Development of a GaAs Photoconductive Switch for the Magneto-Inertial Fusion Electrical Discharge System

Joshua Bell

Development of a GaAs Photoconductive Switch for the Magneto-Inertial Fusion Electrical Discharge System

Joshua Bell

Churchville-Chili Senior High School

LLE Advisor: William Donaldson

Introduction

The Magneto-Inertial Fusion Electrical Discharge System (MIFEDS) is an accessory used in the OMEGA Laser System. MIFEDS is used to generate a very strong magnetic field between two coils positioned around an inertial confinement fusion (ICF) target being shot by the OMEGA laser. This magnetic field is used to trap the high energy electrons that are emitted from the target, providing more energy to the fusion process. To generate this magnetic field, a very large increase in electrical current needs to pass through the two coils in a very short period of time. This current is provided by two large capacitors that are discharged into the coils through a rapid closing switch.[1]

At this time, an ionizing switch is employed to deliver the current, energizing the magnetic field. The ionizing switch uses two electrodes in a nitrogen gas atmosphere. The MIFEDS laser sends a focused pulse through a lens in the switch, ionizing the nitrogen gas allowing the current to arc across the electrodes, discharging the capacitors. The nitrogen gas switch has two limitations due to the arcing. The arc itself reduces the maximum current, which reduces the overall magnetic flux, and the electrodes are damaged from the arcing process requiring that the electrodes be replaced occasionally.

The Laboratory for Laser Energetics would like to evaluate alternative switching devices that can handle the high voltages and current while reliably delivering a fast switching time. One possibility could be to use a laser-triggered gallium arsenide (GaAs) solid state switch. The specific goal of this project was to develop an analytical model and a test setup to imitate the MIFEDS system. This allowed preliminary calculations and measurements to be made which characterized two available samples of GaAs. From this initial analysis and testing it will be determined if laser-triggered GaAs switches are viable candidates for use as a switching device in MIFEDS.

To be used on MIFEDS, the size of the GaAs must be optimized to prevent melting as a result of the energy flowing through it. The GaAs also needs to hold off the flow of current stored in the MIFEDS capacitors that discharge current into the coils until it is hit with the triggering laser. It must deliver an energy pulse of about 30 kV and 100 kA to the coils positioned around the ICF target in less than 400 nanoseconds. The lifetime of the GaAs switch is also important. Over time, the GaAs will be damaged from the laser pulses and the current going through it. The GaAs needs to maintain functionality for a long enough life time to be a feasible alternative to the nitrogen gas switch currently being used.

Analysis and Experimentation

In order to assure that the GaAs would not melt when shot with the laser, a study was done to determine the volume and dimensions of GaAs needed. A spreadsheet analyzing cross-sectional area and length of the GaAs was created. The other variables in the spread sheet are voltage, load resistance, current, specific heat of GaAs, the power of the laser, and the length of the laser pulse. The cross-sectional areas and lengths of the two GaAs samples available were put into the model and found to be sufficient with very little expected rise in temperature.

The samples of GaAs were modified by depositing gold electrodes on each end so that they could be integrated into a test setup (see Figure 1). Gold was chosen as the material because of its low resistance and high malleability.[2]

Figure 1 – Two samples of GaAs with gold electrodes. (The 2.25cm x 2.25cm x 0.3cm GaAs switch was used for all results in this report)

A test chamber was built to simulate MIFEDS. The chamber consisted of the square GaAs switch, capacitors equaling 500 pF, a load resistor of 1 MΩ, a DC power supply, and a 280-nH inductor to simulate the MIFEDS coils (see Figure 2). The test chamber had limitations as to how much voltage it could handle due to the maximum voltage rating on the connectors used. No more than 5000 V could be applied to the test fixture. Voltages approaching the 30 kV required for MIFEDS were therefore not obtainable and not tested at this time.

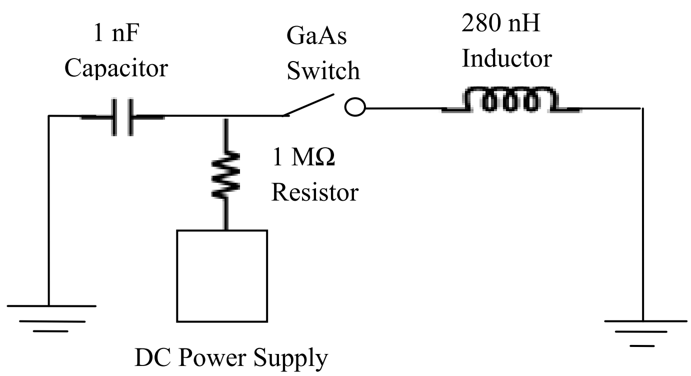

Figure 2 – Schematic of test chamber built to simulate MIFEDS

To get a general feel for how reliable the hold off of the GaAs switch was, the voltage was ramped up slowly until the maximum voltage of 5000 V was achieved. With the capacitors fully charged, the power supply remained set at 5000 V in order to keep the capacitor charge steady. An oscilloscope was placed in the circuit to measure any current increase. At 5000 V, the switch was capable of holding off the flow of current in the capacitors. This proved that GaAs has the potential to work in MIFEDS but still needs to be tested at voltages around 30 kV.

To measure the capability of the GaAs switch to deliver a high energy pulse in less than 400 nanoseconds, the voltage across the inductor and the current of the circuit were recorded using an oscilloscope as the GaAs switch was triggered by the laser. The oscilloscope was triggered when the GaAs switch closed, recording the voltage across the inductor vs. time and the current vs. time. With the power supply set at 5000 V, the GaAs switch was able to deliver 90 amps through the inductor (see Figure 3).

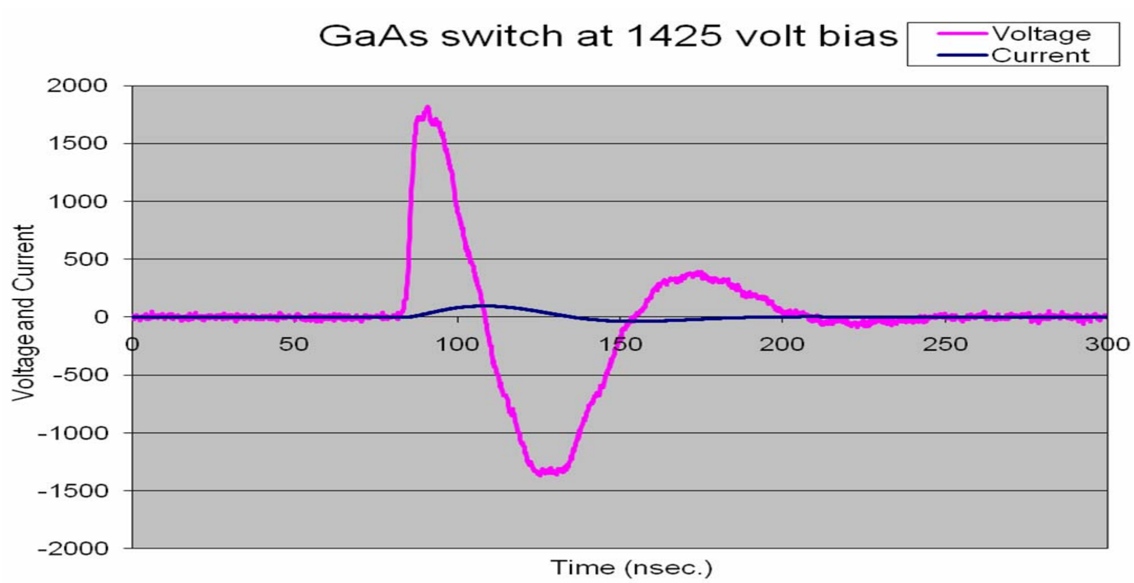

Figure 3 – Current and voltage across a 280 nH inductor produced
by a GaAs switch at a bias of 1.5 kV.

The current versus voltage (I/V curve) characteristic of the GaAs (see Figure 4) can be used as a measure of how well the switch is operating and any deterioration in performance due to damage over time. To evaluate the life of the GaAs switch compared to the nitrogen gas switch currently being used on MIFEDS, the GaAs switch was exposed to over 1000 laser shots coupled with the capacitors discharging. The I/V curve was measured both before and after the 1000 shots. Comparing these two curves shows that the leakage current through the GaAs had increased by about 40% but the switch was still functional. There was also visual damage to the switch electrodes. The fact that the switch was still operational after 1000 shots is promising, but additional testing should be done to fully understand what is causing the damage. Also, experimentation should be done to identify the point at which the damage to the switch becomes too severe for operation. An excess of damage to the switch would cause the switch to leak too much current.

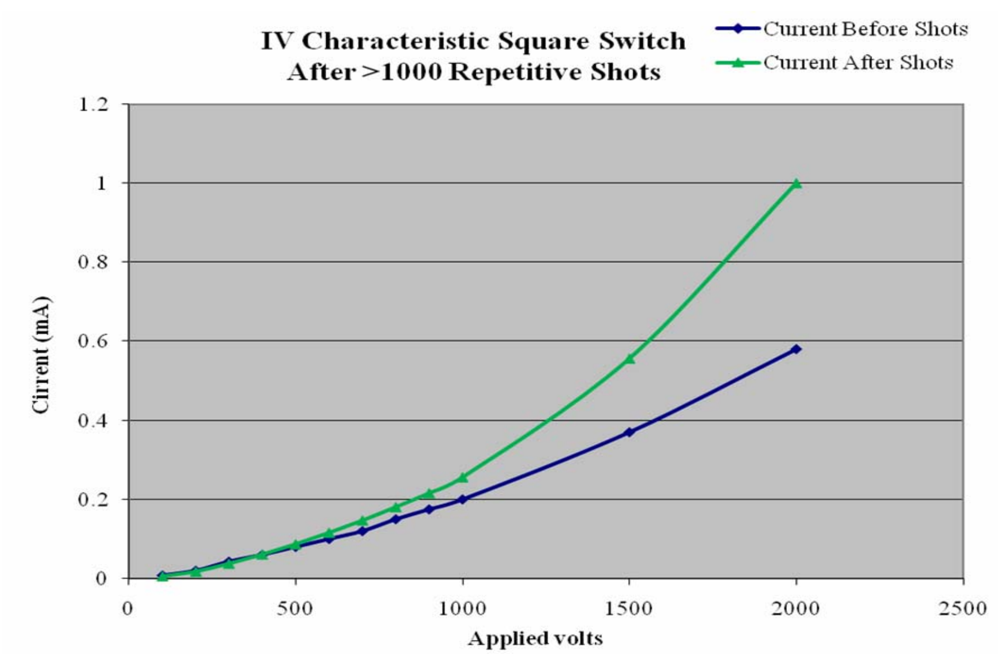

Figure 4 – I/V characteristic of the GaAs switch before and after more than 1000 laser shots.

This leakage current would reduce the energy stored in the capacitor and thus reduce the energy in the pulse used to generate a strong enough magnetic field around the ICF target.

Conclusion

A new GaAs solid state switch trigger has been investigated for the MIFEDS system used to generate very strong magnetic fields for OMEGA experiments. The new switch shows promise as an alternative to the nitrogen gas switch currently used for MIFEDS.

A test chamber for the switch was designed and built. Voltages ranging from 50 V to 5000 V were applied to the test chamber using a 2.3cm x 2.3cm x 0.3cm square sample of GaAs. Successful switching of the GaAs was demonstrated at all voltage levels. The switch was found to have an excellent hold off for the voltages tested. The GaAs switch also held up to over 1000 repetitive shots without being significantly damaged.

Additional testing needs to be done at higher voltages and currents. Also, the cylindrical shaped GaAs sample needs to be tested to further analyze and optimize the size and shape of the GaAs switch.

References:

[1] O. V. Gotchev, N. W. Jang, J. P. Knauer, M. D. Barbero, and R. Betti, “Laser-Driven Magnetic Flux Compression for Magneto-Inertial Fusion”, in *LLE Review* vol. 110, (2007) 65-73.

[2] W. C. Nunnaly and R. B. Hammond, “Optoelectronic Switch for Pulsed Power”, in

Picosecond Optoelectronic Devices, C.H. Lee, Ed. Academic Press (1984) 373-398.

Acknowledgements

Advisors:

William Donaldson

Orlin Gotchev

Machining:

Joseph Henderson

Electronics:

Joe Addamo

I would also like to thank Dr. R. S.Craxton for giving me the opportunity to take part in such a wonderful program.