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TITLE: RATE EFFECTS OF STANDARD AND HIGH STRIP CURRENT MICROCHANNEL PLATE IMAGE INTENSIFIERS (MCPIIs)

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Rate effects of standard and high strip current microchannel plate image intensifiers (MCPIIs)

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ABSTRACT

The gains of gated MCPIIs at high repetition rates (up to 10 kHz) were measured. Comparisons were made between the gain behavior of a standard ITT type F4111 MCPII and similar device incorporating a high strip current microchannel plate. The most notable effect observed for the standard MCPII is a decline in luminous gain with increasing gate repetition rate and with higher input irradiances. The intensifier with the higher strip current microchannel plate (MCP), on the other hand, exhibited little or no reduction in gain for gating frequencies up to 10 kHz under similar test conditions (60 pJ/cm^2 input energy density). The charge storage capacity and recharge time of the standard MCPII are most likely the limiting factors in its ability to maintain a constant gain at high repetition rates. The limiting effect of the recharge time on the MCP gain is calculated and compared to the actual measurements.

1. INTRODUCTION

Previously, MCPIIs have been characterized for Nevada Test Site (NTS) applications requiring the single transient acquisition of a radiation induced optical image with 1 or 2 ns gate widths. Recently, efforts have been directed towards characterizing these MCPIIs under pulsed illumination at variable repetition rates with 5 ns or longer gate widths. This task requires the use of new gate pulsers and possibly new MCPIIs.

In this paper, a new gate pulser capable of operating up to 10 kHz is used, and the results using a new, high strip current MCPII are presented. "Standard" MCPIIs have conductivities on the order of 9 microamps at 930 V. The high strip current MCPII also used in this study has a conductivity that is over three times higher: 33 microamps at 930 V. It is expected that the higher current capabilities of this MCPII will allow it to operate without a drop in luminous gain for gating frequencies that are much higher than previously reported. The effects of input energy density on the gain as a function of gating frequency are also studied. Before presenting the details of this experiment or the results, some of the basic principles of operation for gated MCPIIs are covered.

2. GATED MCPII PRINCIPLES OF OPERATION

The voltages used for testing the two gated MCPIIs are shown in Fig. 1. The potential of the photocathode (PC) is normally greater than the input of the MCP by 60 V. This 60 V back bias prevents photoelectrons from leaving the PC except during the -300 V gate pulse. At that time, the PC potential is 240 V less than the MCP input causing any photoelectrons created by the optical input during the gate pulse to be

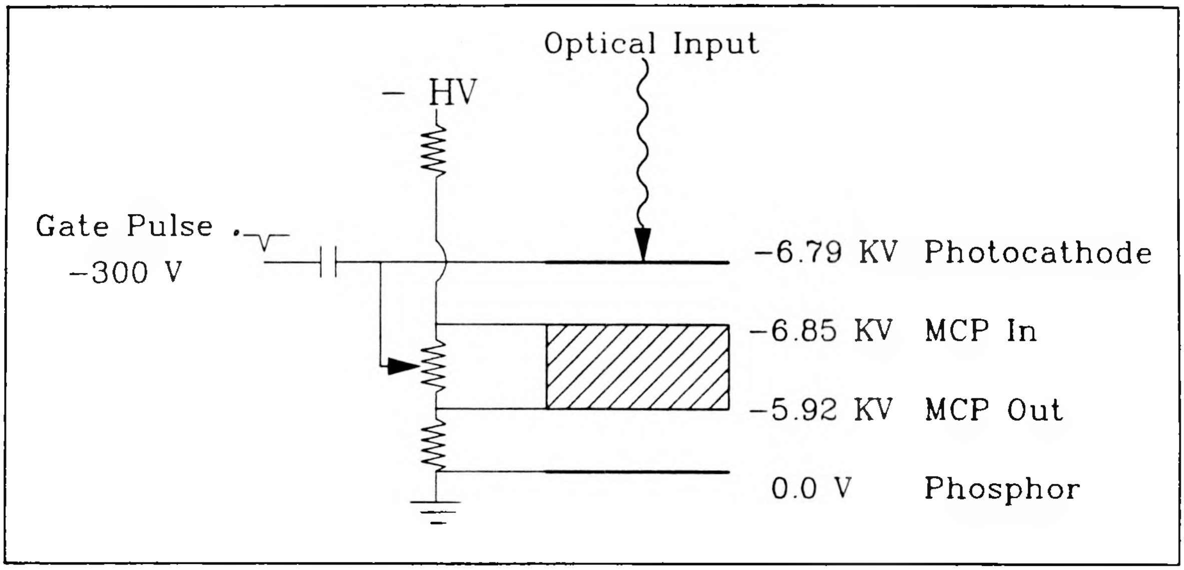

Fig. 1. Schematic representation of a gated MCPII showing bias voltages.

accelerated to the MCP input. These photoelectrons are multiplied as they cascade down through the MCP. The electrons then emerge to be accelerated toward the ground potential at the phosphor output screen.

The electron multiplication is a strong function of the bias applied across the MCP. In fact, a power fit to the data yields $G = (V/460)^{10}$ revealing that the gain (G) is about equal to the voltage (V) raised to the tenth power. A plot of this function is shown in Fig. 2. For the experiments described in the next section, the MCP was initially biased with 930 V. This corresponds to a gain of over 1100. From the curve, it is obvious that a small change in voltage leads to a large change in gain. That fact combined with the limited charge storage (capacitance) and low conductivity are responsible for the limited dynamic range when operated in a repetitious pulsed mode. Therefore, when the MCPII is gated on and an optical signal hits the photocathode, the charge depleted from the MCP causes the voltage across the MCP to drop.

Following the optical signal, the MCP voltage recharges with the characteristic profile of a capacitor. The time it takes to recharge is characterized by the RC product for the MCP front surface sheet resistance (R) and input to output capacitance (C). It is assumed that the capacitance of 18 mm diameter MCPs of the type used is on the order of 10 pF. The conductivity, however, is low and varies with MCP. The standard MCP reported on here has an effective resistance of 105 megaohms at 930 V, and the high strip current MCP has a resistance of 28 megaohms. This corresponds to an RC time of 1.05 mS and 0.28 mS, respectively, when the assumption of 10 pF is made. It is these recharge times that are much longer than the 7 ns optical pulse used in this study that causes problems both with the maximum gain for a single pulse and the gain for repetitious operation. Because there is so little recharging done during the pulse, only the charge previously stored can contribute to the pulse amplification. Also, if the pulse repetition rate is such that the pulse repeats before the MCP has completely recharged it will not be fully amplified. This is illustrated in Fig. 3, which represents MCP voltage as dropping by 6% instantaneously (7 ns) to 874 volts (Vm) at a 1 KHz rate after being in equilibrium at the full applied potential of 930 V. This 6% voltage drop is enough to drop the gain by 50% (see Fig. 2). Even with the faster recharge time, the MCP only recharges to 928 volts (Vp) before the next pulse arrives. However, the longer RC time of 1.05 mS only allows the potential to reach 910 volts in 1 mS. As the repetition rate is increased the recharging time becomes ever more critical. For example, Fig. 4 shows the calculated results of tripling the rate from 1 to 3 kHz using the faster recharge time of 0.28 ms. Therefore, it is

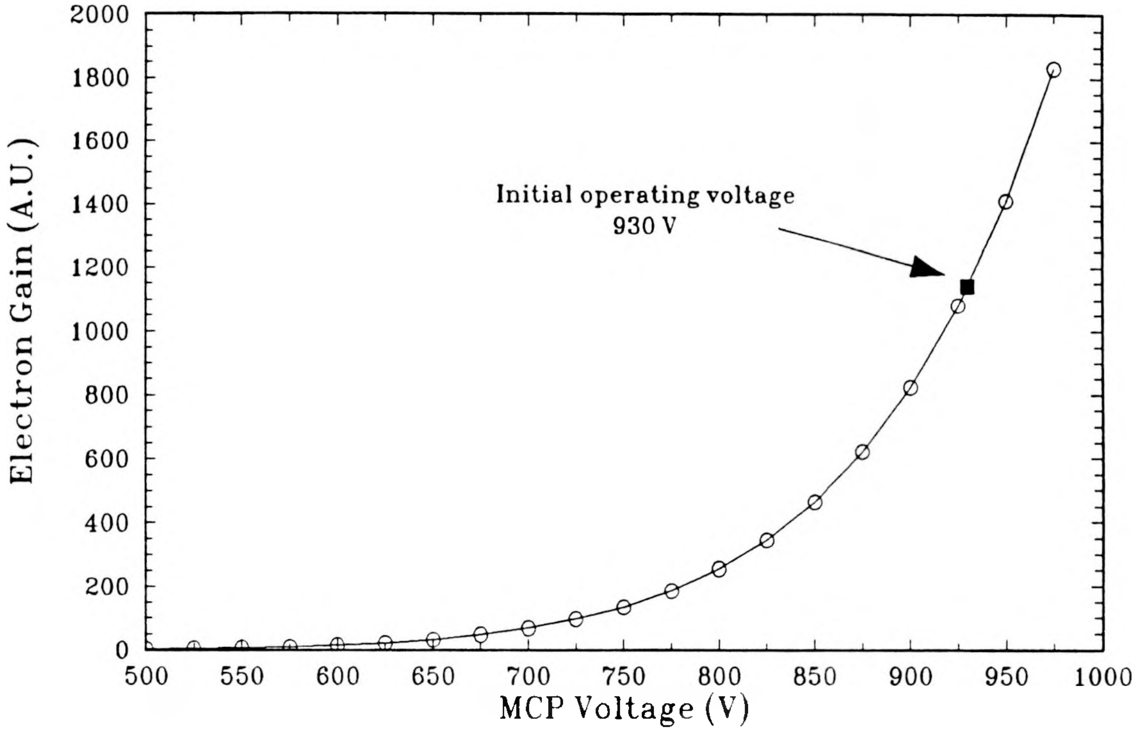

Fig. 2. Electron gain versus applied MCP voltage.

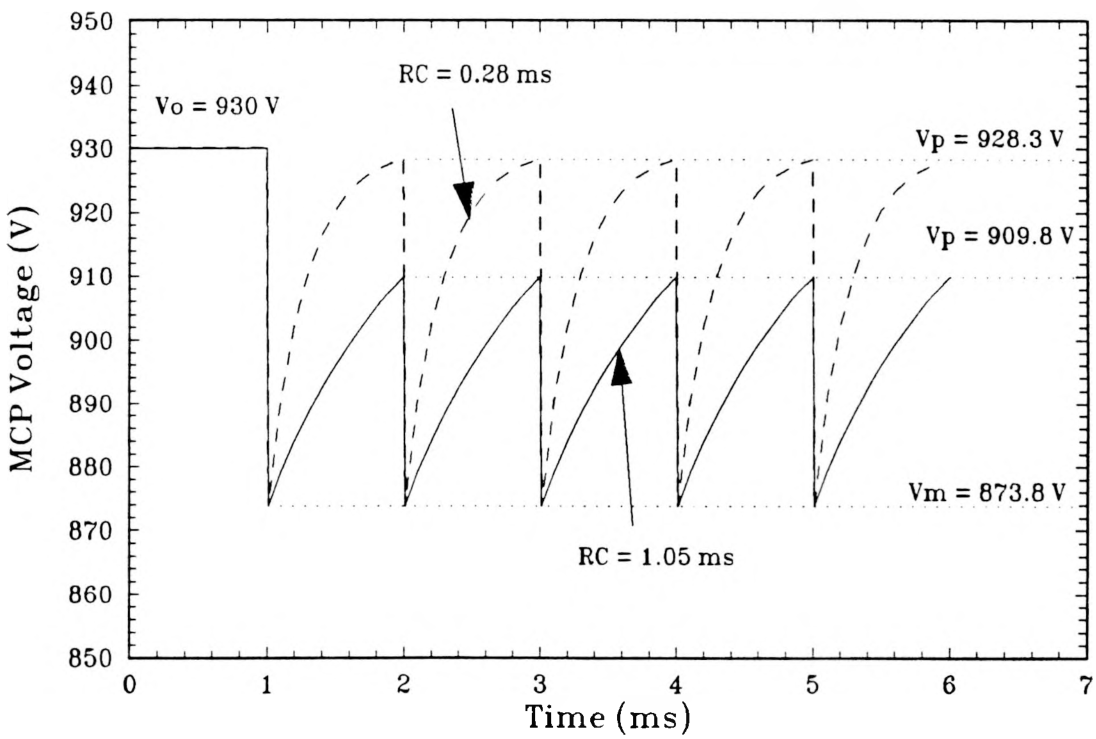

Fig. 3. Calculated recharge timing of two MCPs of different conductivities at 1 kHz pulse repetition rate.

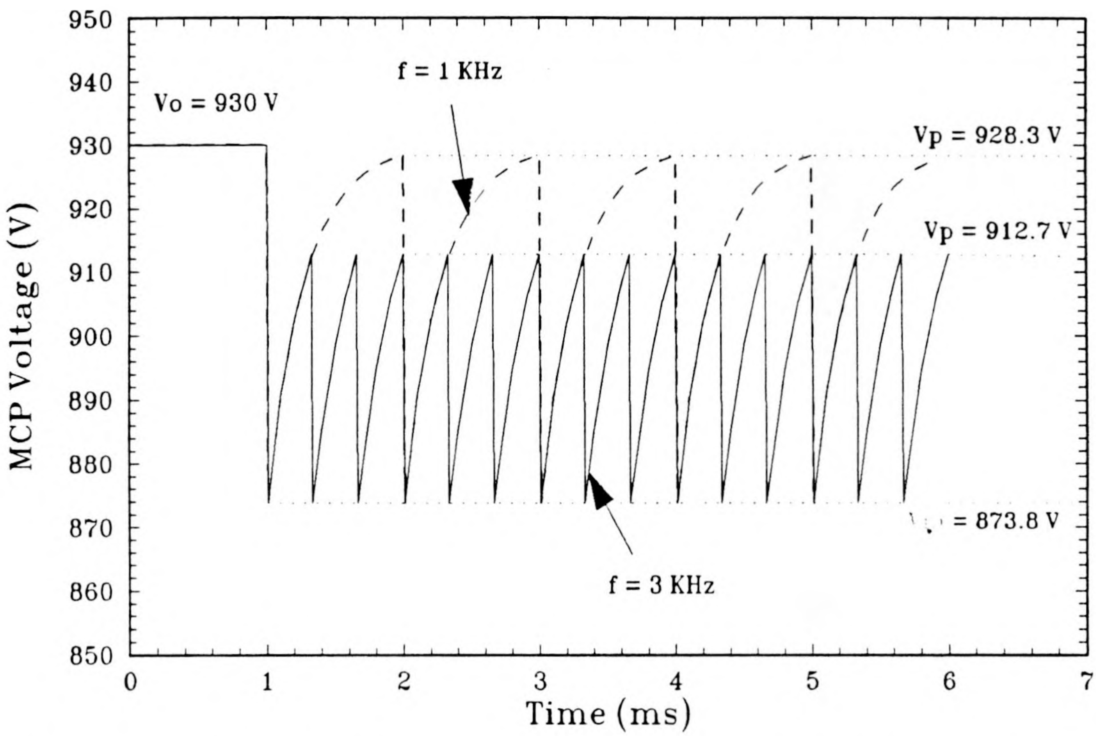

Fig. 4. Calculated recharge timing of one MCP at two different gate repetition rates of 1 and 3 kHz.

expected that the MCP with the higher conductivity would maintain its luminous gain in pulsed operation over a larger dynamic range than the standard MCPII.

3. EXPERIMENT

To determine how the optical gain of a MCPII varies with repetition rate and input optical energy density, a setup similar to that illustrated in Fig. 5 was assembled. It consists of a variable repetition rate pulser, a variable voltage pulser, a laser diode, the MCPII and its bias network, a gate pulser, and a variety of photodiodes, detectors, oscilloscopes, and counters. The procedure for performing the rate and energy dependent measurements is described next.

A Sony SLD201V-3 laser diode with a wavelength of 770 nm was pulsed on with varying amplitude pulses (no dc current) at various repetition rates and its light was projected onto the photocathode of the MCPII with a small lens. The responsivity of both MCPII photocathodes at 770 nm is 14 mA/W. The input pulse's energy was measured with a silicon photodiode, and the pulse's spot size at the MCPII was measured with a CCD camera inserted in place of the MCPII. The amplitude of the optical pulse was varied by changing the voltage from the HP 214B pulse generator. The timing (relative to the gate pulse) and width of the optical pulse was also controlled with the same pulser. The width was maintained at about 7 ns and the peak power was varied between 1 and 20 mW.

The pulse repetition rate of the optical signal and the gate pulse was set using an HP 8012B pulse generator. The period between pulses was measured with a Fluke 1953A counter. The 8012B was used to trigger the 214B. The timing of the optical pulse was synchronized to coincide with the center of the gate pulse at the MCPII by adjusting the delay of the 214B's pulse out. The gate pulse amplitude and width were controlled by the Current Research VSP-100 pulse generator. The amplitude was set to -300 V, and the width was set to 20 ns.

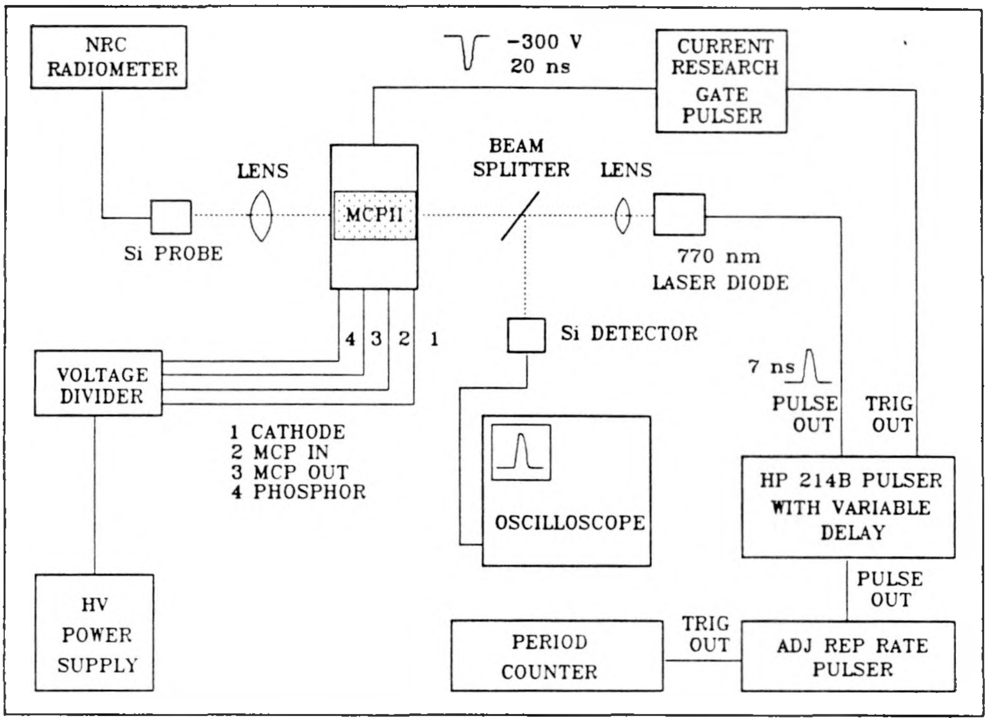

Fig. 5. Experimental setup used to measure MCPIIs at variable repetition rates and irradiances.

The output signal from the MCPII's phosphor was imaged 1:1 onto a NRC 835 radiometer probe with a 1 cm diameter silicon head. This geometry collects about 3.5% of the total optical power emitted by the Lambertian phosphor source. At each repetition rate and energy level, the average optical power collected from the MCPII was measured. The energy per pulse was obtained by multiplying the average power by the pulse period. The results presented in the next section show normalized gain versus gate frequency. The normalized gain was obtained by dividing the output irradiance by the input irradiance and setting the gain of all curves equal to 1.0 at 15.6 Hz. Actually, even without considering the factor of 28 lost in the imaging system, the output power exceeded the input power by nearly three times. This implies an overall gain of about 90 for incident light at 770 nm.

Because the MCPII amplified the quantity of light reaching its photocathode, it was relatively easy to saturate it, especially with small spot sizes and increased irradiances. At 800 Hz, a transfer curve relating output energy to input energy was made for each MCPII with a spot size of 0.143 cm^2. The results indicated that the input energy density should be kept below 100 pJ/cm^2 to avoid saturating the MCP. With this value as a guide, the gain for the standard MCPII was measured as a function of pulse repetition rate for input energy densities of 26.5 pJ/cm^2. The gain for the high strip current MCPII was measured at the higher input level of 59.4 pJ/cm^2. These levels prevented the MCPIIs from becoming locally saturated and led to the fairly predictable responses reported in the next section.

4. RESULTS, DATA ANALYSIS, AND DISCUSSION

The data obtained using the previously mentioned techniques were tabulated and plotted. The parameters key to the plots are normalized gain versus pulse frequency. Variations of MCPII type (recharge time) at a constant input pulse energy and variations of input pulse energy for one MCPII (constant recharge time) are plotted separately. The curve from the theoretical MCPII with an RC time constant of 0.28 ms is also shown for comparison. Details about the two graphs follows.

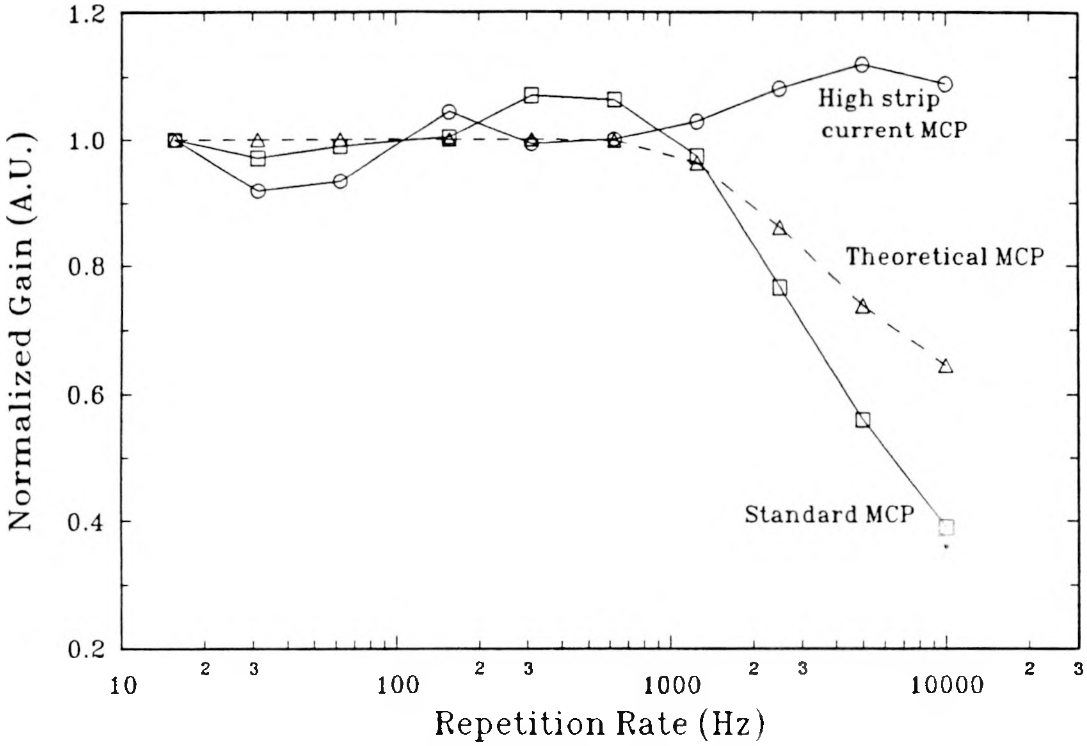

Fig. 6. A comparison of the measured optical gain as a function of gate repetition rate for the standard, high strip current and theoretical MCPII.

In Fig. 6, normalized gain is plotted as a function of pulse frequency for the standard MCPII and the high strip current MCPII at an input energy density of 59.4 pJ/cm^2. The response of the theoretical high strip current MCPII with a 0.28 ms time constant is also plotted. This theoretical curve assumes that the input energy density was at the appropriate level to lower the MCP voltage by 6% and the electron gain by 50%.

It is clear from Fig. 6 that the high strip current MCPII's gain does not roll off, even at 10 kHz. The improved gain response demonstrated by this MCPII is a result of this increased MCP conductivity and thus its faster recharge time. The fact that the gain goes up for frequencies above 2 kHz is probably a result of errors in the data. The data was especially difficult to obtain accurately at the low frequencies. If the gain at the low repetition rates was higher, there wouldn't appear to be a rise in gain at the high rates. Nevertheless, the performance of the high strip current model even exceeded the performance of the theoretical model, which had a normalized gain of 0.8 at 3.3 kHz.

The shape of the standard MCPII's gain curve means that the recharge time of the MCP limited its performance for frequencies above 2 kHz (at 59.4 pJ/cm^2). At a normalized gain of 0.8, the frequency is 2.2 kHz. The rise in gain for frequencies around 400 Hz is also probably due to errors. Because cw optical power on the order of nanowatts was the signal level for both the input and the output, the signal-to-noise ratio was at times no better than 2:1.

To determine the effect that input energy density had on the gain curve, the input level was reduced to 26.5 pJ/cm^2 and the standard MCPII was measured again. In Fig. 7, the response of the standard MCPII is plotted for both input levels: 26.5 pJ/cm^2 and 59.4 pJ/cm^2. Figure 7 shows how reducing the input irradiance improved the frequency response for the standard MCPII. A nearly 50% drop in input irradiance led to an extended frequency roll off (at G = 0.8) of about 1.7 times (from 2.2 kHz to 3.7 kHz).

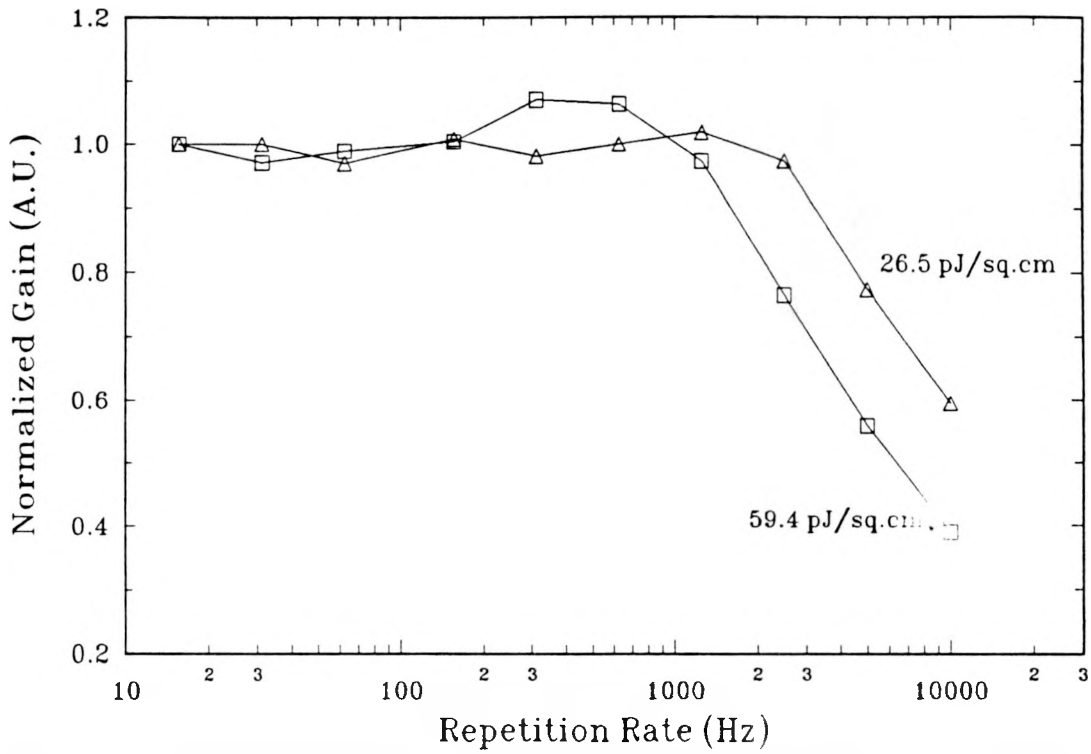

Fig. 7. A comparison of the gain of a standard MCPII at two different input energy densities.

The results of these measurements indicate that a high strip current MCPII (I = 33 microamps at 930 V) is required for high repetition rate gating applications where the gating frequency exceeds 3 kHz. Such a MCPII offers a relatively flat gain for pulse rates up to 10 kHz and input energy densities below 100 pJ/cm^2. Standard MCPIIs (I = 9 microamps at 930 V) can achieve a similar gain response up to 3 kHz, but only for input energy densities below about 25 pJ/cm^2.