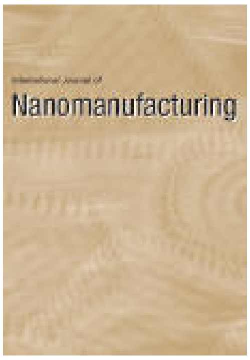

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Study on electrical characteristic and flyer driven ability of Al/Cu exploding foil

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Abstract: In order to reduce the firing energy of the exploding foil blasting machine and optimised its performance, the Al/Cu exploding foil transducer element was fabricated by micro-electro-mechanical system (MEMS) technology, and its electric explosion performance and ability to drive the flyer were studied. The results showed that when the charging voltage was 1.3 KV, the energy utilisation rate of the Al/Cu exploding foil was increased by 25% compared with the traditional Cu exploding foil. Compared with the traditional Cu explosive foil initiator, the Al/Cu explosive foil initiator driven flyer speed is faster and the ignition sensitivity is higher.

Keywords: micro-electro-mechanical system; MEMS; Al/Cu; Cu; electrical performance; flyer velocity.

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Biographical notes: Mi Zhou is a Senior Engineer, engaged in explosive foil research. She has published several articles in related technical fields. She has strong interest in working with nanotechnology.

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1 Introduction

Exploding foil initiator (EFIs) system was an in-line ignition and initiator device with high safety, high reliability and detectability, and was suitable for insensitive ignition and initiator of weapons and ammunition. It had been commercialised and generalised in the USA, and was widely used in a variety of weapon models variety. Since the 1990's, miniaturisation and low energy had been the development trends of the EFI system, and the key to low energy was to improve the energy utilisation rate of the EFI and reduce the ignition energy. The bridge foil was the core component of the initiator. The material, shape, thickness and the bridge foil size had different effects on the EFIs energy utilisation (Chu et al., 2008; Zhou et al., 2012; Wang and Jiang, 2009).

Most of the exploding foils materials at home and abroad were mainly copper, but the energy conversion rate was low, which was not conducive to the development of low-energy weapon systems. It had become a research direction to add energetic materials to the exploding foil and used the rapid exothermic properties of the energetic materials to improve the output capability of the plasma (Ma and Thompson, 1990; Tan et al., 2001; Ren et al., 2021).

At present, home and abroad scholars had carried out related research on Al/Ni, Cu/Al/CuO (Wang and Jiang, 2009; Jin et al., 2012; Wang et al., 2016; Ren et al., 2022), Cu/Au and other materials, but the research on Al/Cu had not been reported. In the paper, the Al/Cu multi-layer composite film was prepared by micro-electro-mechanical system (MEMS) process (Ren and Su, 2020), and the electric explosion performance and the ability to drive the flyer were studied, and the influence rule was obtained.

2 Materials and methods

2.1 Reagents and instruments

- Material: High-purity aluminium target, high-purity copper target, gold target, and ceramic.
- Reagents: Acetone (analytical grade), absolute ethanol (analytical grade), photoreswast AZ4620, NMP, and pure water.
- Instruments: Ultrasonic cleaning machine, glue dwaspenser, lithography machine, magnetron sputtering equipment, low reswastance metre, high voltage power supply, oscilloscope, high voltage switch, PDV, etc.

2.2 Design and preparation of reaction bridge membrane

The exploding foil was composed of five elements: the back plate, the explosive bridge foil, the flyer, the barrel and the exploding column. Figure 1(a) was a schematic diagram of the structure of the shock foil initiator. The explosive bridge foil was bonded to the back plate, and the flyer, the barrel and the output grain were stacked on the bridge belt in turn. The backplane material was ceramic with a thickness of 500 µm. The explosive bridge foil adopts Al/Cu multi-layer composite film, the thickness of Al film was 200 nm, the thickness of Cu film was 100 nm, the total thickness was 4 µm, and the size was 0.4 mm × 0.4 mm. The flyer was a polyimide film with a thickness of 25 µm. The barrel was made of ceramics with a hole diameter of 0.5 mm. The multi-layer composite film was prepared by magnetron sputtering equipment, and the pattern was fabricated by MEMS process. The main process flow was shown in Figure 2. The physical map of the explosive bridge foil was shown in Figure 1(b). Figure 1(c) was the SEM image of the multi-layer Al/Cu. It could be seen from the figure that the multi-layer composite film had a clear structure, and the connection between layers was dense and defect-free.

Figure 1 Initiator exploding foil parts diagram, (a) the structure of EFIs (b) the prepared samples of exploding foil (b) the SEM images of the Al/Cu film (see online version for colours)

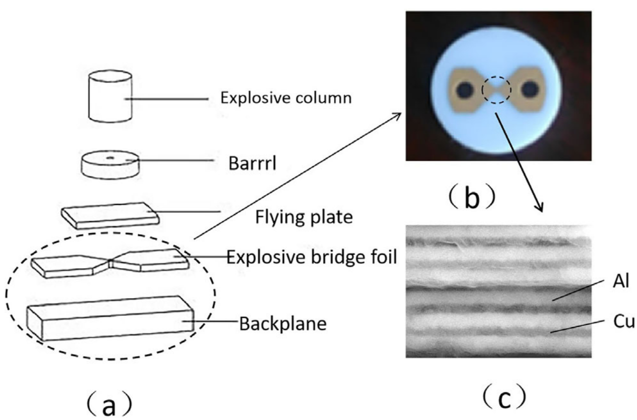
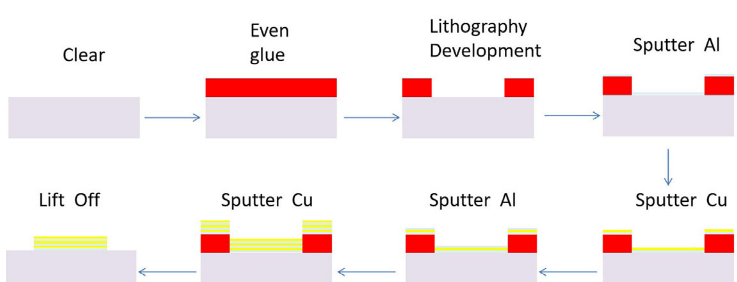


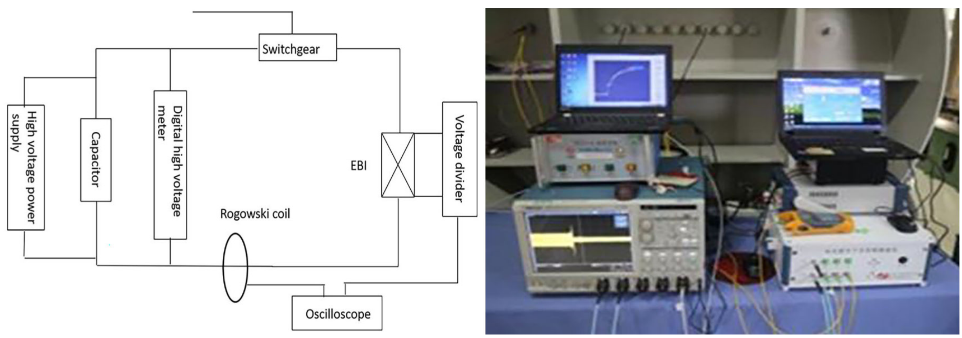
Figure 2 The fabrication process of Al/Cu (see online version for colours)



2.3 Experiment device

In the electric explosion characteristic test experiment, a Rogowski coil was used to record the current waveform, voltage divider was used to record the voltage waveform, and the burst current and burst voltage signal of the bridge foil were stored and displayed through an oscilloscope. The high-voltage capacitance was 0.22 μF; the high voltage switch adopts spark gap switch, the trigger voltage is fixed at 2.0 KV, and the high voltage power supply charges the high voltage capacitor. The figure was shown in Figure 3(a). In the experiment, PDV was used to measure the multi-layer velocity composite film driving the flyer. Figure 3(b) was a physical diagram of the PDV test device. The sensitivity test is basically the same as the electro detonation performance test device. It does not need Rogowski coil, voltage divider and oscilloscope. Other devices are the same.

Figure 3 Test circuit diagram, (a) schematic diagram of electric explosion test (b) physical map of PDV (see online version for colours)



(a) (b)

3 Results and discussion

3.1 Electric explosion characteristic test

The electric explosion of the bridge foil generally occurred in the 1/4 cycle of the current curve, that was, the current rising section. The exploding foil bridge area generated Joule heat under the pulse high current density, the bridge area underwent a solid-liquid-gas transition, the resistance rose rapidly, the bridge area resistance reached the maximum, the voltage reached the peak value, and an explosion occurred. Ideally, the explosion moment of the bridge foil should be as close as possible to the current peak value, that was, the voltage peak value was consistent with the current peak value, and its energy utilisation rate was maximised. Performance parameters of Al/Cu bridge foil and traditional Cu bridge foil at 1.3 KV and 1.5 KV charging voltage, respectively (burst current, peak current, burst voltage, burst current density and peak current time – burst time Δt, effective energy EE and energy utilisation) were shown in Table 1. It could be seen from Table 1 that with the increase of the charging voltage, the burst current, peak current and burst voltage of the two-material exploding foils all increased. When the

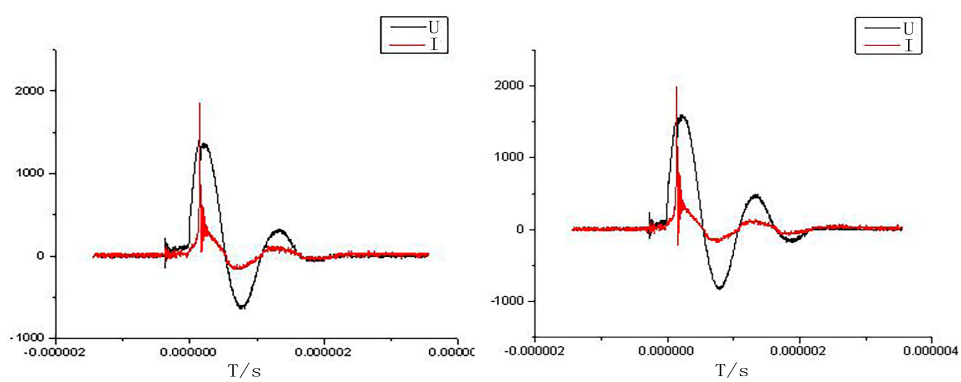
Al/Cu exploding foil was at 1.3 KV, the burst current coincided with the peak current, it showed that under the charging voltage of 1.3 KV, the Al/Cu exploding foil had the best energy utilisation efficiency, and the energy utilisation efficiency was as high as 71.35%. The burst point was earlier than the peak point, the energy waste at this time was relatively large, and the energy utilisation efficiency was 58.96%. At 1.3 KV, the burst point of the traditional Cu exploding foil was later than the peak point, indicating that the energy at the time was obviously insufficient, which was not conducive to the flyer later drive. The energy utilisation efficiency was 46.55%. Under the charging voltage of 1.5 KV, the burst current and the peak currents were basically coincident, and the circuit parameters at the time had reached a better matching state, the energy utilisation rate was better, and the energy utilisation efficiency was 59.62%. At a charging voltage of 1.3 KV, the energy utilisation efficiency of the Al/Cu multi-layer composite film was 25% higher than that of the traditional Cu bridge foil.

Table 1 Experiment data of different materials exploding foils under different ignition voltages

Transducer	*U/KV*	I_b/A	I_m/A	V_b/V	Δt/ns	E_E/J	*Energy utilisation efficiency*
Al/Cu	1.3	1,520	1,520	1,004	0	0.132	71.35%
	1.5	1,560	1,830	1,210	43	0.145	58.96%
Cu	1.3	1,280	1,480	980	–32	0.085	46.55%
	1.5	1,560	1,580	1,140	5	0.147	59.62%

Figure 4 showed the burst voltage burst current curves of Al/Cu exploding foil at 1.3 KV and 1.5 KV charging voltage. It could be seen from the figure that at 1.3 KV charging voltage, the burst current coincided with the peak current, the Al/Cu the best energy utilisation efficiency was obtained by the exploding foil explosion. Under the charging voltage of 1.5 KV, the explosion current time was earlier than the peak current time. At the time, the system had more matching energy remaining, resulting in energy waste.

Figure 4 Burst voltage burst current curve of Al/Cu exploding foil, (a) 1.3 KV (b) 1.5 KV (see online version for colours)

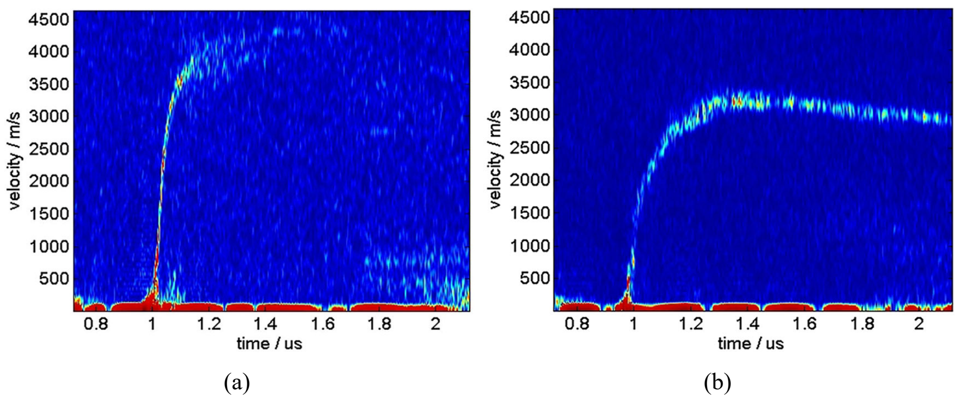


(a) (b)

3.2 Flyer velocity test

Flyer was an important parameter used to characterise the basic data and laws of typical explosives and booster explosive in the impact detonation of exploding foil impactor. The same parameters of the transducer element were used to assemble the test sample, and at a charging voltage of 1,300 V, a velocity comparison test of the Al/Cu multi-layer composite material exploding foil and the Cu material exploding foil flyer was carried out, as shown in Figure 4. From Figure 5 it could be intuitively seen that the ability of the Al/Cu multi-layer composite material to drive the flyer was stronger than that of the Cu material exploding foil, and the flyer acceleration was faster. The maximum velocity was 3,850 m/s, the Cu material exploding foil velocity was 3,480 m/s, and the time point when the flyer reached the highest point moved backward.

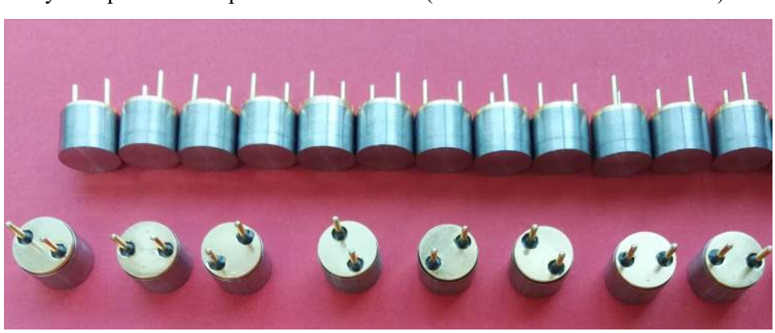
Figure 5 Flyer velocity curve under 1,300 V charging voltage, (a) Al/Cu (b) Cu (see online version for colours)



3.3 Sensitivity test

According to the test procedure of Langley method in GJB/Z 377A-1994 'mathematical statistics method for sensitivity test', the ignition sensitivity test of Al/Cu multi-layer composite explosive foil initiator and Cu explosive foil initiator is compared. The initial HNS-IV drug column size was Φ4.5 mm × 3.5 mm, and the theoretical maximum density (TMD) of 1.566 g/cm^3 was 90%. The real explosive foil initiator is shown in Figure 6.

Figure 6 Physical picture of explosive foil initiator (see online version for colours)



According to the Langley method test procedure, the ignition sensitivity test of Al/Cu multi-layer composite explosive foil initiator and Cu explosive foil initiator is carried out. The upper limit of ignition voltage *XU* = 1600 V, and the lower limit of ignition voltage *XL* = 1,000 V. The comparison of test results is shown in Table 2. The test results show that the full ignition voltage of Al/Cu multi-layer composite explosive foil initiator is 1,158.5 V, 50% ignition voltage is 1,088.3 V, the full ignition voltage of Cu explosive foil initiator is 1,355.6 V, 50% ignition voltage is 1,166.0 V. The full ignition voltage of Al/Cu multi-layer composite explosive foil initiator is nearly 200 V lower than that of conventional Cu explosive foil initiator.

Table 2 Comparison of test results of ignition sensitivity

Transducer	$U_{99.9\%}/V$	$U_{50\%}/V$
Al/Cu	1,158.5	1,088.3
Cu	1,355.6	1,166.0

4 Conclusions

The Al/Cu exploding foil prepared by MEMS process had the best energy utilisation efficiency under the charging voltage of 1.3 KV, and the energy utilisation efficiency was as high as 71.35%, which was 25% higher than that of the traditional Cu bridge foil. The AL/Cu exploding foil pushed the flyer. The experiment showed that when the exploding foil thickness was 4 μm and the charging voltage was 1.3 KV, the flyer velocity could reach 3,850 m/s. The Al/Cu exploding foil provided technical support for reducing the EFI firing energy. The full ignition voltage of Al/Cu multi-layer composite explosive foil initiator is nearly 200 V lower than that of conventional Cu explosive foil initiator.

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