tested much higher, the limiting factor seems to be the coating-substrate interface. This is also supported with the lower damage threshold of the HR coated substrate with light incident from the back side than the front side.

The damage threshold of the AR coated substrates lay between that of the HR coated and the dichroic coated substrates. This is as expected since the light is passing through the whole structure and we in effect are testing both surfaces. The damage probability distribution indicates that the AR coatings are limited by damage from point defects.

Future work will aim at increasing the damage threshold of the AR and dichroic coatings by improving the coating-substrate interfaces. Some of the factors that can be optimized are substrate polishing, substrate cleaning, and managing electromagnetic field at the interface by optimizing the coating design. The high damage threshold on the HR coated samples indicate that the coating itself is not the main limiting factor for AR and dichroic coatings.

References

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