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TITLE: GRAPHITE AS A PICOSECOND LASER ACTIVATED OPENING SWITCH

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Graphite as a Picosecond Laser Activated Opening Switch

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Abstract:

Highly Oriented Pyrolytic Graphite exhibiting a high conductivity in the dark and a high resistivity when illuminated by intense laser light was used as an opening switch.

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In a recent experiment, Malvezzi et al. have observed a large decrease in the reflectivity of a semimetallic sample of highly oriented pyrolytic graphite (HOPG) as it is illuminated by an intense picosecond laser pulse when the fluence is above the melting threshold. They have found that the imaginary part of the refractive index reaches lower than -0.5 at 566 nm [1]. This unexpected result indicates that a phase transformation occurs and that the high temperature phase, which they believe to be liquid, is non-metallic. This experimental observation is consistent with the result of the recent pseudo-potential calculation that there is an energy gap in "isotropic" carbon [2]. The time resolved experiments [1] also show that the phase transformation is completed in time scales as short as $\sim 10\text{ ps}$. In the work presented here, we directly assess the change of resistivity of a HOPG sample used as a laser activated switch. We confirm the results reported in [1] by observing a large increase in the sample's resistivity under intense picosecond laser illumination. This unique property could allow one to use graphite as an opening switch since it is a semi-metal. Its conductivity in the dark state ($\sim 2.5 \times 10^5 (\text{ohm.cm})^{-1}$) is almost as good as that of pure copper. It could then be compared to semiconductor optoelectronic switches, noting that its operation is exactly inverse. It is conductive in the dark and its resistance increases when illuminated above the threshold. The main application of this type of switch is in the pulse power technology where the recent interest for inductive storage systems has created a need for an efficient, repetitive, jitter free opening switch [3]. In [4,5], we proposed to use a semiconductor material as opening switch and demonstrated that it is feasible. In this paper, we demonstrate that graphite is a suitable alternate material for opening switch applications with some advantages. To assess the possibility of using HOPG as a practical device, it is of great importance to measure the speed of the phase transition as well as the speed of its recovery. The technique used in [1] only allows to perform these measurements at the surface of the sample. Here, we directly study the opening speed of the HOPG switch which is equal to the response time for the phase transition and

find the best opening speed to be less than one nanosecond.

To demonstrate the operation of HOPG as opening switch, a circuit configuration of current charged transmission line as described in [4] was used (Fig. 1). In this type of circuit, the energy is stored under magnetic form in a transmission line and a square pulse is generated when the switch opens. The duration of the square pulse (30ns) is determined by the length of the transmission line (3m). The rise and fall time of the square pulse are equal to the switch opening time. A Q-switch mode-locked Nd:YAG, providing 30ps pulses at 1.06 μ m was used to illuminate the HOPG sample. The waveforms shown in Fig. 2 indicate that the opening switch action was obtained. It was found as in [1] that a high laser fluence is necessary to obtain this result (>140 mJ/cm²). The opening time was not reproducible from shot to shot; the fastest speed was less than 1 ns (oscilloscope limited). The maximum DC current in the c-plane that the sample can sustain was estimated to be 160 kA/cm². The switching efficiency was quite high: 90%, corresponding to a resistance of the sample of 450 ohms after illumination. The lack of reproducibility is attributed to the fact that the laser intensity and mode pattern were fluctuating. One other difficulty was that the thickness of the HOPG sample was not controlled. This is a determining factor since, for the opening action to be optimum, it is necessary that the total sample cross-section illuminated by the laser pulse undergoes the phase transformation. Although it is reported in [1] that the new phase is probably liquid, these first experiments do not allow to accurately identify its nature. A better understanding of the new phase would certainly allow us to better determine the switching parameters. Further research is necessary in this direction.

The subnanosecond opening speed, the fact that the switching efficiency of this material is quite good, and the fact that it can sustain a high current density make it a very promising candidate for opening switch applications. From a more fundamental point of view, it is of particular interest to note that HOPG is, to our knowledge, the only material exhibiting this type of behavior.

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Fig. 1: Experimental set-up for the generation of square pulses using a laser activated switch and a current charged transmission line.

Fig. 2: Three examples of waveforms generated as the graphite switch opens. Each trace is obtained with a different laser pulse but the sample of graphite is the same. The laser pulse energy is: a: 0.15 mJ, b: 0.14 mJ, c: 0.16 mJ.