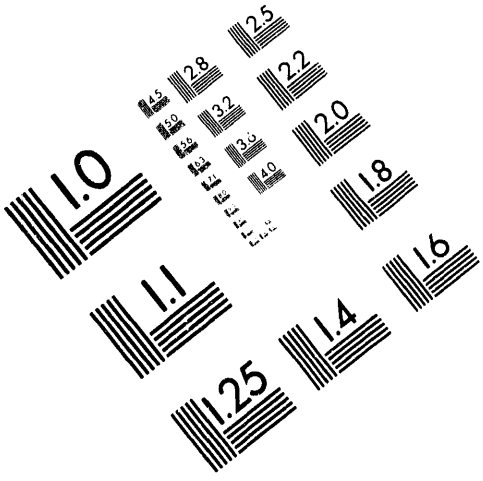

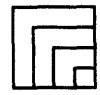

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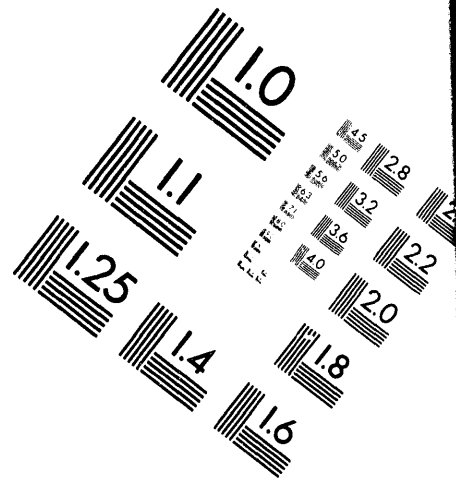

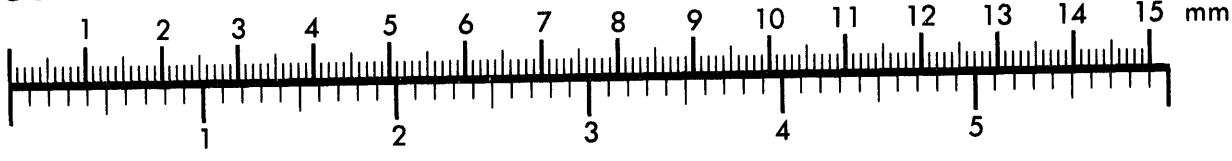

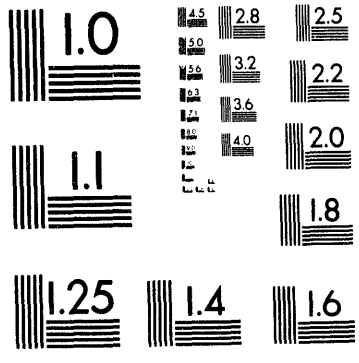

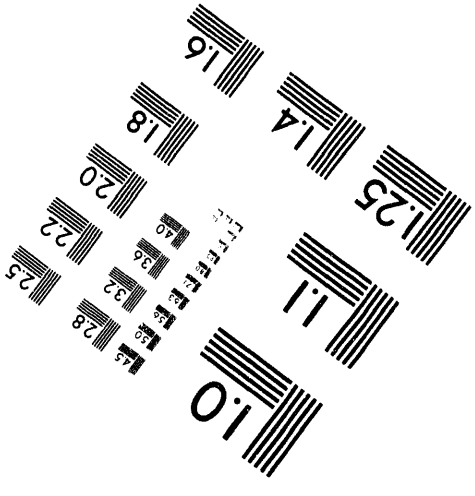

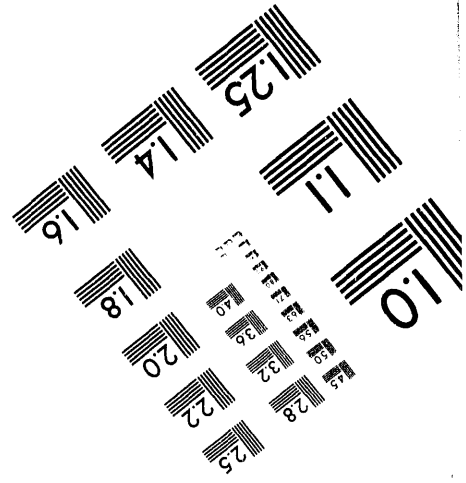

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PREPRINT

Pulsewidth-Dependent Damage Measurements of Dielectric Materials

B. C. Stuart, S. Herman, B. W. Shore and M. D. Perry

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Pulsewidth-Dependent Damage Measurements of Dielectric Materials

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The application of chirped pulse amplification to short-pulse lasers [1] has led to a dramatic increase in the number of high-power, sub-picosecond laser systems. Accordingly, knowledge of the short-pulse damage thresholds of optical components and the scaling of the damage thresholds with pulsewidth has become increasingly important. The development of high energy, (e.g., kilojoule class) short-pulse lasers is contingent on the ability to produce optical components capable of withstanding high fluence nanosecond and femtosecond pulses. In this paper, we report on our measurements of the front-surface damage threshold of many different dielectric materials including windows, multilayer mirrors, and diffraction gratings over the pulsewidth range of 0.1 to 3000 ps.

Pulses from 0.4-900 ps were generated by a Ti:sapphire CPA system operating at 1053 nm [2]. Seed pulses of 100 fs from a Ti:sapphire oscillator were stretched to 1 ns and then amplified up to 65 mJ in a linear regenerative amplifier followed by a ring regenerative amplifier, both producing TEM_{00} modes. A single-grating compressor with varible spacing was used to compress the pulses, resulting in a continuously adjustable pulsewidth. We shaped the stretched spectrum in the first amplifier to a near-Gaussian profile to give temporally smooth compressed pulses. The pulses were focused onto the samples by a 1-m lens. The short-pulse data was taken with a 0.5-mm (e^{-2}) diameter spot size, while the long-pulse data required higher fluences and a 0.3-mm diameter spot. The absolute uncertainty in fluence is estimated to be 20%, but relative values are within 5%.

To avoid the complications of spatial and temporal distortion caused by self-focusing, group velocity dispersion and self-phase modulation when propagating pulses through optical materials, we considered only front-surface damage. Often the rear surface or bulk of the transparent materials would damage before the front surface, so we were careful not to let this damage propagate to the front surface. A Nomarski microscope was used to observe the sample before and after irradiation, and damage was defined as any visible modification to the surface (down to sub-micron size spots). Initial damage at threshold, especially in the short-pulse regime, consists of the ablation of a very small amount of material, which is very difficult to detect. For this reason, we often examined our samples with high resolution electron microscopy in addition to optical measurements with the Nomarski microscope.

Due to the small amount of material ablated for short pulse damage and the desire to minimize statistical uncertainty, we conducted our damage testing with multiple pulses of a given fluence on each site to allow the damage to grow to an observable size. Six hundred shots at 10 Hz were used, unless damage was obvious sooner. Many fluence levels (10-15), with and without damage, were used to zero in on the threshold value. Our measurements for super-polished fused silica are shown in Figure 1. For long pulses, the damage fluence follows a characteristic $t^{1/2}$ dependence [4]. Near 10 ps, however, a change in damage mechanism is evident and below 10 ps the damage fluence becomes *nearly independent of pulsewidth*. Electron micrographs show that the long-pulse damage is characterized by heating and melting of the surface, while short-pulse damage, with no time for heat dissipation during the pulse, consists of ablation and fracture.

Damage to calcium fluoride shows a similar dependence on pulsewidth (Figure 2). The long-pulse damage spots showed evidence of melting and resolidification, while the short-pulse damage clearly initiated on scratches left from polishing which enhanced the electric field [5]. We have performed similar measurements on a wide range of dielectric materials (MgF_2, BaF_2, LiF), and consistently find a very weak dependence (essentially a plateau) of the damage threshold on pulsewidth below approximately 10 psec. These results are in contrast to the single-shot results of Du, et al [6] where the damage threshold was observed to increase with decreasing pulsewidth below 10 ps.

Damage to a dielectric mirror with a multilayer design similar to that employed in our gratings [7] also scaled as $t^{1/2}$ for longer pulses with a break near 10 ps (Figure 3). Long-pulse damage consisted of a general melting of the surface, while the short pulses ablated away individual layers of the multilayer stack. Initiation of damage was dominated by defects and nodules left from the coating process [8]. The short pulse damage plateau for these samples occurs at 600 mJ/cm^2. However, by eliminating the defects and modifying the coating design we have recently been able to increase the short pulse plateau to over 1.1 J/cm^2.

The theoretical description of laser-induced damage is complicated and even after thirty years of research very little consensus exists on the relative roles of electron impact ionization, multiphoton ionization, heating and ionization at defect sites, inverse Bremstrahlung heating, and electron-phonon coupling. We have developed a simplified theory for laser damage to dielectrics at pulse durations short enough that electron-phonon coupling and electron diffusion into the bulk can be neglected (< approx. 10 psec). We show that although the damage fluence can be expected to increase with short pulses when avalanche ionization [10] is the only mechanism [6], inclusion of multiphoton effects and electron heating results in a plateau in the threshold damage fluence for the 0.1-few ps range and then a decrease again for shorter pulses.

References

[1] D. Strickland and G. Mourou, Opt. Comm. **56**, 219 (1985); P. Maine, D. Strickland, P. Bado, M. Pessot, and G. Mourou, IEEE J. Quantum Electron. **QE-24**, 398 (1988).

[2] B.C. Stuart, S. Herman, M.D. Perry, IEEE J. Quantum Electron., submitted (1994).

[3] T. Ditmire, H. Nguyen, and M.D. Perry, J. Opt. Soc. Amer. B, (1994)

[4] J.R. Bettis, R.A. House, and A.H. Guenther, *NBS Spec. Publ. 387*, 338 (1976); W.H. Lowdermilk and D. Milam, IEEE J. Quantum Electron. **QE-17**, 1888 (1981).

[5] N. Bloembergen, Appl. Opt. **12**, 661 (1973).

[6] D. Du, X. Liu, G. Korn, J. Squier, and G. Mourou, Appl. Phys. Lett. **64**, 3071 (1994).

[7] M.D. Perry, J. Britten, C. Shannon, and E. Shults, US Patent Pending.

[8] M.R. Kozlowski and R. Chow, *SPIE Proc. Vol. 2114*, to be published, 1994.

[9] A.J. Morgan, F. Rainer, F.P. De Marco, R.P. Gonzales, M.R. Kozlowski, and M.C. Staggs, *NIST Spec. Publ. 801*, 47 (1989).

[10] N. Bloembergen, IEEE J. Quantum Electron. **QE-10**, 375 (1974).

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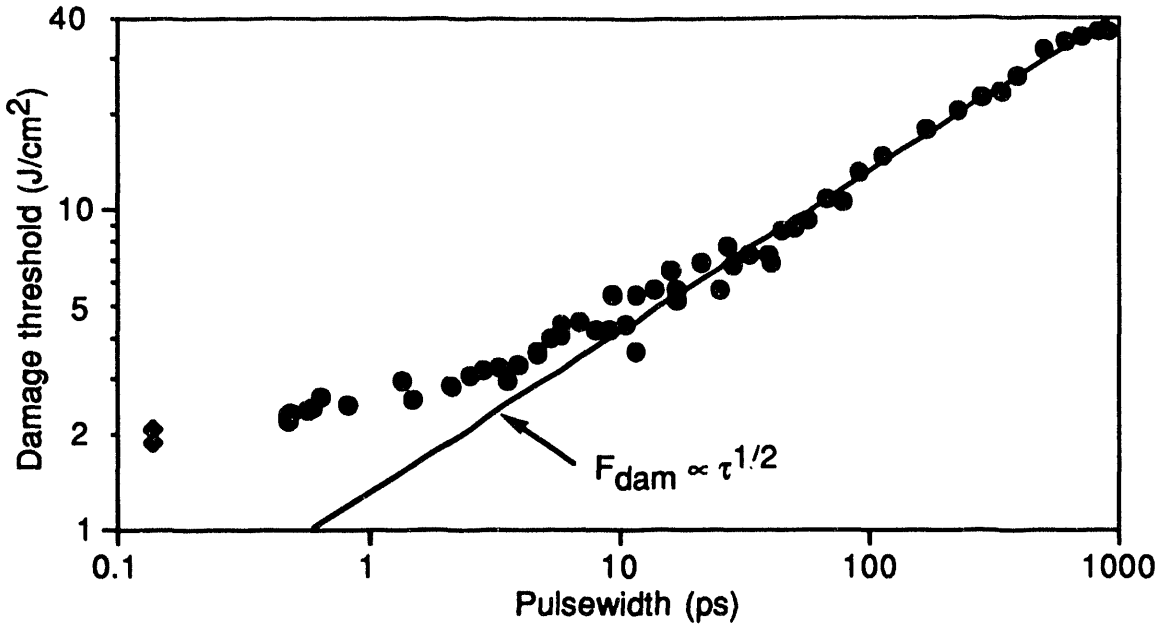

Figure 1. Pulsewidth dependence of 1053-nm front-surface damage threshold of super-polished fused silica. Values at 140 fs taken with 825-nm system [3].

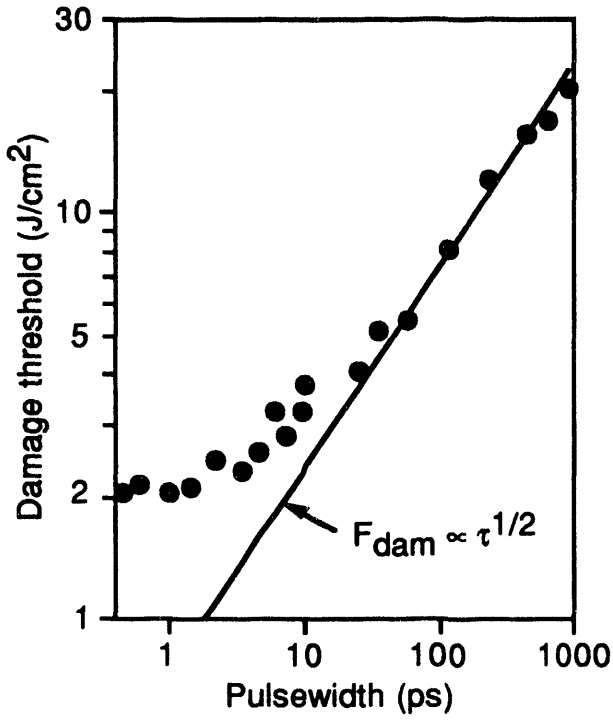

Figure 2. Pulsewidth dependence for damage threshold of calcium fluoride.

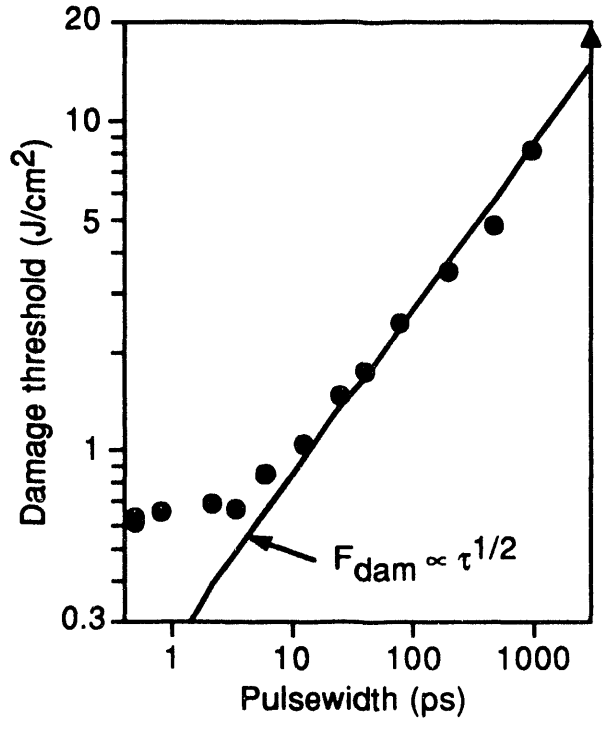

Figure 3. Pulsewidth dependence for damage threshold of an oxide multilayer dielectric mirror. Value at 3 ns with 1064-nm Nd:YAG system [9].

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