

Effect of Substrate Thickness on Exploding Films

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Abstract—The exploding wire phenomenon is well researched due to its vast and practical applications which include, but are not limited to, shock wave generation, pulsed power, Z pinch physics, plasma ignition, fuses, and fusing applications. However, the focus of this research is on a surrogate for exploding wires. In this research, metallized capacitor grade-polypropylene film was used as an alternative for the traditional wire of a uniform diameter. The films that were studied have a broad variety of thicknesses ranging from 7 micron to 5 mil, lengths ranging from 5.08 cm to 19.05 cm, and sheet resistances of 1 ohm/square and 7 ohms/square. These films were used to study the effect of film properties on the transient plasma generation mechanism when exposed to a rapid high voltage discharge. The effect of these properties can be seen in the current waveform, similar to that of a uniform diameter exploding wire. By precisely understanding how the film properties affect the transient plasma formation, one can fine tune these variables to control the resulting characteristic pulse wave shape to fit a desired application.

I. INTRODUCTION

Exploding wire phenomenon is widely studied; however, there are many different theories that try to explain the transient plasma formation that takes place. This is due largely to the fact that this phenomenon has different, interrelated properties which include thermodynamic, electrical and mechanical properties [1]. Thermodynamic properties account for the necessary heat required in the system, while electrical properties account for the power, energy, voltage, and current in the system. Mechanical properties account for forces and tension in the system (i.e.: the loud bang associated with the phenomenon). The issue is further complicated by many variables in the transient plasma formation that are dictated by experimental parameters, which are in turn application driven. The aim of this paper is to explore exploding film as a surrogate to the exploding wire. Several relevant theories will be used to explore the characteristics of both phenomena.

II. EXPERIMENTAL SETUP

Five samples of different properties were used to study the effect of film properties on plasma formation. The thin films used were metallized, capacitor grade polypropylene samples. These included 7 micron, 5 mil, and low resistance 7 micron, as shown below in Table 1.

To study the effects of film thickness, thermally conductive and electrically non-conducting materials were used to

TABLE I
SAMPLE SPECIFICATIONS

Samples	Metallization Thickness	Substrate Thickness	Resistance
7 micron	100 Å	7 micron	7 ohm/square
Low Resistance 7 micron	100 Å	7 micron	1 ohm/square
5 mil	100 Å	5 mil	7 ohm/square
Insulated Low Resistance 7 micron	100 Å	Greater than 7 micron	1 ohm/square
Insulated 5 mil	100 Å	Greater than 5 mil	7 ohm/square

increase the thickness of the film. The resulting films are referred to as insulated low resistance 7 micron and insulated 5 mil. The widths of all the film samples were held constant at 0.32 cm.

The length of the films ranged from 5.08 cm to 19.05 cm. All of the experiments were carried out under standard room temperature and pressure. A capacitive discharge power source, shown in Fig. 1, was used.

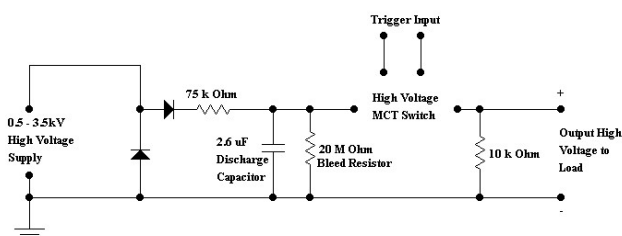


Fig. 1. Schematic of capacitive discharge pulser.

The power source contains a 2.6 μF capacitor that discharges through an NMOS controlled thyristor into the load. Pearson type 411 current monitors with conversion factors of 0.1 Volts/Ampere and 0.01 Volts/Ampere were used. A Tektronix P6015 voltage probe with an attenuation ratio of 1000:1 was also used. The pulse was discharged across the sample through two stainless steel electrodes, as illustrated in Fig. 2. The electrodes were 2.54 cm in diameter and the length between the high voltage and ground electrode was dictated by the length of the film samples. For all experiments, the capacitor was charged to a constant voltage of 2.5 kV_{dc}.

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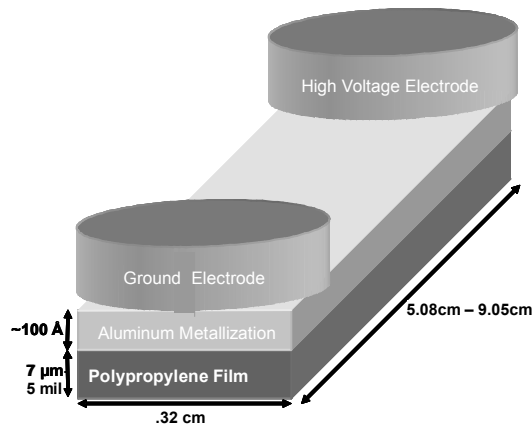


Fig. 2. Surface flashover experimental setup.

III. RESULTS

The waveform for the current of an exploding wire is typically of the form shown in Fig. 3 [2, 3]. Emphasis will be placed on Fig. 3D, which is the best representation of the exploding wire phenomenon, depicted in Fig. 4. This waveform is characterized by three phases, explained below. It is important to note that the resulting waveform in Fig. 5 from the exploding film is identical to that of the classic exploding wire.

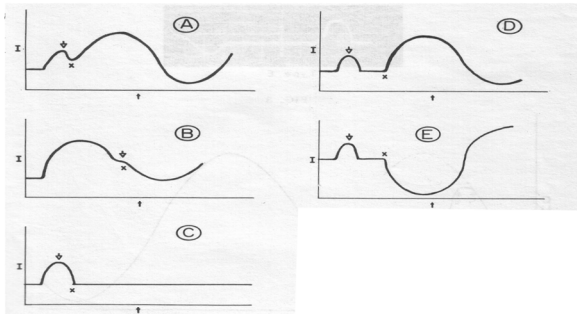


Fig. 3. Typical exploding wire current waveforms [2].

A. Initial Strike

After the thyristor switch has been triggered and voltage is applied to the film sample, ohmic heating causes the metallization on the film sample to melt by increasing current flow. As observed by Woffinden in his experiments, thicker films produce a higher initial strike [4]. This was shown where three films of different thicknesses, vacuum evaporated on a substrate of glass and plexiglass, were electrically exploded by a capacitive discharge source with energy ranging from 1 to 10 J.

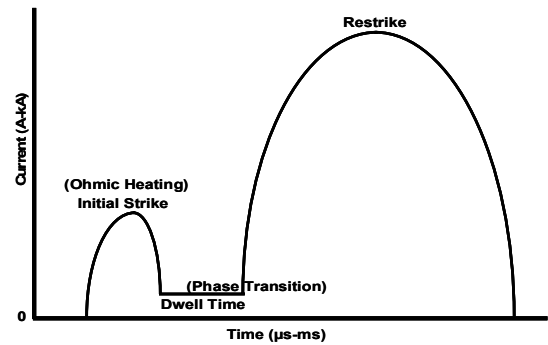


Fig. 4. Typical current waveform for uniform diameter exploding wires.

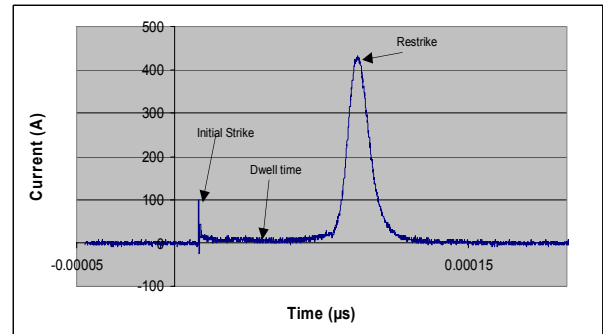


Fig. 5. Waveform of a 10.16 cm low resistance 7 micron sample.

There is a slower heating rate of the sample since the amperes per square centimeter of the cross section is reduced. However, it was noticed in our experimental results that resistance of the sample seems to play a major role in the initial strike. As seen in Fig. 6, the magnitude of the initial strike of the low resistance 7 micron sample is significantly higher, between 81.43 A and 193.7 A, than the higher resistance 7 micron and 5 mil samples, which ranged between 17.99 A and 44 A, and 22 A and 55.6 A, respectively. This is in agreement with a portion of Woffinden's result which states that low resistance materials usually have higher initial strike amplitude [4]. It was also observed that the magnitude of the initial strike reduces with an increase in the length when width is fixed. The exception is the low resistance 7 micron sample, which has higher initial strike magnitude at 19.05 cm.

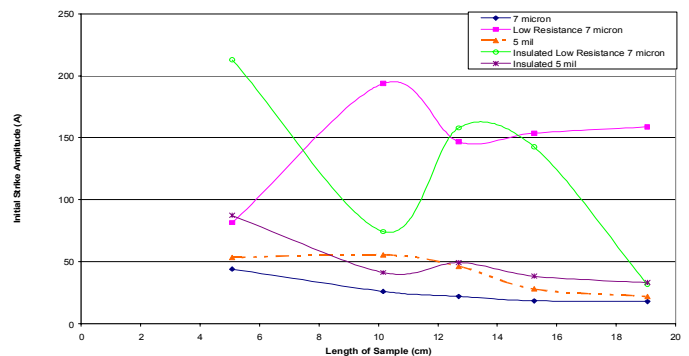


Fig. 6. Experimental result of length vs. initial strike amplitude.

The thickness of the insulating substrate also had a notable effect on the initial strike. Collectively, the insulated samples had a higher initial strike amplitude at 5.08 cm than the regular samples. The initial strike amplitude for the insulated 5 mil was 87.25 A, and for insulated low resistance 7 micron, 212.86 A. However, the highest non-insulated film (low resistance 7 micron) had a maximum initial strike amplitude of 81.43 A. There appears to be an inflection point for all samples at a length of approximately 10.16 cm, the significance of which is yet to be addressed.

B. Dwell Time

At this state, phase transition occurs from liquid to gas and the electrodes are now conducting only through gas. As a result, current is flowing at a constant, but low rate. The experimental results show that a trend exists between all samples. At 5.08 cm, the dwell time of all samples was similar, with a minimal difference in time deviation ranging between 0.8 μ s and 3.2 μ s. However, as the length of the samples increased to 19.05 cm, the dwell time also increased, as shown by Fig. 7. It was also noted that at 19.05 cm, the dwell time of insulated samples was smaller than the non-insulated samples.

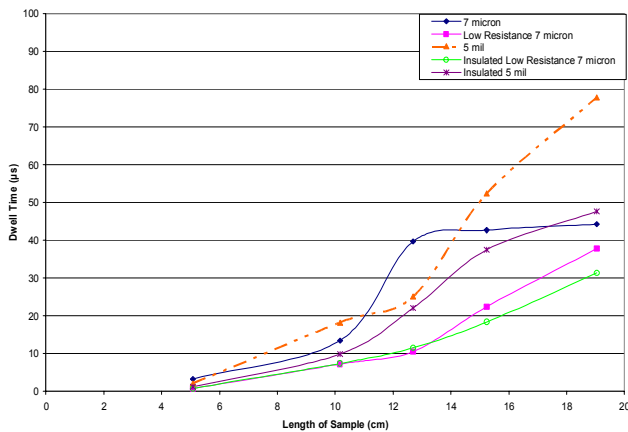


Fig. 7. Experimental result of length vs. dwell time.

C. Restrike

Once the aluminum vapor fully transitions to the plasma state, there is an increase in current flow. Above the length of 12.7 cm, the 7 micron sample does not exhibit restrike. The resulting waveform was similar to that of Fig. 1C. At all lengths, the restrike amplitude of the samples was similar and followed a comparable trend, shown in Fig. 8. The amplitude of the restrike decreased as the length of the samples increased. At 5.04 cm, the maximum restrike current of all tested samples was for insulated 5 mil film, with a current magnitude of 1368.33 A. At 19.07 cm, the current amplitude dropped to 581.6 A. The 5 mil film had minimum current magnitude at 5.04 cm with a current magnitude of 127.14 A.

The minimum current magnitude at 19.07 cm was 518.37 A, exhibited by the insulated low resistance 7 micron film. Therefore, one can conclude that at a given length, the thickness of the substrate has minimal effect on the restrike amplitude.

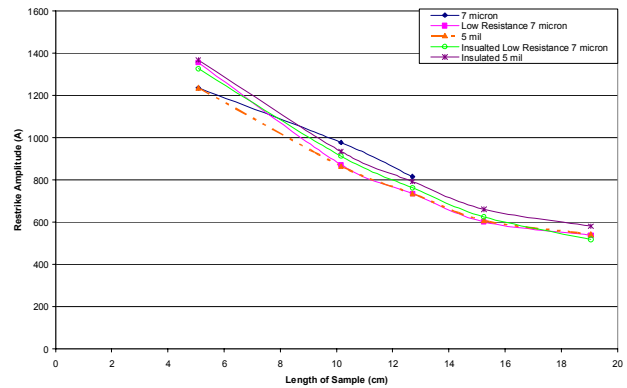


Fig. 8. Experimental result of length vs. restrike amplitude.

The duration of the restrike of the insulated samples is slightly lower than the non-insulated samples, as shown in Fig. 9. The duration of the restrike decreases with an increase in the length of the samples. As shown in Fig. 9, there was an inflection point in all samples at 12.7 cm, except for the 7 micron sample, which does not exhibit restrike beyond 12.7 cm.

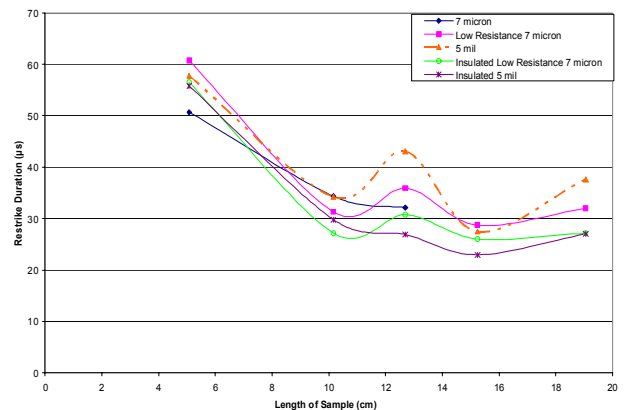


Fig. 9. Experimental result of length vs. restrike duration.

D. Total Duration

The total time duration of the phenomenon increased with an increase in the sample's length. At 5.04 cm, the total duration was 70 μ s, and increased to over 100 μ s at 19.07 cm. 7 micron samples are an exception, in the sense that the waveform is symmetrical about 12.7 cm. 7 micron has the highest time duration of 96.74 μ s, at 12.7 cm, as shown in Fig. 10.

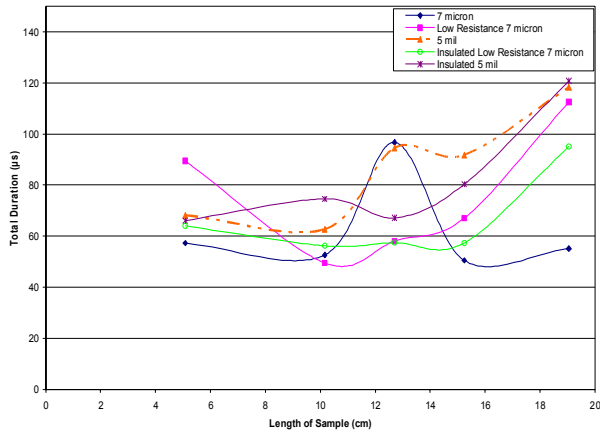


Fig. 10. Experimental result of length vs. total duration.

E. Power

Power waveforms were created via multiplication of the current and voltage waveforms. The peak power of all samples reduced with length. For instance, low resistance 7 micron film changed from 1920 kW at 5.04 cm to 879.79 kW at 19.07 cm. The peak power of the non-insulated 7 micron reduced drastically above 12.7 cm due to no restrike in the waveforms of these samples.

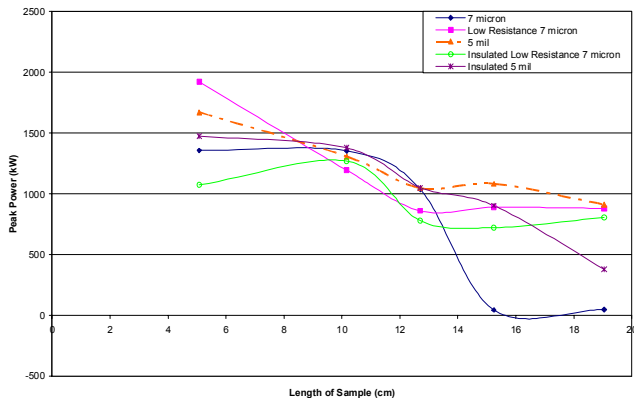


Fig. 11. Experimental result of length vs. peak power.

F. Energy

The energy waveform was derived from the voltage, power, and current waveforms. Likewise, non-insulated 7 micron samples had lower energy above 12.7 cm due to no restrike. The low resistance 7 micron exhibits the highest energy between the lengths of 5.08 cm to 8 cm and at 19.05cm. This might be due in part to the fact that the low resistance 7 micron has the least resistance. It was also noted that the insulated samples had lower energy than the non-insulated samples. However, results show that a common trend exists with all the samples. Energy decreases with an increase in length.

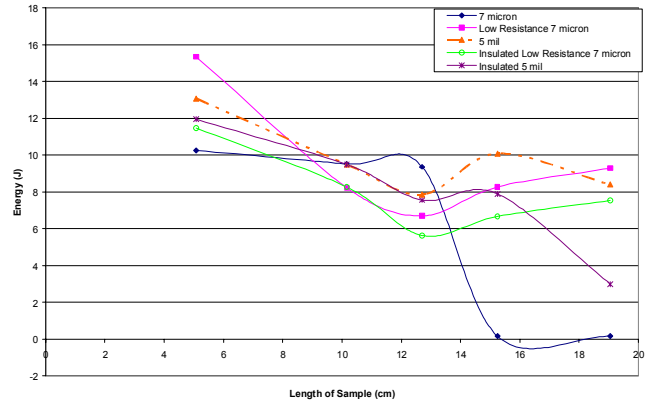


Fig. 12. Experimental result of length vs. energy.

V. CONCLUSION

Based on the results, one can safely conclude that thin films can be effectively used as a surrogate for a wire in exploding wire applications. It has also been demonstrated that some variables, including film thickness, film resistance, and film length, affect the resulting waveform of the transient exploding film phenomenon.

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