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Brewster Angle Polarizing Beamsplitter Laser Damage Competition: "P" polarization

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Brewster Angle Polarizing Beamsplitter Laser Damage Competition: "P" polarization

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ABSTRACT

Brewster angle plate polarizing beamsplitters play a critical role in splitting and combining beams within high power laser systems. A laser damage competition of polarizer beamsplitter coatings creates the opportunity to survey the current laser resistance these coatings within private industry, governmental institutions, and universities by a direct comparison of samples tested under identical conditions. The requirements of the coatings are a minimum transmission of 95% at "P" polarization and minimum reflection of 99% at "S" polarization at 1064 nm and 56.4 degrees angle of incidence. The choice of coating materials, design, and deposition method were left to the participant. Laser damage testing was performed according to the ISO 11254 standard utilizing a 1064 nm wavelength laser with a 10 ns pulse length operating at a repetition rate of 20 Hz. A double blind test assured sample and submitter anonymity so only a summary of the results are presented. In addition to the laser resistance results, details of cleaning methods, deposition processes, coating materials and layer count, and spectral results are also shared. Because of the large number of samples that were submitted, damage testing was conducted at "P" polarization only with "S" polarization damage testing reserved for next year on these submitted samples. Also the samples were only tested in the forward propagating direction; specifically samples were irradiated from air as the incident medium, through the thin film, and then through the substrate. In summary, a 6:1 difference existed for "P" polarization damage fluences amongst all of the competitors with the dominate variables that impacted the laser resistance being the deposition materials, deposition process, and cleaning method.

Keywords: damage testing, polarizer, thin film, Brewster angle, multilayer, 1064 nm laser, nanosecond pulse length, and ISO21254-2

1. INTRODUCTION

This latest thin film laser damage competition represents the fifth in a series of damage competitions started in 2008 at the Boulder Damage Symposium. To date, a large range of coating types have been tested including a 1064 nm normal incident high reflector[1] tested with 5 ns pulses, a 786 nm femtosecond (200 fs) normal incident high reflector[2], a 351 nm antireflection coating[3] tested with 7.5 ns pulses, a 193 nm excimer mirror[4] tested with 13 ns pulses, and finally this year's competition of a Brewster angle 1064 nm polarizer. In each competition, it was observed that a wide range of laser resistance exists between the lowest and highest laser resistant samples with the largest range being over 100× for the 1064 nm nanosecond mirrors. Although this is not a formal study isolating a single variable to test a hypothesis, general trends can be observed in this competition between thin film variables and the range of capability within the coating industry in manufacturing high resistance polarizers.

2. PARTICIPATION

Twenty-six samples were submitted this year from seventeen different participants who represented six different countries. A list of the participants, their respective countries, and number of years of participation in this series of thin film laser damage competitions are listed in table 1. The participating countries and number of samples were:

China (9), Germany (8), USA (4), United Kingdom (3), Japan (1), and Switzerland (1). This was the first year that participants from the United States were in the minority of participating countries.

Table 1 List of participating companies or institutes for the BDS than film damage competition

Company / Institute	Country	Years of participation
Changchuan Institute of Optics	China	1
CVI Melles Griot	USA	1
CVI Melles Griot	UK	1
Hardin Optical Company	USA	1
Laser Components GmbH	Germany	3
Laser Zentrum Hannover	Germany	5
Laserhof Frielingen GmbH	Germany	2
Laseroptik GmbH	Germany	1
Okamoto Optics	Japan	2
Optimax Systems	USA	1
Opturn Company Ltd	China	1
Sandia National Lab (NM)	USA	1
SCHOTT	Switzerland	1
Shanghai Institute of Optics and Fine Mechanics	China	4
Sichuan Corder Technology Inc.	China	1
SLS Optics	UK	2
Tonjgi University	China	1

3. SAMPLES

The coated samples had a spectral requirement of >95% transmission at "P" polarization and >99% reflection at "S" polarization at 1064 nm at 56.4 degrees (Brewster's angle). Environmental requirements were ambient lab conditions (40% relative humidity and 20 degrees Celsius). Participants supplied 50 mm diameter substrates that were 10 mm thick in either fused silica or BK7. No significant correlation between substrate material and damage threshold was observed. Participants each provided a spectral plot as shown in figure 1, to validate spectral performance. Participants also provided a description of the coating deposition process, coating materials, layer count, and cleaning method.

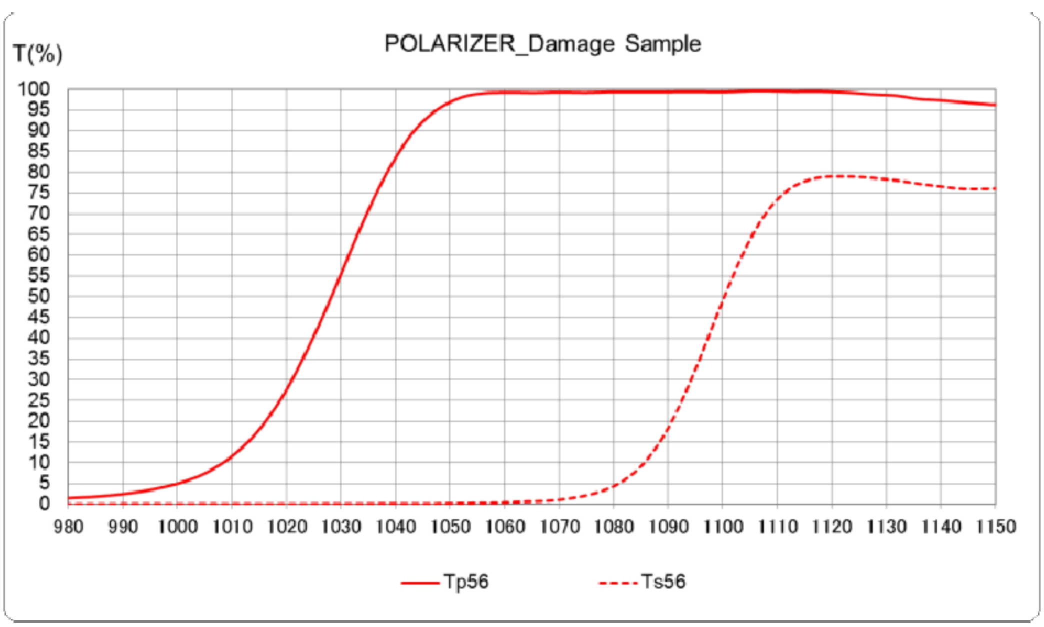

Fig. 1 Representative spectral characteristics of the contributed samples.

Samples were assigned a unique two digit participant code to maintain sample anonymity. The first digit consisted of a letter ranging from A to R for the seventeen participants. The second digit was a sample number consisting of a 1 or 2 depending on how many samples were supplied by the participant. The identity of the suppliers and participant code was only known by an administrative assistant to maintain a double blind experiment. The author and damage testing service only had access to the participant code so as to remain unbiased and to protect the identities of participants whose samples had lower laser resistance.

All of the spectral plots indicate that a long wave pass design strategy was employed by each participant. When designing polarizer coatings, a series of compromises and optimizations must be made. Spectrally, polarizers are tilted coatings that can be designed as either a short wave pass or long wave pass.[5] These different design strategies impact the polarizing spectral bandwidth, extinction ratio, design complexity, overall film thickness, and electric field profile.[6-9] The long wave pass design is most common because it yields a wider polarizer spectral bandwidth and thinner coating, but it does have an unfavorable electric field profile in both "P" and "S" polarization.

Three different deposition processes, e-beam, ion beam sputtering, and ion assisted deposition, were used to manufacture the samples for this composition. Four different high index coating materials, HfO_2, Ta_2O_5, ZrO_2, and a mixture of HfO_2 & Al_2O_3, were used. Histograms of the deposition processes and coating materials are shown in figures 2 and 3. The most common deposition process used to manufacture the samples was electron beam deposition. Within the IBS sample population, a few of them were rugate films (either discrete or continuous). These will be identified in the damage threshold plots discussed in section 5. SiO_2 was the low index material used in all of the samples. HfO_2 is the standard high index material choice for high laser resistance at 1064 nm which is reflected in more than half of the submitted samples being manufactured with this material. However, this material has a lower refractive index than Ta_2O_5 or ZrO_2 which results in a lower polarizing spectral bandwidth. HfO_2 also tends to be polycrystalline leading to higher scatter than Ta_2O_5 which tends to make very low scattering amorphous films. The lower refractive index and scattering drawbacks for HfO_2 motivate interest in alternate high index coating materials.

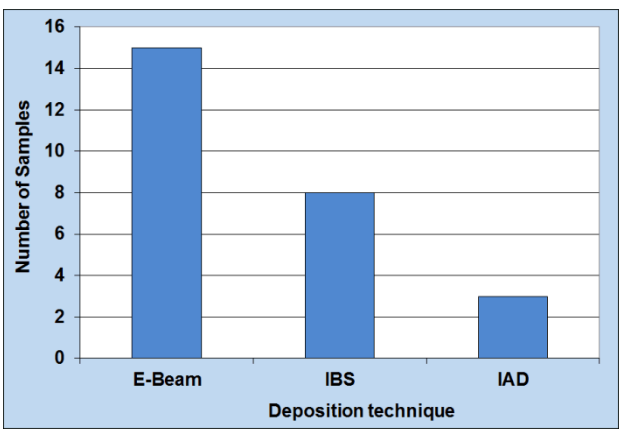

Fig. 2 Coating deposition process histogram.

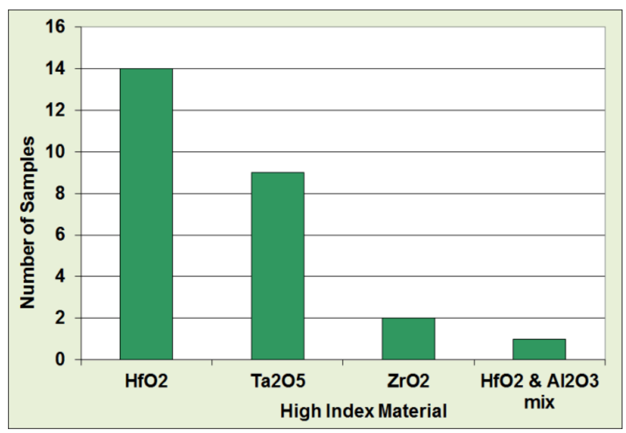

Fig. 3 Coating material histogram.

4. DAMAGE TESTING

The LIDT measurements where performed at Quantel USA according to ISO 11254-2[10]. An illustration of the setup is in figure 4. The test laser operates at a wavelength on 1064 nm with a 10 ns pulse length and repetition rate of 20 Hz. The beam diameter was 0.53 mm at the sample plane in TEM_{00} mode. The tests were conducted at 56.4 degrees incidence angle at "P" polarization. The samples were tested in the forward propagating direction only, specifically the laser direction went from air, through the film, and then into the substrate.

100 sites were tested on each sample with 200 shots per site. Laser damage was determined by optical microscope inspection of the irradiated area of the sample at 20× magnification. The damage threshold was determined by the damage frequency method. Damage probability statistics were gathered as illustrated in figure 5. A least squares linear fit of the data was calculated to determine the zero percent failure intercept. A full description of the damage set up and testing method are described in detail on the Quantel website.[11]

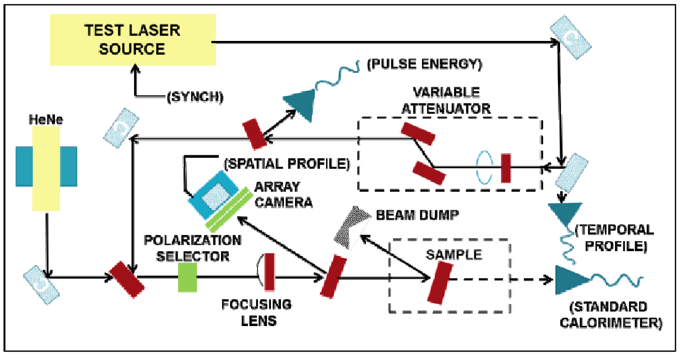

Fig. 4 Laser damage test setup.

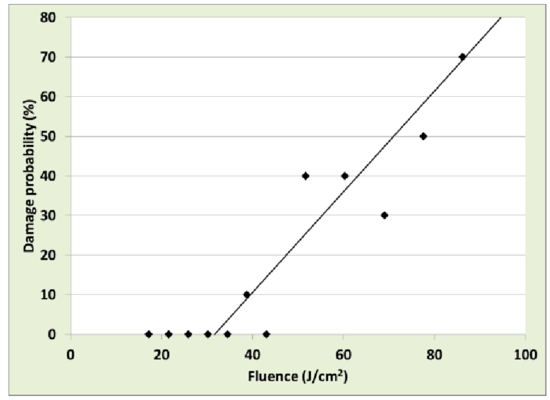

Fig. 5 Damage threshold probability results for the highest laser resistant sample.

5. RESULTS

A summary of the damage threshold results are shown in figures 6 and 7. The coatings deposited by electron beam tended to have the highest laser resistance. Of the electron-beam deposition films, the highest laser resistant high index material was HfO_2. Ta_2O_5 coatings tended to have higher laser resistance for the densified coating processes, IAD and IBS. What is particularly interesting is that the highest laser resistant coatings from each deposition process were cleaned using ultrasonics and the lower laser resistant coatings tended to be cleaned manually. For the densified coating processes, the highest laser resistant coatings were also dry etched before coating deposition by either plasma or ion sources. A similar trend was observed in the first damage competition where the highest damage threshold 1064 nm high reflector coating was dry etched before deposition.

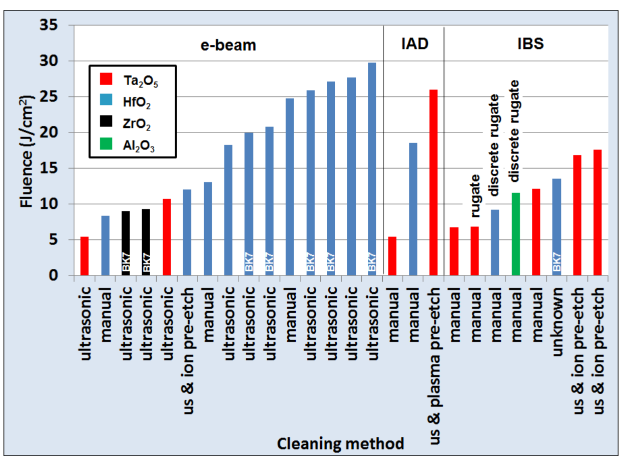

Fig. 6 Laser resistance as a function of deposition process, coating material, and cleaning method (us = ultrasonic).

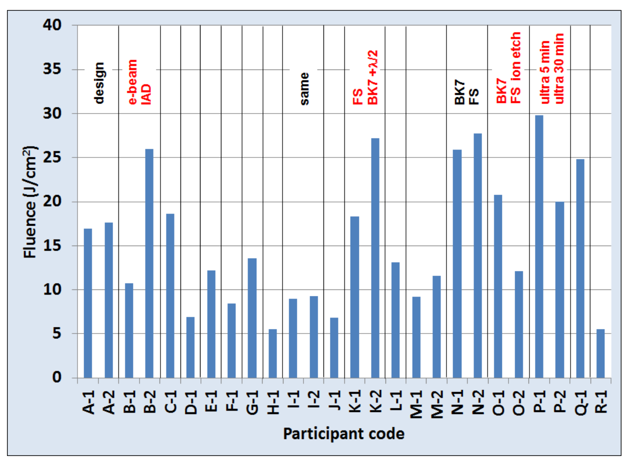

Fig. 7 Laser resistance by participant (ultra = ultrasonic).

The rugate designs deposited by ion beam deposition did not show a significant advantage from a laser resistance perspective. The Al_2O_3 mixture with HfO_2 was the most laser resistant of the rugate coatings. Some of the coating participants provided two samples and described the differences between the coatings creating an opportunity to observe trends with minimal variables. Similar laser resistance was observed with differing designs (participant A), identical deposition conditions (participant I), and for a coating deposited on substrates of different material composition, BK7 versus fused silica (participant N). Where there were significant observed differences in laser resistance between different samples supplied by the same participant a significantly higher laser resistance for an IAD coating over e-beam coating was observed for participant B. For participant K they changed the substrate material and added a thicker overcoat to one of the coatings. In this case the thicker overcoat deposited on BK7 had a higher laser resistance than the thinner overcoat deposited on fused silica. For participant O, two variables were also changed. The coating on the BK7 substrate had a higher laser resistance than the coating deposited on a fused silica substrate which was also ion etched before deposition. Finally, participant P showed that samples cleaned for only 5 minutes with ultrasonics performed better than substrates that were cleaned with ultrasonics for 30 minutes.

In order to observe potential trends with substrate material, BK7 substrates are indicated in figure 6. The remaining substrates were fused silica. There does not appear to be a significant dependence of substrate material and laser resistance of the coated sample. No significant trends were observed between laser resistance and the number of coating layers. In the first damage competition of the 1064 nm high reflector coatings, it was possible to determine if overcoats were used in the coating design by either an even or odd number of layers and the impact of the overcoats in the laser resistance of the coating. Polarizer coatings tend to be highly optimized designs so it is impossible to determine the use of an overcoat by whether the number of layers is odd or even so unfortunately the only available overcoat information was the data provided by participant K. Overcoat thicknesses have been determined to have a significant impact on the laser resistance of Brewster angle plate polarizers at "S" polarization, however, this remains an unanswered question at "P" polarization.[12]

6. CONCLUSIONS

The range of laser resistance for these Brewster's angle thin film polarizers submitted to this competition and tested at "P" polarization is 6×. The most significant variables that appeared to have a positive impact on the laser resistance of these coatings were deposition process (e-beam), coating material (HfO_2), ultrasonic cleaning, and dry etching of the substrate before deposition of the film. Next year the samples will be retested at "S" polarization which should lead to some interesting comparisons between polarization dependent laser resistance.

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