RAPID INITIATION OF REACTIONS IN Al/CuO-BASED REACTIVE MULTILAYER FILMS

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Introduction

Recently, metastable intermolecular composites (MICs) have aroused much attention because of their fast energy release rate and large amount of reaction heat produced, among which, layer structure MICs exhibit superiority over the others for their easily integration with microelectronic and mechanical systems (MEMS) [1-3]. In this paper, aluminum (Al) and copper dioxide (CuO) are chose to be the ingredients of the reactive multilayer films (RMFs) because of their relatively large reaction heat (974.1 cal/g) and high reaction adiabatic temperature (2843 K) compared with most of other thermite reactions or intermetallic reactions [4]. We hope to further broaden the application range of MICs in rapid initiation process, for example, the development of low energy exploding foil initiator (LEEFI).

Experimental

Materials

Al target, CuO target and Cu target. The purity of the targets used was ultrahigh with pureness all over 99.99%.

Apparatus and Procedures

Standard microsystem technology and RF magnetron sputtering technology were used to produce Cu film and Cu/Al/CuO RMFs, respectively. The thickness of Cu film was 1 μm, while for Cu/Al/CuO RMFs, Cu layer with the thickness of 1 μm was first presented followed by alternative deposition of Al films and CuO films with single layer thickness set to be 250 nm and 500 nm, respectively, to appropriately obtain a stoichiometric ratio. The total thickness of Al/CuO RMFs was 3 μm. The size of the bridge was 0.45 mm×0.45 mm with the resistance 200 mΩ-250 mΩ for both types of films.

Fig.1 shows the schematic drawing of the circuit used in our tests, the capacitor is 0.324 μF with the inductance L and resistance R calculated to be 56 nH and 180 mΩ through short circuit current test, respectively.

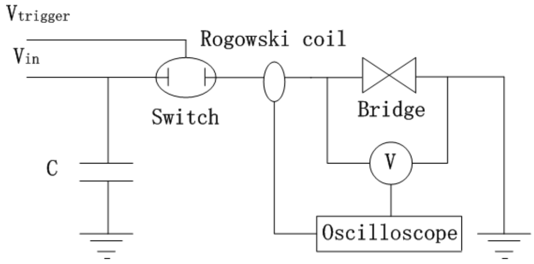

Fig.1 Schematic drawing of the test circuit.

NETZSCH STA 449C differential scanning calorimetry (DSC) was employed to ascertain the amount of heat released in the thermite reaction between Al films and CuO films.

Explosion processes of the two types of films were observed by HG-100K high speed camera.

Reaction temperature was determined by using atomic emission spectroscopy double line technique.

The piezoelectricity of polyvinylidene fluoride (PVDF) film was employed to measure the average velocity of the slapper sheared by the explosion of the films.

Results and Discussion

Fig.2 displays a typical DSC curve of the as-deposited Al/CuO RMFs with the heating rate 50 K/min. Integration of the total exothermic peak areas gives a heat of reaction equal to approximately 2024 J/g.

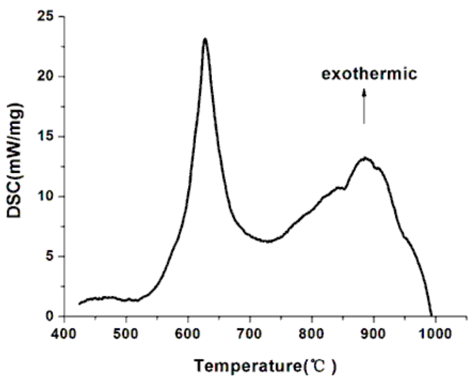

Fig.2 DSC plot of as-deposited Al/CuO RMFs.

For a fixed set of apparatus, a specific structure of film corresponds to an optimized charging voltage in pulse current induced electrical explosion process. 600V was ascertained to be the optimized charging voltage for our tests.

Fig.3 depicts the typical explosion images for Cu film and Cu/Al/CuO RMFs both charged to 600 V, respectively. The interval between adjoining pictures is 100 μs. For Cu/CuO/Al RMFs, apart from a bright flash of light, a fierce combustion process could clearly be seen with large amounts of product particles ejected to a distance far away.

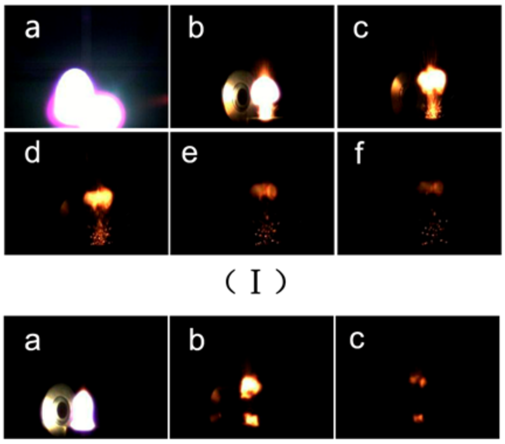

Fig.3 High speed camera observation of electrical explosion process at 600V: (I) images of Cu/Al/CuO RMFs. (II) images of Cu film.

Fig.4 shows the comparison of temperatures for Cu film and Cu/Al/CuO RMFs with charging voltage both 600 V. The temperature of Cu/Al/CuO RMFs is about 30% larger than that of Cu film, which can be attributed to the heat released during the thermite reaction of Al/CuO RMFs. The results of the temperature determination correspond well with those of the high speed camera observation.

As we all know, for a typical EFI, the kinetic energy of the slapper usually derives from the rapid expansion of Cu plasma, which correlates closely with the explosion temperature. In other words, the heat released in the thermite reaction of Al/CuO RMFs can promote the slapper velocity theoretically.

We made 10 shots tests for both types of films, respectively, and the average velocities of the slappers were calculated to be 381 m/s and 326 m/s for Cu film and Cu/Al/CuO RMFs, respectively. It was found that unlike the results obtained in article [5], the utilization of Al/CuO RMFs didn't increase the slapper velocity in our tests. We notice that electrical explosion is finished in the timescale of 100's of ns, which probably means the energy released during the thermite reaction can't be transduced to kinetic energy of slapper effectively within such a short time in our tests. Although the dimension of films used in our experiments has almost reached nanoscale, thinner film is needed to further increase the energy release rate of the Al/CuO RMFs to meet the demand of EFI function, and the structure of the Cu/Al/CuO RMFs should also be optimized to obtain a better performance.

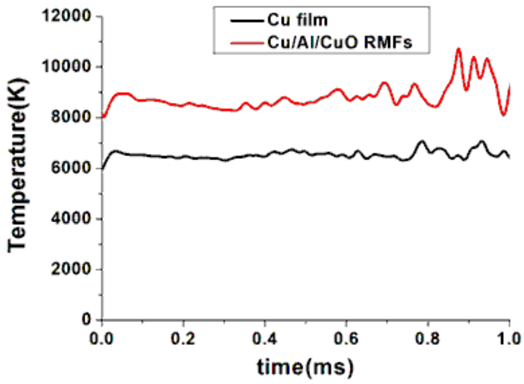

FIG.4 Explosion temperature histories for two types of films.

Conclusion

In our research, Al/CuO RMFs has definitely proven to possess the potential to improve the development of LEEFI. However, the velocity tests revealed that the average velocity of the slapper didn't increase in our tests. The problems may lie in the relatively low reaction rate of Al/CuO RMFs as well as the imperfect film structure, and further research will be focus on the optimization of Al/CuO bilayer thickness, Al/CuO mass ratio, and the structure of the Cu/Al/CuO RMFs.

References

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