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Transient Photoconductivity in the Ferromagnetic Semiconductor $CdCr_2Se_4$

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Abstract. The transient photoconductive response time of the ferromagnetic semiconductor $CdCr_2Se_4$ was measured to be smaller than 90 ps, the response time of the scope. The measurements were performed at room temperature (300 K) for 0.53 and 1.06 μm excitations using a mode locked frequency-doubled YAG laser.

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Recently, there has been much interest in the fabrication and application of photonic switches. The applications of these switches range from material studies to the measurement of the transient response of fast electronic devices. Photoconductive switches with response times ranging from 6 ns to ~1 ps have been reported [1–4]. Semiconductors such as Si [1], Cr:GaAs [2], Fe:InP [3], and amorphic Si [4] have recieved much attention. Variation of responses is attributed to carrier relaxation lifetime, contact effects and method of biasing the switch. The use of Si as a material for semiconductor switches has the disadvantage that carrier recombination in Si is slow, of the order tens of microseconds; therefore the repetition rate of this device is limited. A high repetition rate of the order of 1 GHz can be obtained by using Cr:GaAs, which has a free carrier lifetime of 100 ps. In contrast with Si, this device turned off automatically owing to the short life time of the carriers. The introduction of defects in silicon (now amorphous silicon) will vary the rate of decay of the photocurrent from greater than 200 ps to less than 4 ps, depending on the density of defects. Fe:InP optoelectronic switches have been developed with response times which vary from 6 ns to less than 100 ps depending on the starting material processing procedure. These devices have shown an efficient and broad band high speed response to a broad spectrum of excitation, and may be better suited for highspeed analog signal processing applications than previously reported Si and GaAs switches. $CdCr_2Se_4$ a ferromagnetic semiconductor has been intensively studied due to the strong mutual influence of magnetic, optical and electrical properties, which leads to an anomalous dependence of absorption edge, electrical conductivity and magnetoresistance on temperature and on magnetic field [7–11]. We have reported an ultrafast photoluminescence recombination time of 3.8 ps for $CdCr_2Se_4$ at room temperature [7]. This short carrier recombination time suggests that $CdCr_2Se_4$ can be used for an ultrafast on and off optoelectronic switch.

We report the performance of a new ultrafast photoconducting switch using the ferromagnetic semiconductor, $CdCr_2Se_4$. The $CdCr_2Se_4$ sample (0.5 mm × 1 mm × 2.0 mm) was attached to a microstripline. The active region of the photoconductive switch is defined by a 0.5 mm separation (gap) between the upper electrodes of the microstrip line. The dimensions of the microstrip line were such as to produce an approximate 50 Ω characteristic impedance (Z_0). The excitation consisted of 0.53 and 1.06 μm pulses of durations approximately 30 and 45 ps, respectively, from a mode locked frequency-doubled YAG laser. Using an EG&G Princeton Applied Research (EG&G) 4420 boxcar averager, 4421 sampled integrator, 4402 signal processor and a Tektronix S-4 sampling head, the photoconductive response of the $CdCr_2Se_4$ switch to the 0.53 μm excitation (Fig. 1) displays a rise time (t_r) and fall time (t_f) of approximately 90 ps. The ultrafast switch output signal is

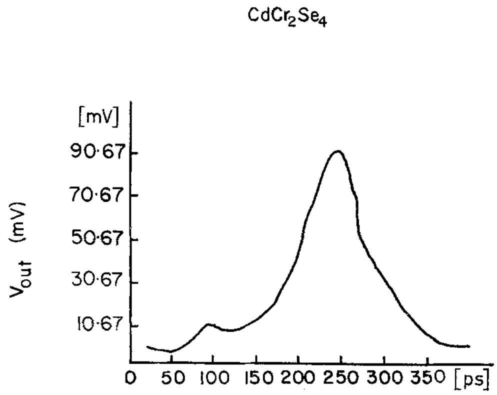

Fig. 1. Sampled response of $CdCr_2Se_4$ ultrafast switch to the excitation of wavelength (λ) 0.53 μm ($t_f = t_r \approx 90$ ps)

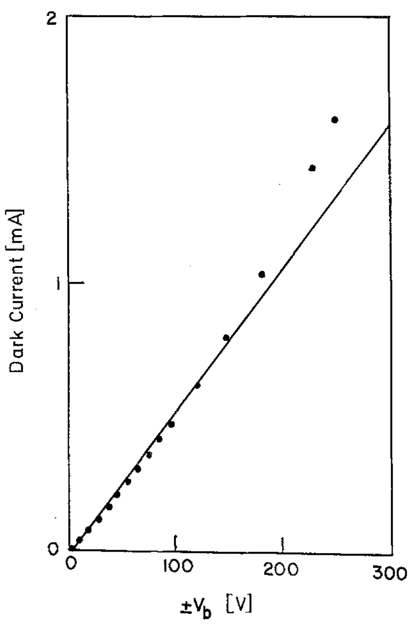

Fig. 2. Dark current [mA] as a function of negative and positive voltage. Region of linearity is between −149 and +149 V

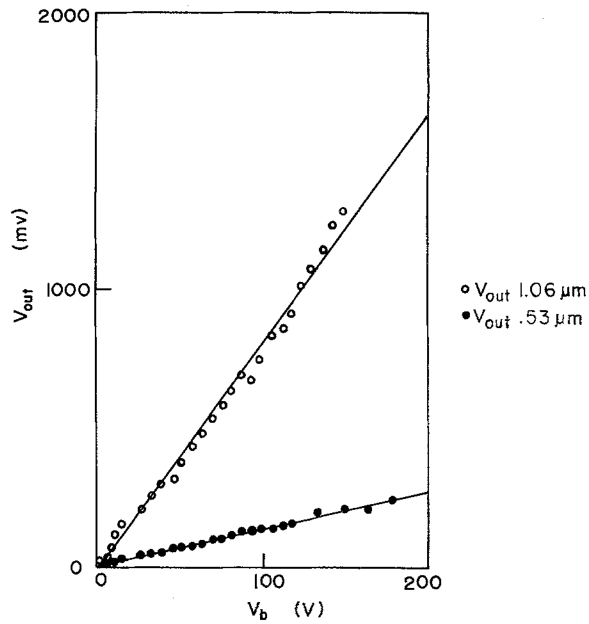

Fig. 3. Bias voltage (V_b) dependence of the photoconductive response (V_{out}) for 0.53 and 1.06 μm at 3.1 and 11 GW/cm^2 illumination intensity, respectively. Note the linear relationship in both cases

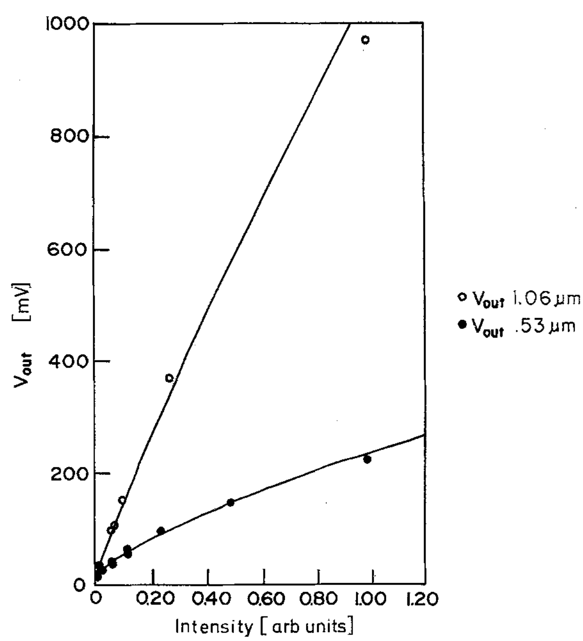

Fig. 4. The photoconductive response as a function of illumination intensity (arb. unit) for 0.53 and 1.06 μm at a maximum illumination intensity of 3.1 and 11 GW/cm^2, respectively. Note the sublinear relationship in both cases

limited by the measuring device response time. The jitter of the unit limits its response time to approximately 90 ps. The excitation energy was 55 μJ (10 Hz rep. rate), and the applied bias was 100 V. The dark current, bias voltage dependence is linear for a range of −149 to +149 V as shown in Fig. 2. Above 149 V the dark current increases superlinearly. This implies that without excitation the contacts are ohmic up to 149 V. Displayed in Fig. 3 is the photoconductive response of the ultrafast switch with respect to bias voltage (V_b) under the illumination intensities of 3.1 and 11 GW/cm^2 at 0.53 and 1.06 μm, respectively. Notice that in each case the photoconductive response is linear. The sublinear intensity dependence of the photoconductive response of 0.53 μm, as shown in Fig. 4, indicates that the electrical contacts are non-ohmic in character for the carrier densities achieved and "blocking" contacts do form. One explanation for this behavior is that the contacts could not supply additional carriers to replace those excited by the light pulse, thus the photocurrent would not increase linearly with illumination intensity but instead would tend to saturate. The slightly sublinear intensity dependence of the photoconductive response at 1.06 μm, as shown in Fig. 4, may be explained by one of two ways: 1) The below gap response may be due to defects in the sample and the partially blocking contacts have a small effect on the intensity dependent photoconductive response. 2) A two photon absorption process is occuring and the contacts are completely nonohmic and are having a severe effect on the photoconductive response. It seems the first case is more probable, where the *d*-levels contributed by the chromium plays an important role along with defects in the below gap response.

A space charge field will be generated near a nonohmic contact resulting in the collapse of the applied electric field across the semiconductor, which artificially reduces the photoconductive decay time. In addition to a photoconductive decay time that is not representative of electronic transport within the semiconductor, there is usually a fairly strong photovoltaic response. In the case of the $CdCr_2Se_4$ switch, there was no photovoltaic response, suggesting (in conjunction with the linear relationship between the photoconductive response and bias voltage) that the contacts are only partially nonohmic. The effects of a nonohmic contact to the photoconductive response can be circumvented by applying a pulsed electric field with a temporal duration less than the space charge field build up time, the dielectric relaxation time. Depending upon the particular semiconductor and the photoexcitation, the dielectric relaxation time can vary from microseconds to femtoseconds.

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