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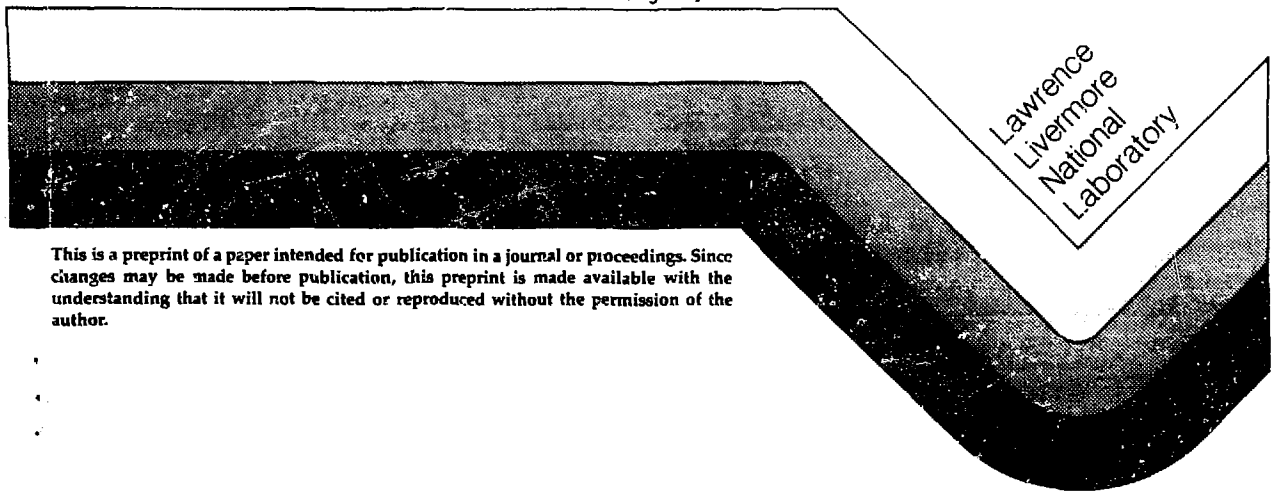

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ABSTRACT

Predamage electron emission shows a dependence on fluence, bandgap and wavelength consistent with multiphoton excitation across the bandgap and inconsistent with avalanche ionization and thermionic emission models.

The electron emission scales with pulselength as $\tau^{-1/2}$.

INTRODUCTION

Optically transparent materials exposed to laser irradiation of sufficient intensity suffer irreversible damage, thereby limiting the performance of most high power laser systems. The damage threshold in the bulk depends on its impurity concentration. The threshold for optical surfaces is usually lower, as much as an order of magnitude or more, and is highly dependent on surface preparation. The physical phenomena involved in damage are presently not well understood.[1]

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Damage at bare surfaces appears to result from electron avalanche-ionization and subsequent absorption by the created plasma. One has to postulate that the electron avalanche ionization creates a conduction band electron density of $N > 10^{17}$ el/cm^3 in the surface region for damage to occur.[2] Alyassini and Parks[3] estimated from changes in the reflected intensity of a probe beam that 10^{18} el/cm^3 are present in the conduction band at the surface when damage occurs.

In this study we measure the emission of these electrons from surfaces of insulators and semiconductors as a function of laser intensity, wavelength and pulse duration.

The long range objective is to use photoelectron emission as a tool to predict surface damage thresholds and to determine the effect of surface structures and surface composition on damage thresholds.

Laser induced charged particle emission from insulator surfaces has been studied before (see ref. 4 and references therein), but found to be irreproducible. It is our contention that the irreproducibility is a consequence of irreproducible surface conditions created by performing the experiments in vacua with pressures great than 10^{-6} torr.

EXPERIMENTAL PROCEDURE

We used equipment and techniques developed at LLNL for rapid and reliable laser-damage threshold measurements.[5] The laser has a wavelength of 1064 nm and a pulse-width variable from 1 ns to 40 ns. Frequency doubling and

tripling equipment has been used. Laser pulse energy is measured by calorimeters developed at LLNL. The peak fluence is measured in two ways: (1) A silicon-vidicon system[6] electronically records pulse intensity and computer analysis determined peak fluence within several minutes after exposure. (2) The pulse also exposes a photographic plate, which is later developed, densitometered and analyzed to obtain peak fluence. Agreement between these two measurements in now ± 10%.

The target is held inside a insulated Faraday cup suspended on a precision manipulator in a UHV vacuum system (Figure 1). The openings in a Faraday cup are slits 1/2 inch wide and 1 inch high. The beam diameters is approximately 3 mm. The diameter of the inner Faraday cup is 4 inches. In the experiments reported here no voltage is applied between the target and the Faraday cage. The emitted charge is measured with a Digital Keithley Autoranging Coulombmeter (Model 616). During the laser pulse the ion pump and the ion gauge are switched off to reduce the background of charged particles in the chamber held at pressures lower than 10^{-7} Pa by a Helium Cryopump. An experiment begins by exposing the target to several laser pulses with a fluence 1/4 to 1/2 of the damage threshold until reproducible electron emission is measured. These "surface cleaning" pulses are associated with measurable bursts in the pressure of the vacuum chamber, indicating that laser stimulated desorption of contaminants from the target surface occurs. Re-contamination of the surface thereafter is small since the laser fires approximately every 3 minutes, and only a small fraction of a monolayer would readsorb from the vacuum environment at 10^{-7} Pa during 3 minutes. All

measurements are performed on the same precleaned spot unless the damage threshold is accidentally exceeded. A new spot is then cleaned. The new spot yields the same results, within experimental errors. The data shown in the next section are usually from a number of different sites.

RESULTS

1.) Electron emission as a function of Laser Fluence (Pulse length = 1 ns). Figure 2 shows electron emission as a function of fluence for ZnS and SiO_2 for $h\nu$ = 1.16 eV. The slope of the best fit lines is indicated. Figure 3 gives electron emission as a function of laser fluence for $h\nu$ = 3.5 eV for W, ZnS, GeO_2 and SiO_2. Table I summarized the observed functional dependence of electron emission as a function of fluence for two wavelengths and a number of different materials.

2.) Electron emission as a function of pulselength. Figures 4 and 5 depict the electron emission from CdTe as a function of laser fluence for $h\nu$ = 1.16 eV at pulselengths of 1 ns, 9 ns and 40 ns. In Figure. 5 the fluences at different pulselengths are scaled according to (pulse length)$^{1/2}$, e.g., the electron emission observed for fluence I is plotted at fluence I/(pulse-length)$^{1/2}$. Figure 6 documents for $h\nu$ = 1.16 eV the electron emission as a function of fluence from ZnS for 1 ns and 20 ns pulselength. In Figure 7 we have plotted for $h\nu$ = 1.16 eV the electron emission from NaCl as a function of fluence for 1 ns and 40 ns pulselength. In Figure 8 the results for 40 ns pulselength have been plotted at a flux scaled by $40^{-1/2}$.

SUMMARY

The results of laser induced electron emission from surfaces allow the following conclusions:

1) The electron emission shows a functional variation with fluence up to the damage threshold consistent with a model that assumes that electron emission into the vacuum is controlled by multiphoton excitation across the bandgap (see table 1). The dependence on bandgap and wavelength are inconsistent with a model assuming thermionic electron emission.

2) There is no evidence of an avalanche process as one approaches the threshold for optically visible damage.

3) The electron emission scales with pulselengths for materials with narrow and wide bandgaps as $\tau^{-1/2}$, when τ is the pulselength.

CONCLUSION

Pre-damage electron emission is a reproducible measure of the approach of a surface to the damage threshold. The spatial variation of electron emission will be used in the future to determine which local impurities or local structural variations lead to damage.

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[5] D. Milam, "Measurement and Identification of Laser Damage Thresholds in Thin Films," Proceeding of the Society of Photo-Optical Instrumentation Engineers, Vol. 140, Optical Coatings II.

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EXPERIMENTAL EQUIPMENT

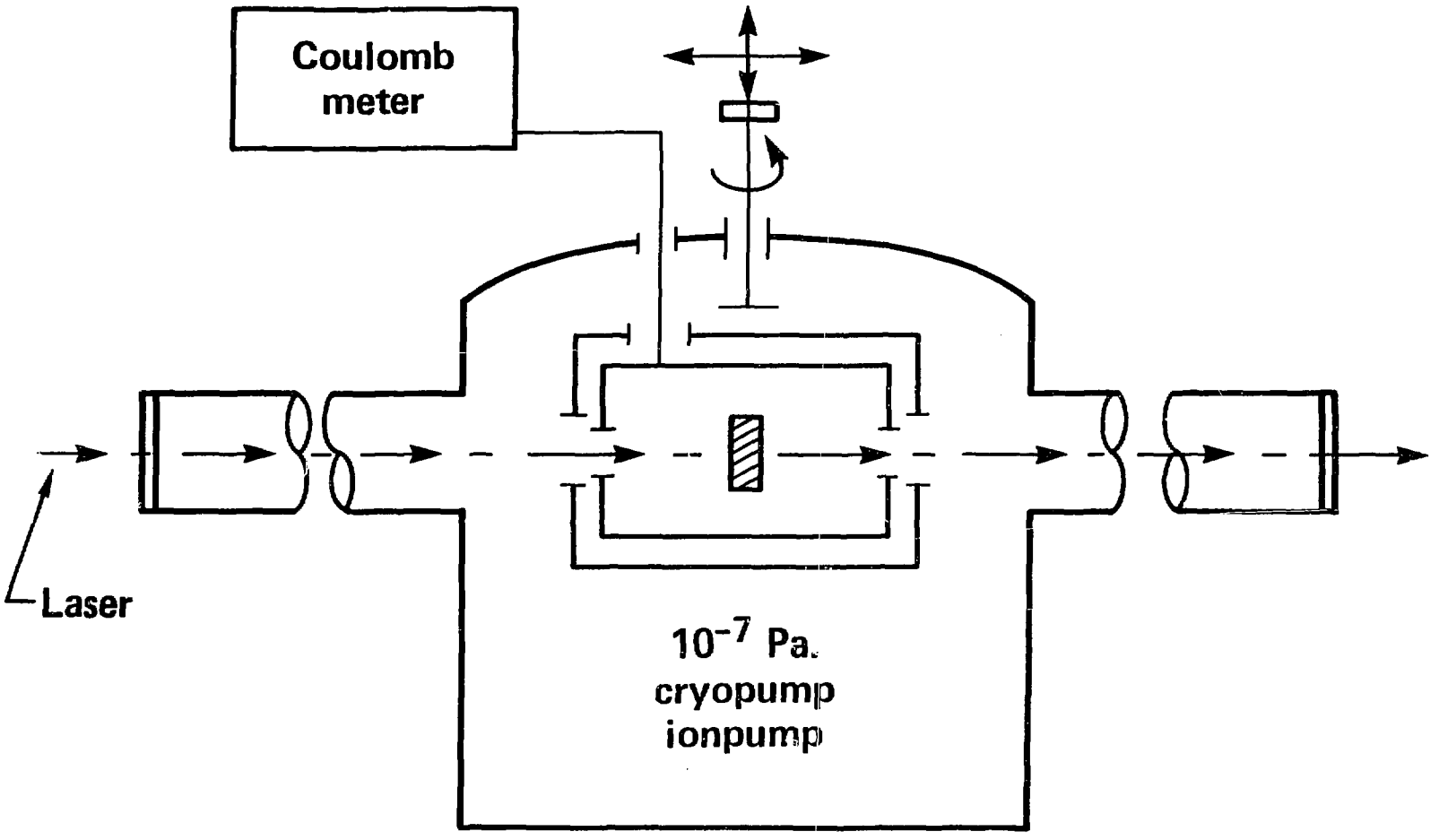

Figure 1

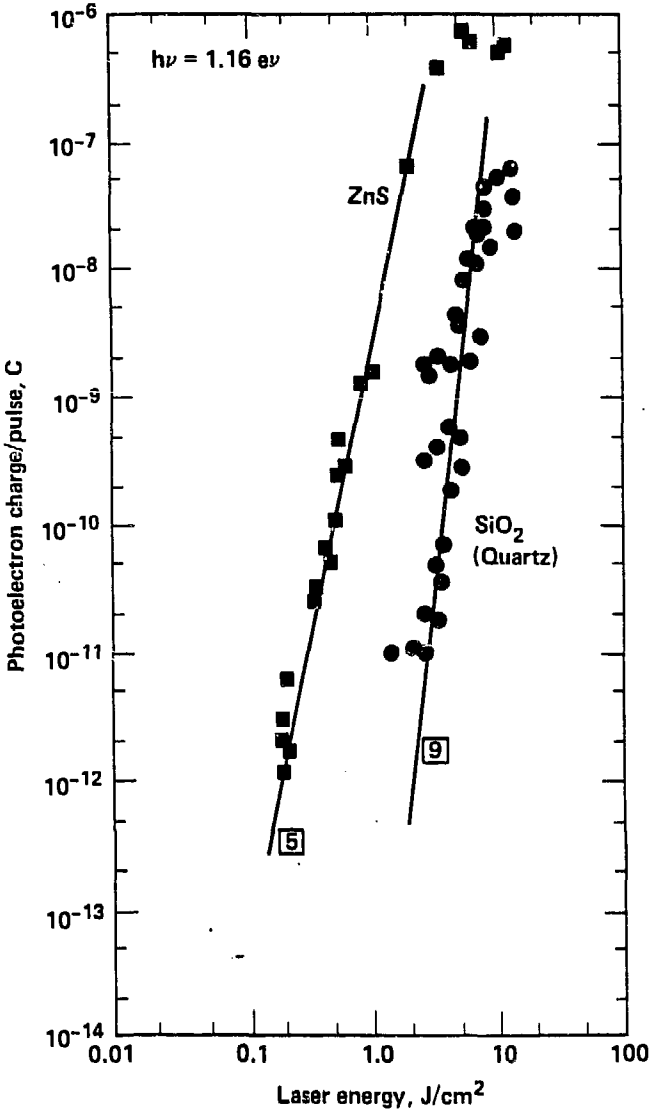

Fig. 2. Electron emission as a function of fluence. hν = 1.16 eV

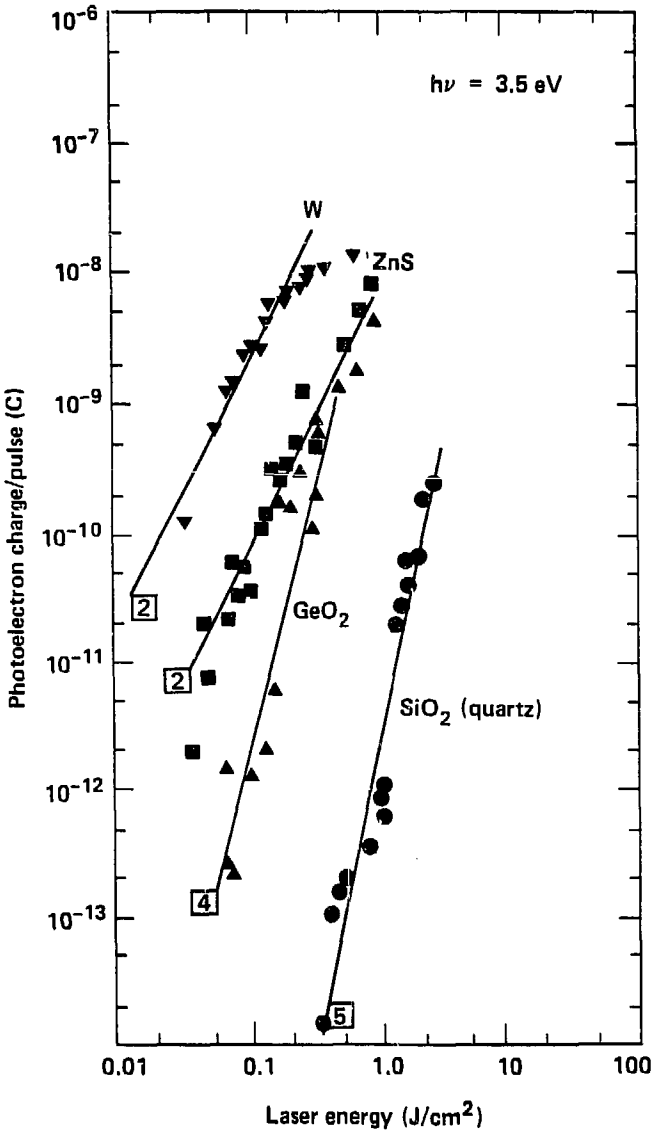

Fig. 3 Electron emission as a function of fluence. $h\nu$ = 3.5 eV

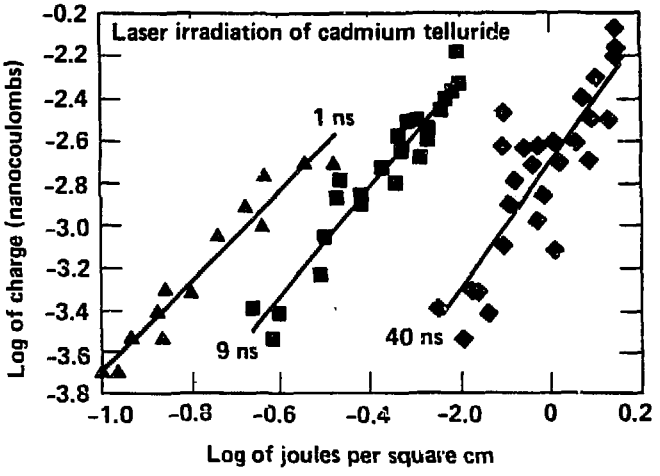

Fig. 4 Electron emission from CdTe as a function of fluence. Pulse length 1 ns, 9 ns, 40 ns

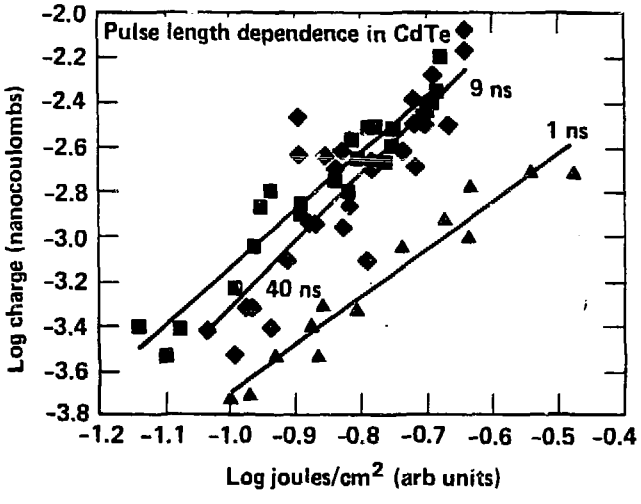

Fig. 5 Electron emission from CdTe as a function of fluence. Pulse length 1 ns, 9 ns, 40 ns. This abscissa is scaled by (pulse length)$^{-1/2}$ for each pulse length.

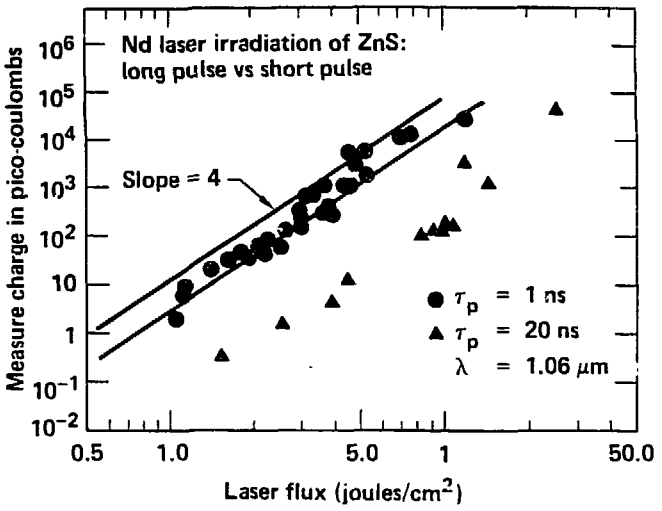

Fig. 6 Electron emission from ZnS as a function of fluence. Pulse length 1 ns and 40 ns.

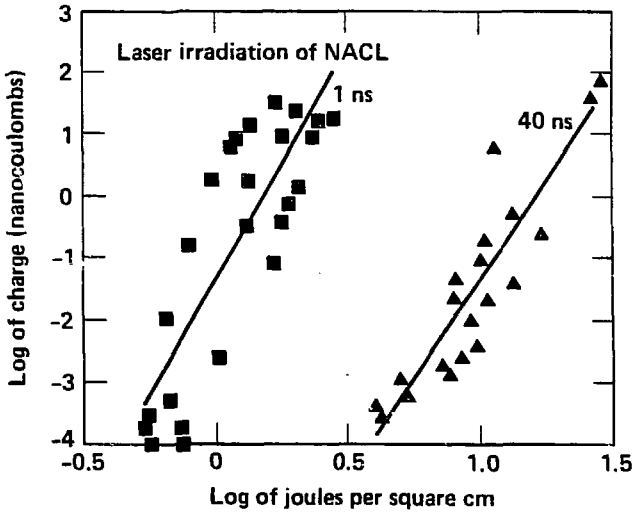

Fig. 7 Electron emission from NaCl as a function of fluence. Pulse length 1 ns and 40 ns.

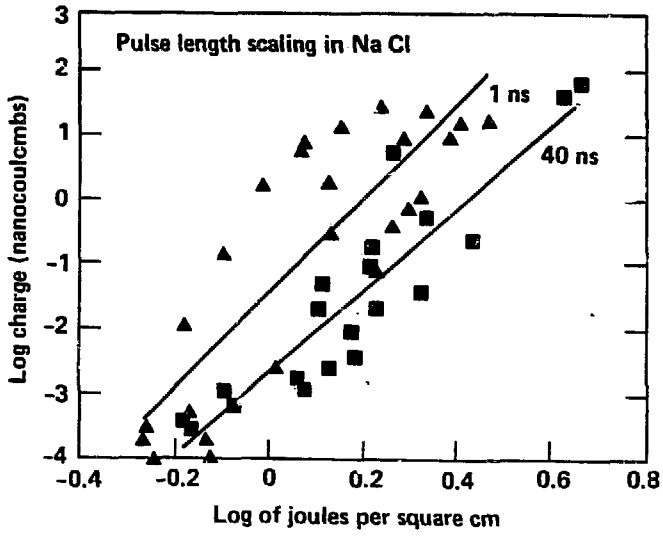

Fig. 8 Electron emission from NaCl as a function of fluence. Pulse length 1 ns and 40 ns. The abscissa is scaled by (pulse length)$^{-1/2}$ for the 40 ns pulse length experiments.

Table 1

Material	E_{gap} (eV)	E_{work} (eV)	E_γ	$N^*_{predicted}$	$N^*_{observed}$
CdTe	1.5	6.0	1.16	2	2
NaCl	8.75	4.2	1.16	8	8-9
SiO_2	8-8.4	5.0	1.16 3.5	7-8 3	9 5
ZnS	3.88	5.5	1.16 3.5	4 2	4-5 2

*Predicted slope from a simple, multiphoton model: $(E) = AI^N$