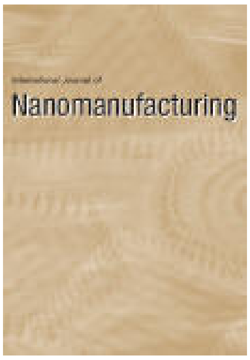

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Fabrication and performances of TaN@(Al/CuO) thin film

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Abstract: To reduce the ignition energy of the reactive multilayer films and improve the ignition performance, this paper designed three types of Al/CuO, and Al/CuO was combined with TaN by micro-electro-mechanical system (MEMS) technology to prepare TaN@(Al/CuO). The experimental results were obtained by high-speed photography of the flame height. The ignition experiment results showed that: when the firing voltage was 50 V and the capacitance was 33 μf, the flame height of the Al/CuO (50 nm/100 nm) was the highest with a flame height of about 16 mm; the flame height increased with the increase of voltage, and the flame duration also increased under the same conditions.

Keywords: TaN; Al/CuO; micro-electro-mechanical system; MEMS; firing voltage; flame height.

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1 Introduction

Reactive multilayer films (RMFs) were composite films deposited by metals and metal oxides and they were reactive. They could have chemical or alloying reactions under the action of thermal or electrical energy, releasing a large amount of energy (Zhang et al., 2017; Ni et al., 2018). Common reactive multilayer films included Al/CuO, Al/MoO_3, Al/Ni, B/Ti and so on (Ren et al., 2021; Shi et al., 2022; Wang et al., 2019; Guan et al., 2017; Cai et al., 2015). This type of thin film had the advantages of high energy density and fast reaction rate, and had broad application prospects in the fields of micro-energy-containing devices, rocket propellants, and position adjustment of micro-satellites.

The energy converter unit was the key device for realising energy initiation and energy conversion in MEMS initiators and pyrotechnics. At present, the commonly used thin film resistor materials mainly included SCB, Ni-Cr alloy, TaN, Pt, Cr and so on. TaN had excellent electrical properties, stable thermal properties, and good oxidation and corrosion resistance. Compared with metal materials, TaN had a negative TCR value, and its resistance decreased with the increase of temperature; some properties were equivalent to SCB, which was beneficial to realise the reduction of energy of the energy converter unit (Ren et al., 2022; Ren and Su, 2020).

Now, Chinese and foreign research institutions had studied the combustion features and reaction mechanism of Al/CuO, and most of them studied the ignition features of SCB@(Al/CuO), which had a large input energy. In this paper, in order to reduced the input energy and increase the ignition energy, three types of Al/CuO was designed, and Al/CuO was combined with TaN by MEMS technology to prepare TaN@(Al/CuO), and the ignition properties of the samples were tested and analysed.

2 Materials and methods

2.1 Reagents and instruments

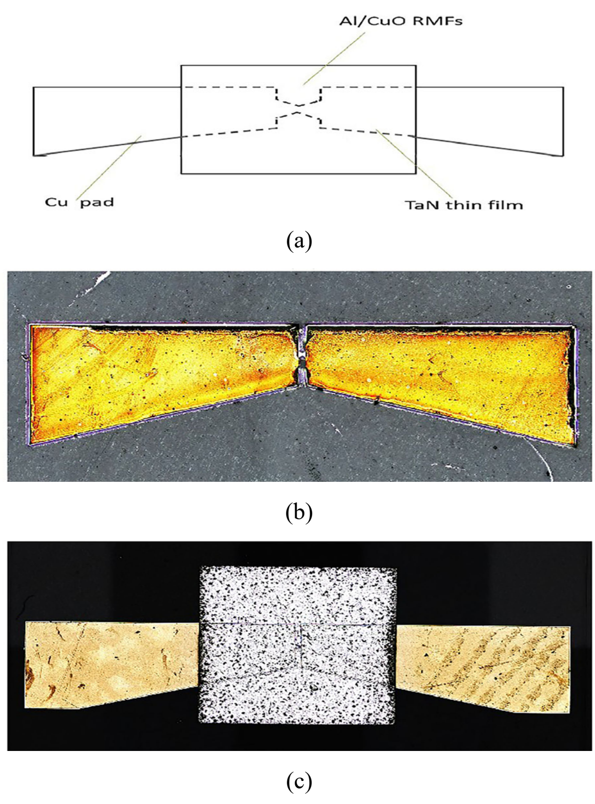
Reagents: TaN target (Ta:N = 1:1, 99.9%), CuO target (Cu:O = 1:1, 99.9%), Cu target (99.99%), Al target (99.99%), acetone, alcohol, AZ4620, AZ3740, NMP, $FeCl_3$ pure water.

Instruments: ultrasonic cleaning machine, glue dispenser, lithography machine, hot plate, magnetron sputtering equipment, high-speed photography, oscilloscope, power supply, etc.

2.2 Design and preparation process

The structure of TaN@(Al/CuO) was shown in Figure 1(a). The substrate was BF33 glass, the size was 10 mm × 5 mm × 0.5 mm, the size of the TaN energy converter unit's bridge area was 80 µm × 50 µm × 0.9 µm, and the size of the Cu bonding pad was 4.8 mm × 3 mm × 1 µm. The Al/CuO multilayer film was covered on the TaN energy converter bridge area, and its size was 2 mm × 2 mm. Three types of Al/CuO were designed: 50 nm/100 nm, 100 nm/200 nm, 150 nm/150 nm, with a total thickness of 3 µm.

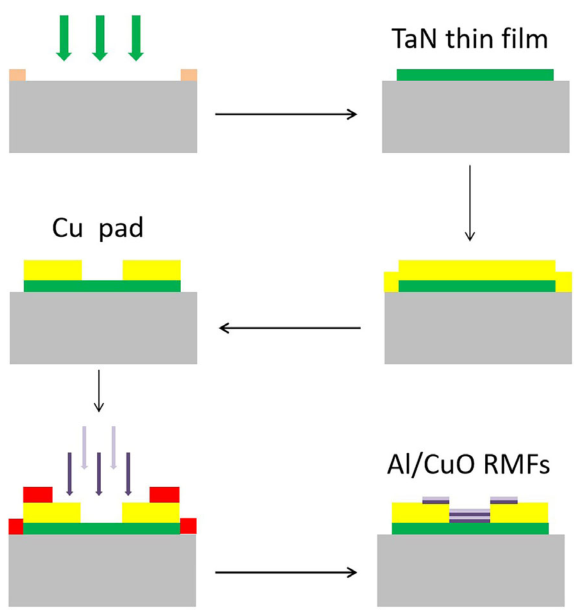
Figure 1 Structure of TaN@(Al/CuO), (a) schematic diagram of the TaN@(Al/CuO) (b) the physical drawing of the TaN (c) the physical drawing of the TaN@(Al/CuO) (see online version for colours)



A brief flow chart of the preparation of TaN@(Al/CuO) was shown in Figure 2. BF33 glass was cleaned with acetone, alcohol and pure water in turn. After it was dried with N_2, AZ4620 glue was applied evenly, and the TaN energy converter pattern was prepared by pre-baking, photolithography, post-baking and development. The sample was put into the magnetron sputtering equipment, and the TaN film was sputtered. The preparation process of the TaN film was as follows: the sputtering pressure was 4 × 10^{-3} Pa, the substrate temperature was 70°C, the argon gas flow was 30 sccm, and the DC power was 200 W, and the deposition time was 50 min. The photoresist was stripped with NMP solution. After cleaning, it was put into a magnetron sputtering equipment for sputtering Cu thin film. The preparation process of Cu thin film was: sputtering pressure 4 × 10^{-3} Pa, substrate temperature 100°C, argon flow rate 30 sccm , DC power 300 W, deposition time 30 min. The AZ3740 was evenly glued on the plated copper film, and the Cu pad pattern was prepared by pre-baking, photolithography, post-baking and development. The actual photo of the good TaN energy converter sample was shown in Figure 1(b).

AZ4620 was evenly applied on the TaN energy converter unit sample, and the reactive thin film pattern was prepared after pre-baking, photolithography, post-baking and development. The sample was put into the magnetron sputtering equipment, and the reactive film was sputtered on. Al film and CuO film were alternately prepared in the equipment. The argon flow rate was 30 sccm, and the DC power was 100 W. The preparation process of CuO thin film was as follows: sputtering pressure was 4 × 10^{-3} Pa, substrate temperature was 20°C, argon gas flow was 30 sccm, and radio frequency power was 100 W. The sputtering time of the Al thin film and the CuO thin film was adjusted according to the thickness. The photoresist was stripped with NMP solution. Dry with N_2 after cleaning. The photo of the prepared sample was shown in Figure 1(c).

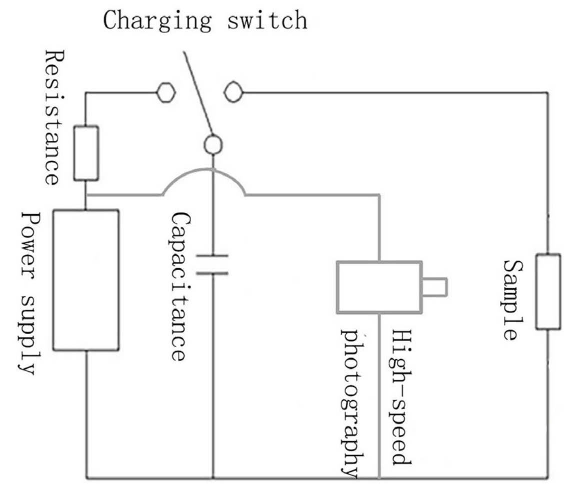
Figure 2 The fabrication process of TaN@(Al/CuO) thin-film initiator (see online version for colours)



2.3 *Firing susceptibility test of tantalum nitride films*

The firing test of TaN@(Al/CuO) film bridge was showed in Figure 3, with detonation circuit, using 33 μF firing capacitor.

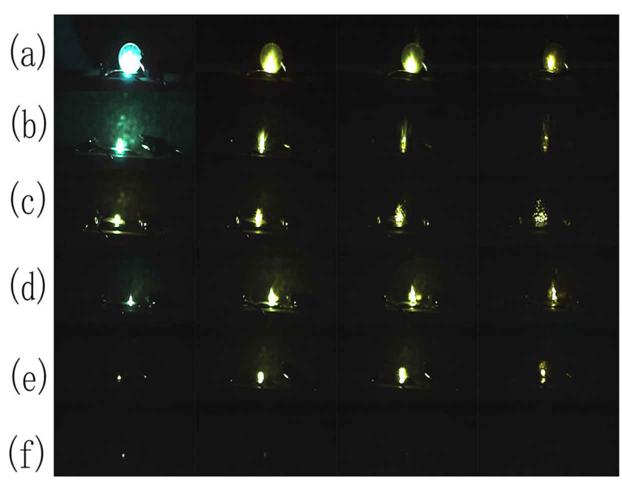
Figure 3 Schematic diagram of initiation circuit



3 Performance characterisation

The action process of TaN@(Al/CuO) was that the current passed through the TaN bridge area, which experienced temperature rise, melting, gasification and generated plasma. The plasma transferred high heat to the reactive film. Al and CuO reacted rapidly with a large amount of reaction heat. The heat instantly caused a sharp rise in temperature in a small range, thus igniting a small range of Al and CuO.

Figure 4 The flame diagram of Al/CuO, (a) 50:100, 50 V (b) 100:200, 50 V (c) 150:150, 50 V (d) 50:100, 30 V (e) 50:100, 10 V (f) 50:100, 7 V (see online version for colours)



When the input voltage was 50 V, the high-speed image of three different types of Al/CuO was shown in Figures 4(a), 4(b) and 4(c). The results were as follows: Al/CuO (50 nm/100 nm) had the brightest flame with the highest flame height, followed by Al/CuO (100 nm/200 nm) and Al/CuO (150 nm/150 nm). Analysis reason: Al/CuO (50:100), the shortest mass transfer distance between reactants, transport interface area increased, energy release rate was higher. By comparing the Al/CuO (50:100) flame with the one yuan coin (diameter 25 mm), the flame height was about 16 mm. The high-speed image was shown in Figure 5.

Figure 5 The flame diagram of Al/CuO (50:100) (see online version for colours)

When the Al/CuO ratio was 50:100 and the total thickness was 3 μm, the capacitance was 33 μf and the voltages were 50 V, 30 V, 10 V, 7 V. The high-speed image of three different types of Al/CuO was shown in Figures 4(a), 4(d), 4(e) and 4(f). The experimental results shown that the flame height and flame duration increased with the increase of the input voltage. When the voltage was 7 V, the TaN bridge generated plasma, but the temperature was not enough to ignite Al/CuO. At 10 V, the plasma generated in TaN Bridge area could ensure Al/CuO combustion and the flame height was about 4 mm.

4 Conclusions

1. TaN energy converter units and Al/CuO multilayer films could be prepared with MEMS process, and the combination was very good, which was good for mass preparation.
2. When the voltage input was 50 V and the capacitance was 33 μf, the total thickness of the reaction film was 3 μm, the type of Al/CuO was 50:100, the flame was the brightest and the largest. The flame height was about 16 mm.
3. The total thickness of the reaction film was 3 μm, the type of Al/CuO was 50:100, and the capacitance was 33 μf: when the voltage input was 7 V, plasma was generated in the TaN bridge area, but the temperature was not enough to ignite Al/CuO. When the voltage input was 10 V, TaN could ignite Al/CuO.

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