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3.B A New Engineering Damage Criterion for Thin-Film Optical Coatings

Laser damage tests are usually carried out to monitor quality control for established thin-film coating designs or to gauge optical survival potential for new, experimental coating designs. The procedure widely followed in laser damage tests is a one-on-one test regimen. That is, each sample site is irradiated only once, and the occurrence or non-occurrence of damage is monitored immediately after irradiation. Changing the irradiation fluence as one sample site after another is irradiated allows us to find a sample's average damage threshold. This average is often determined by splitting the difference between the highest fluence which any sample site survived without showing damage and the lowest fluence which did cause damage. Repeating this procedure for many identical samples yields an average damage threshold for a given coating design and a corresponding standard deviation. Both are obtained in conventional, statistical fashion.

One reason for carrying out damage tests in this manner is the long-standing problem in maintaining constant laser-intensity profiles both spatially and temporally within the irradiation volume. As a consequence of pulse-to-pulse laser-output fluctuations, it was recognized that multiple irradiations of a sample site made a meaningful interpretation of damage results virtually impossible. Single irradiation of each sample site therefore became a necessity.[1]

This strictly instrumental restriction puts severe limits on the utility of one-on-one damage-test results obtained. For what can ultimately be inferred from these data is that for a given coating design, the fluence on the first shot should not exceed a certain threshold value, if damage is to be avoided. Very few laser systems are, however, intended for just a single-shot useful life. To predict from these data, laser-system component performance over many shots requires two important assumptions. First, the status of the component can be in only one of two states, undamaged or damaged. Moreover, the undamaged state is required to remain entirely constant during all irradiations up to the damaging event. These assumptions deserve some scrutiny.

We have recently started to monitor both the conventional one-on-one average damage threshold and the multiple irradiation behavior of sites. These tests were carried out on polymer-oxide-AR surface structures on fused SiO_2. These coatings exhibit peculiar damage morphologies which are especially suitable for such tests (see Fig. 20.23). Damage manifests itself there in an orange-peel pattern of hundreds of small scattering centers separated from one another by much larger distances than their average size. The larger of these damage sites can be detected by the unaided eye. From a practical viewpoint, only such damage sites are detected in the field during routine maintenance inspection of large optical components. Unless such evidence appears, a component is normally judged fit for further use. Appearance of such damage sites could therefore be termed an engineering damage criterion. This differs from the conventional damage criterion in which the appearance of a single, additional scattering center within the irradiated volume is counted as evidence of damage. A single scattering center can be observed only under high-resolution microscopy.


G1501

Fig. 20.23
Typical polymer-oxide "orange-peel" damage morphology after large-spot irradiation by 1-ns, 351-nm laser pulse (magnification 110X).

Our method of experimentally distinguishing single-center, conventional damage from engineering damage also sheds light on the issue of damage-initiation versus damage-propagation thresholds. Experiments at Los Alamos[2] showed that new scattering centers observed after a first irradiation neither multiply nor grow in size upon subsequent irradiation at constant fluence. Significantly higher fluences were required to cause added damage to such pre-irradiated sample areas. No explanation was available for this phenomenon.

The most important finding of the LLE multiple-irradiation tests is the sample-hardening effect. Repetitive irradiation with slowly increasing laser fluences makes sample sites survive final fluence levels which, without exception, cause other sites on the same sample to suffer massive damage on first irradiation. A pattern emerges from these measurements in which the hardening of sites depends critically on the rate at which the fluence is raised from shot to shot. Yet the hardening does not seem to depend on the shot-to-shot stability of the laser's spatial intensity distribution. For polymer-oxide coatings, fluence increases exceeding 42% cause engineering damage. This happens irrespective of the absolute fluence level from which the increase occurs as long as that level lies above 1.5 J/cm^2. Below this level, increases of 100% or more are of no consequence.

Damage evolution on a typical, hardened site proceeds in three stages. During low-fluence initial irradiation, very few scattering centers are created, indicative for one-on-one damage. No new or enlarged existing centers are noticed through successive irradiations of slowly raised fluence until an excessive laser-intensity fluctuation in the upper fluence range causes massive engineering damage. Although the cause for the initial few-scatter damage is not known, it is likely to be different from that for the massive damage. The absence of progressive damage after first irradiation casts doubt on the significance of the early-damage mechanisms and thereby on the whole one-on-one damage evaluation itself.

The microscopic process of hardening is currently not understood. We observe that samples with one-on-one damage thresholds near 1 J/cm^2 will sustain fluence levels above 3.5 J/cm^2 after hardening. Limited evidence indicates the possible existence of a critical hardening path for polymer-oxide coatings. If that path were known, all sample sites could be treated in a similar, controlled fashion. Further insight into the detailed hardening mechanism could be gained. Also, a logically consistent N-on-one damage threshold could be constructed.

In the absence of a well-analyzed critical path, we assume that limited deviation from such a path can be tolerated and that our narrow data base permits the derivation of such an N-on-one damage threshold. In Fig. 20.24 the traditional one-on-one average damage threshold for three polymer-oxide samples is compared with N-on-one thresholds obtained from the same samples. The marked improvement due to hardening is evident.

Answers to several questions are currently being sought:

- Is the hardening path linear or non-linear?
- Does low-fluence pretreatment also affect one-on-one thresholds?
- Can hardening procedures be devised which prepare polymer-oxide coatings to meet given, specific design requirements?

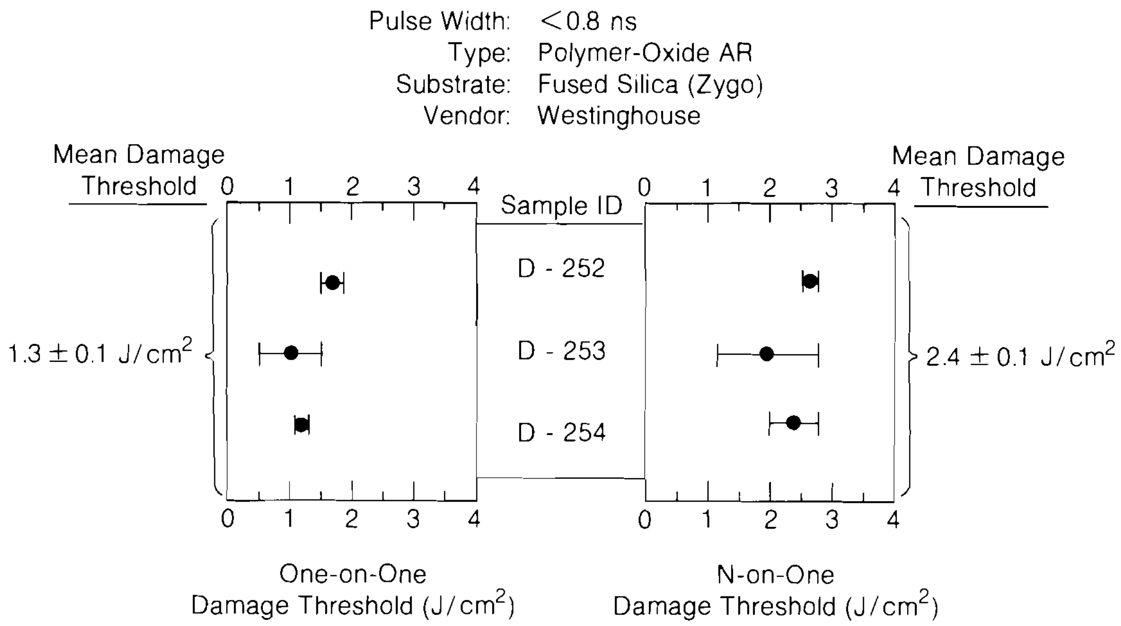

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Fig. 20.24
Composition of single-shot and N-on-one average damage thresholds for selected polymer-oxide samples.

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