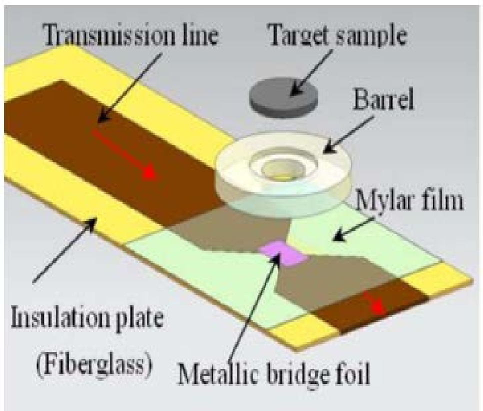
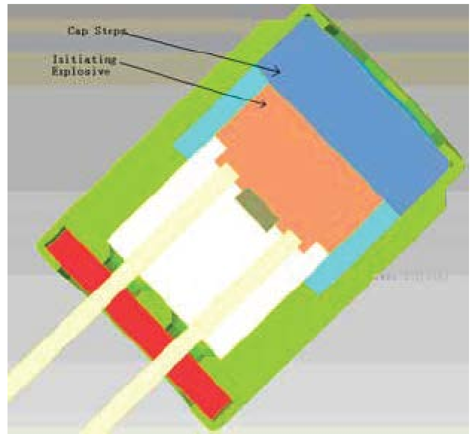
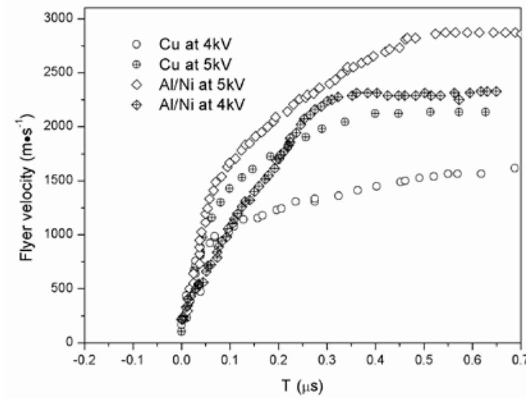
ICM

Institute of Chemical Materials







Reactive Materials for electrical initiators

WANG YAO

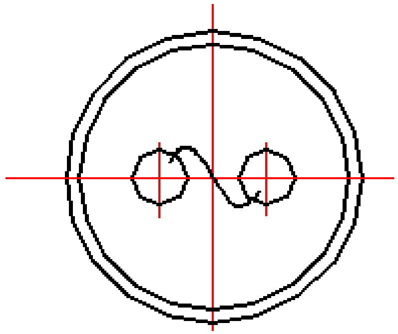
Email: wangyaocindi@caep.cn

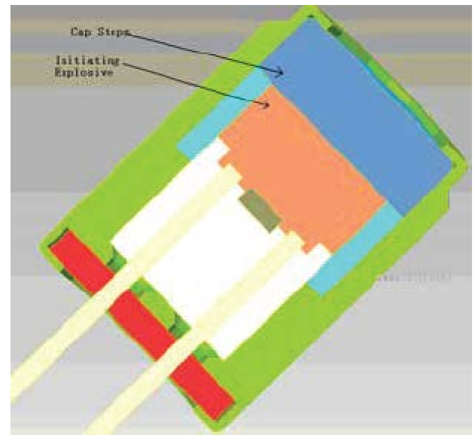
CAEP

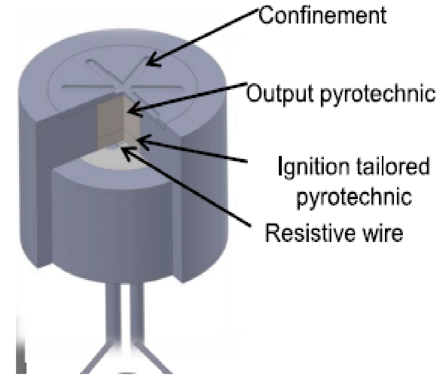
Electrical initiators

- ignition：

Resistance wire
Resistance bridge
SCB
Exploding wire

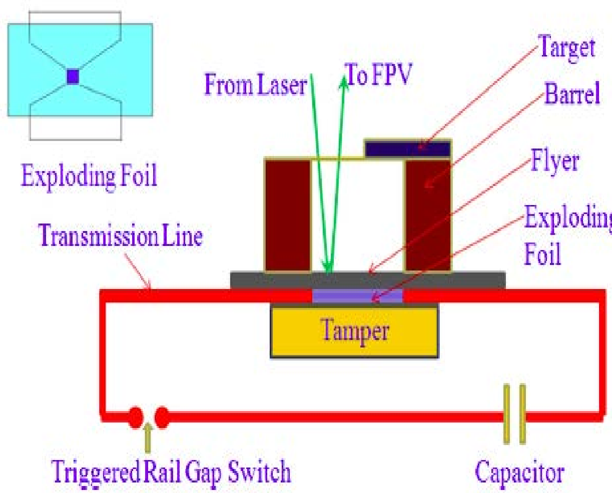


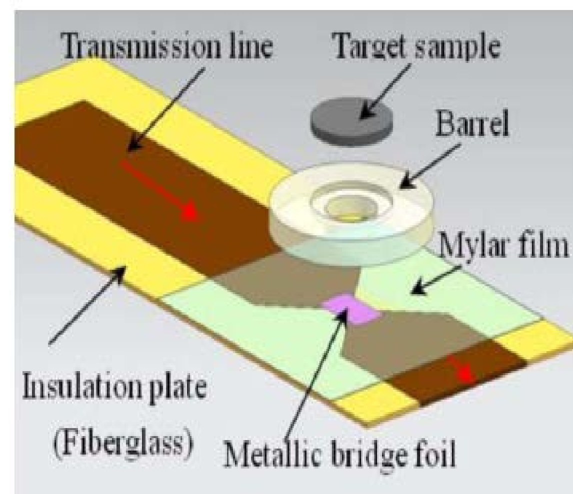




- Explosion:

Exploding foil





Reactive Materials

SAND98-1176C
To be presented at the 24th International Pyrotechnics Seminar,
Monterey, CA. July 1998

THEORETICAL ENERGY RELEASE OF THERMITES, INTERMETALLICS, AND COMBUSTIBLE METALS†

S. H. Fischer and M. C. Grubelich
Sandia National Laboratories
Albuquerque, NM 87185-1453

reactants		adiabatic reaction temperature (K)		state of products		gas production		heat of reaction	
constituents	ρ_{TMD}, g/cm^3	w/o phase changes	w/ phase changes	state of oxide	state of metal	moles gas per 100 g	g of gas per g	-Q, cal/g	-Q, cal/cm^3
$2Al + 3Cu_2O$	5.280	4132	2843	liquid	l-g	0.1221	0.0776	575.5	3039
$2Al + 3NiO$	5.214	3968	3187	liquid	l-g	0.0108	0.0063	822.3	4288
$Be + CuO$	5.119	3761	2820	s-l	liquid	0.0000	0.0000	1221	6249
$2Al + 3CuO$	5.109	5718	2843	liquid	l-g	0.5400	0.3431	974.1	4976
$2Al + 3CoO$	5.077	3392	3201	liquid	l-g	0.0430	0.0254	824.7	4187
$3Ti + 2Fe_2O_3$	5.010	3358	2614	liquid	liquid	0.0000	0.0000	612.0	3066
$Ti + Fe_3O_4$	4.974	3113	2334	liquid	liquid	0.0000	0.0000	563.0	2800
$3Ti + 2Cr_2O_3$	4.959	1814	1814	solid	solid	0.0000	0.0000	296.2	1469

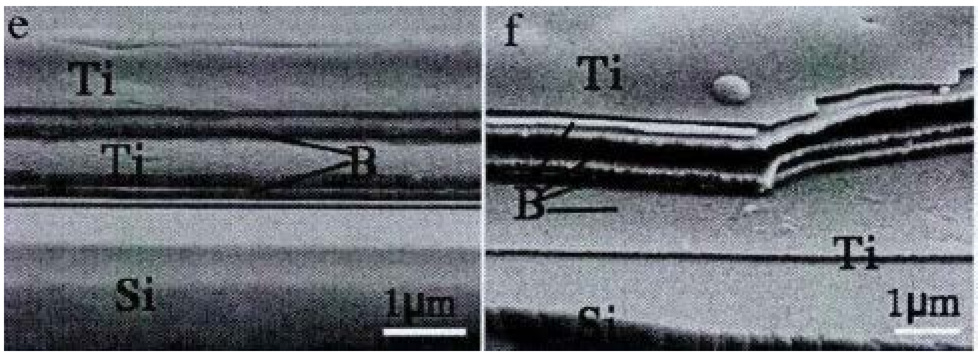
reactants		adiabatic reaction temperature (K)		state of intermetallic product	gas production		heat of reaction	
constituents	ρ_{TMD}, g/cm^3	w/o phase changes	w/ phase changes		moles gas per 100 g	g of gas per g	-Q, cal/g	-Q, cal/cm^3
Al + 2B	2.607	2251	>1252	l-g	0 - 2.1	0 - 1	742	1940
4Al + 3C	2.574	1673	1673	solid	0.0	0.0	371	965
2Al + Ca	2.051	2836	1738	liquid	0.0	0.0	558	1140
4Al + Ca	2.248	1880	>972	s-l	0.0	0.0	348	782
4Al + Ce	4.095	1173	1173	solid	0.0	0.0	126	458
Al + Co	5.171	2195	>1912	s-l	0.0	0.0	307	1590
4Al + Co	3.581	*	*	*	*	*	231	637
5Al + 2Co	3.999	1755	>1452	s-l	0.0	0.0	277	1110
3Al + Cr	3.568	793	793	solid	0.0	0.0	120	430
Al + Cu	5.294	935	935	solid	0.0	0.0	108	573
Al + Fe	4.844	1423	1423	solid	0.0	0.0	211	1020
3Al + Fe	3.688	1407	1407	solid	0.0	0.0	278	1020
4Al + La	3.946	1495	*	s-l	0.0	0.0	166	780
Al + Li	1.476	1160	>972	s-l	0.0	0.0	345	509
Al + Mn	4.676	803	803	solid	0.0	0.0	124	586
Al + Ni	5.165	2362	>1910	s-l	0.0	0.0	330	1710

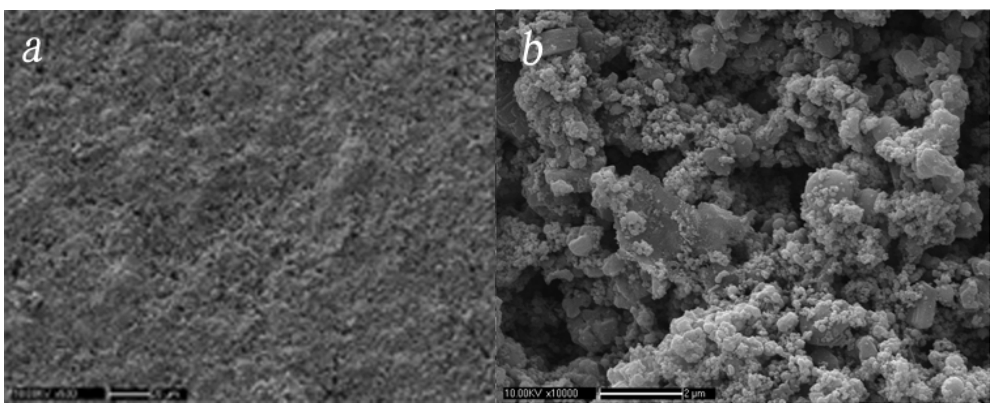
- Al + CuO: ΔH = 974.1 cal/g;
- Al + Ni: ΔH = 330 cal/g;
- B + Ti: ΔH = 1320 cal/g;

Reactive Materials for Ignition

1 B/Ti reactive materials

Thickness:3-4μm Bilayer:Ti(230nm) Bi(250nm)

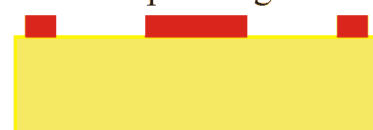




Cu film by magnetron sputtering

Photoresist

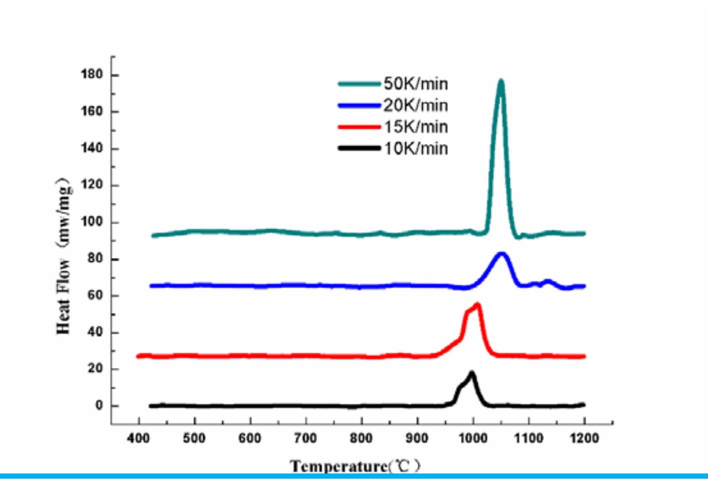
Cu exploding foil



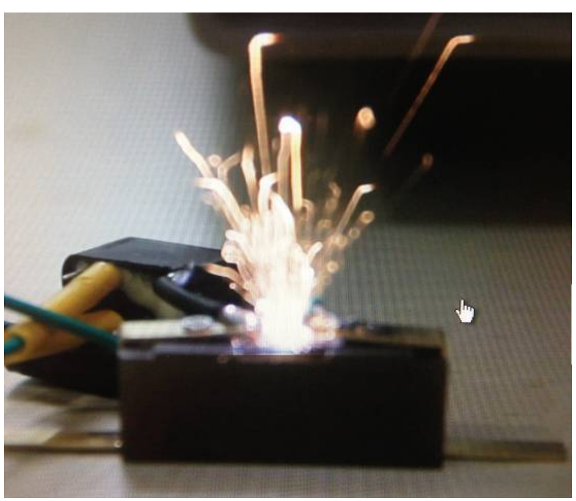
B/Ti by electrophoresis

Reactive Materials for Ignition

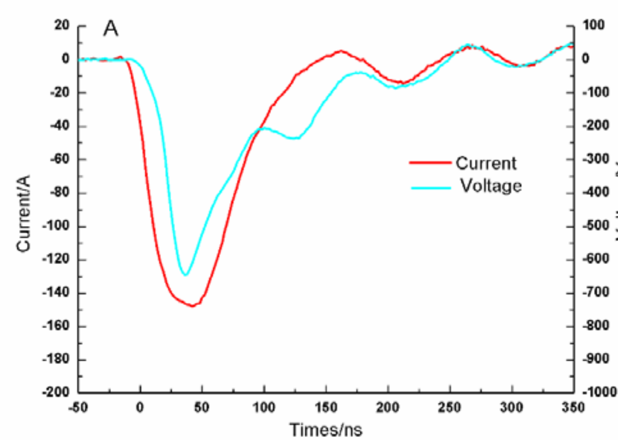
The exothermic reaction of B/Ti energetic materials :



- ✓ Single exothermic reaction;
- ✓ Onset temperature is 976℃ to 1023℃ (< B 2076 ℃and Ti 1678 ℃);
- ✓ Reaction heat was 1259J/g (<5517J/g).

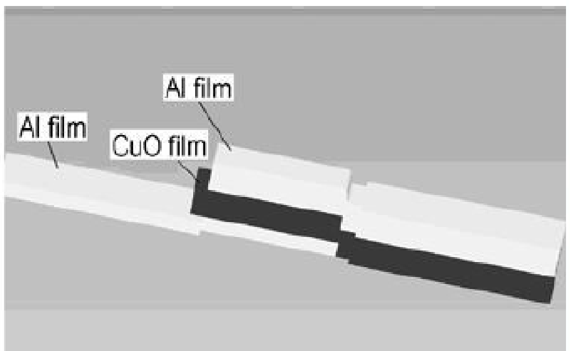


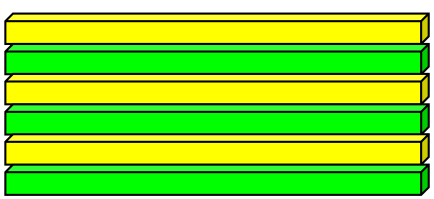
- ✓ Output energy:1.43mJ;
- ✓ Energy transformation efficiency: 71.5%;
- ✓ The height of flame can be reach to several millimeter.

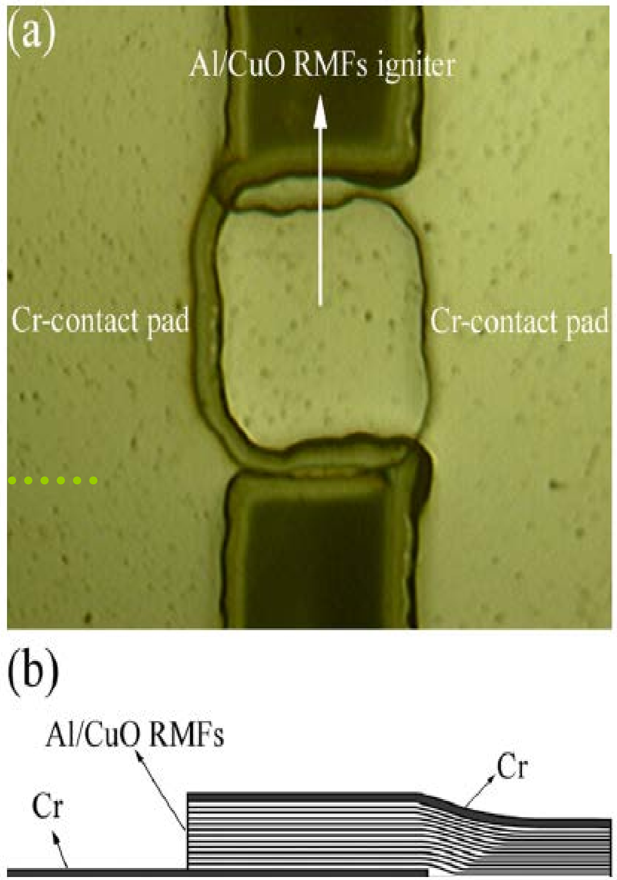


Reactive Materials for Ignition

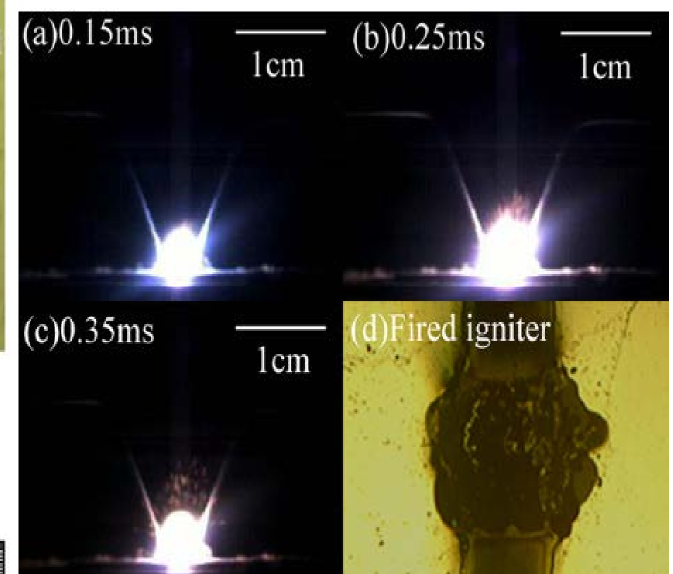
2 Al/CuO multilayers







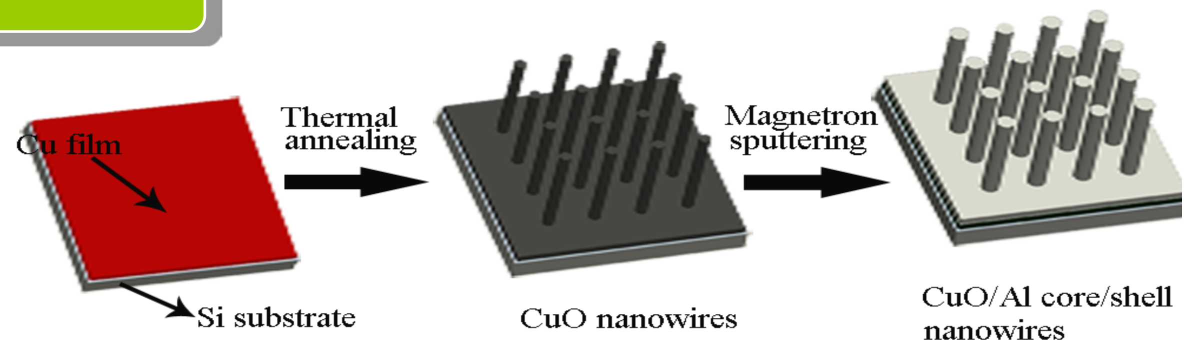
the igniter. The ignition delay time and total released energy of the igniter discharged in 40 V are 0.7 ms and 482.34 mJ, respectively. For one igniter, the energy released by chemical reactions is accounted for 21% of the total energy, which can be improved by adjusting the deposition conditions of Al/CuO RMFs and by tuning the Al deposition to reach a stoichiometric reaction. Furthermore, the explosion temperature could keep an approximately constant value of 3500 °C for 1.4 ms.



Reactive Materials for Ignition

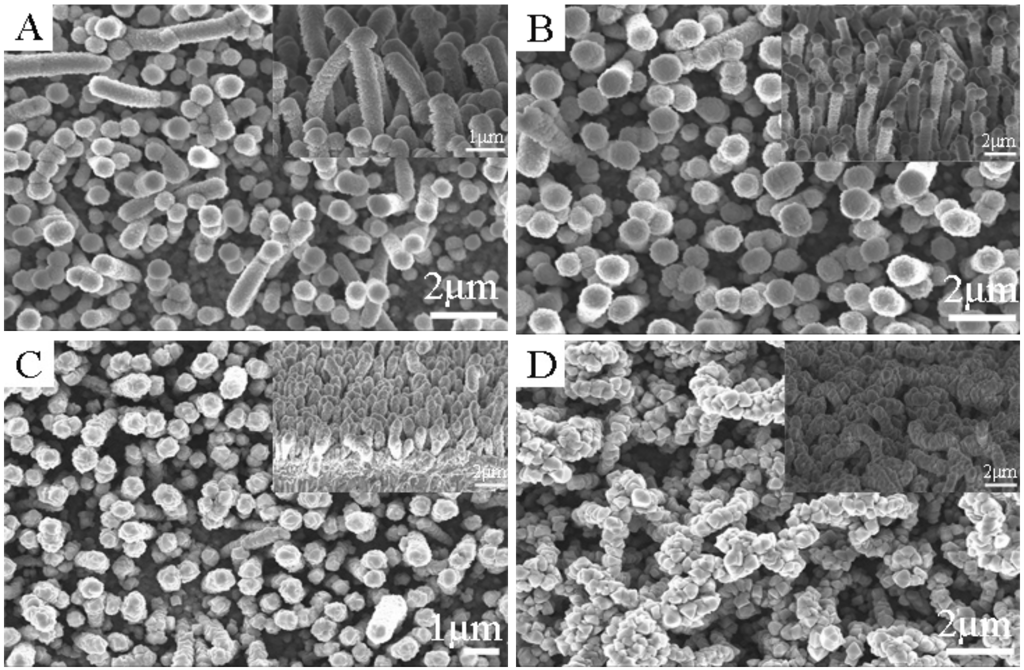
2 Al/CuO nanowires

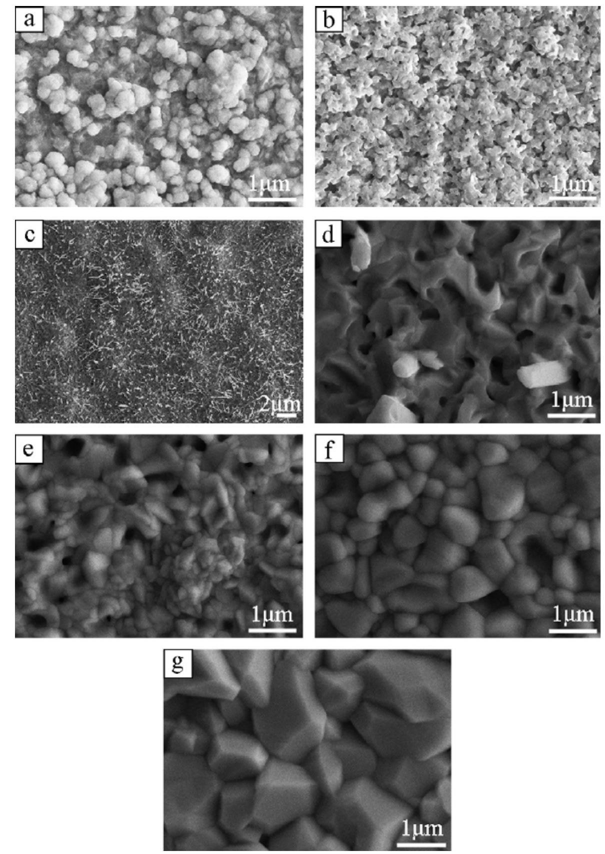
1) Al/CuO nanowires grown from Cu thin film deposited onto silicon substrate.
2) The copper film is deposited byelectro beam Evaporation.
3) The CuO nanowires is synthesized by annealing copper film.
4) The formation of Al_2O_3 would consume Al nanoparticles which reduce the heat reation.
5) The reaction between fuel and oxidizer should destroy Al_2O_3 which has high melting temperature.



Processing	t_p/°C	Q/（$J \cdot g^{-1}$）	Al/CuO摩尔比
Ultrasonic wave	549. 5	473. 2	2：3
Sol-gel approaches	561. 2	574. 9	2：3
Core-shell	500	1085	-

The core-shell structure



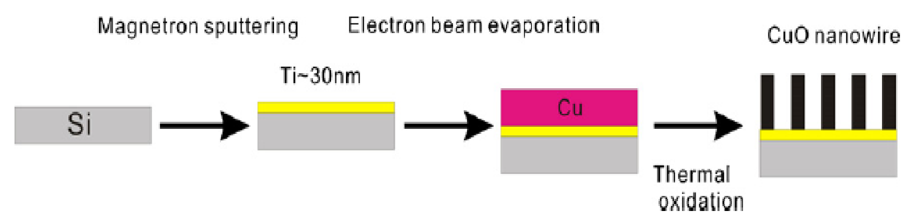


1) The annealing temperature: 400℃

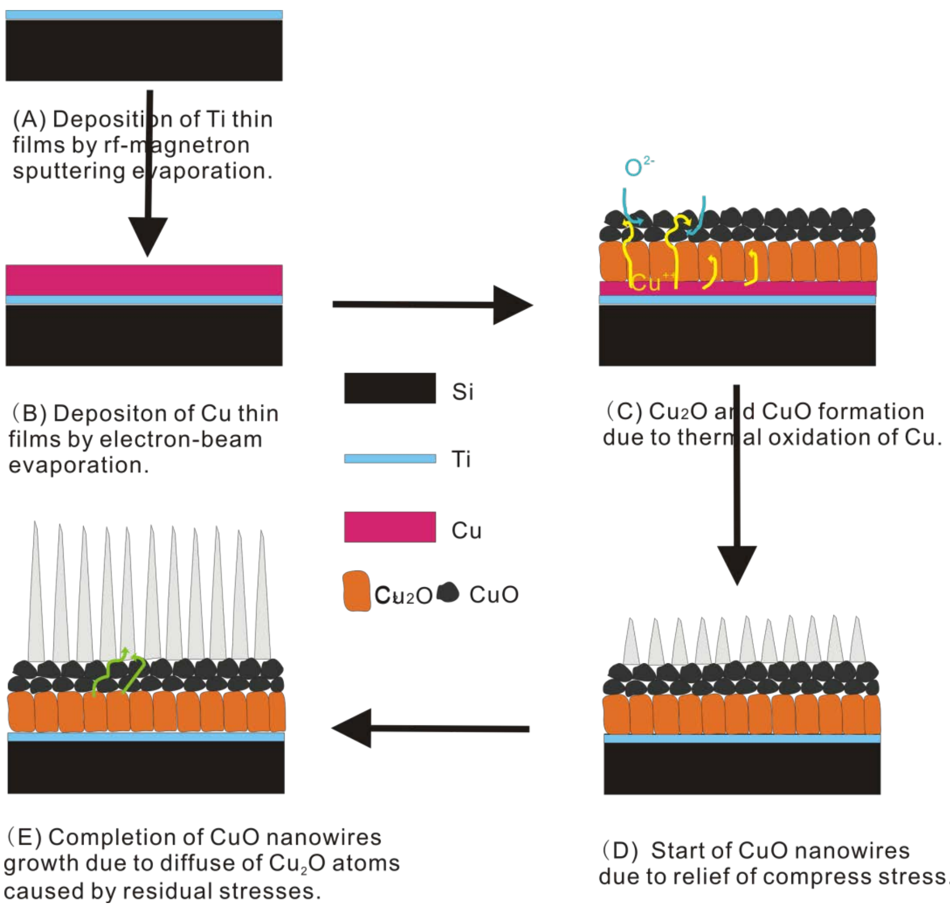
2) The film thickness: 1μm

3) The electron-beam evaporation: 0.15A

4) The annealing time: 4h



The growth mechanism



The CuO growth mechanism:

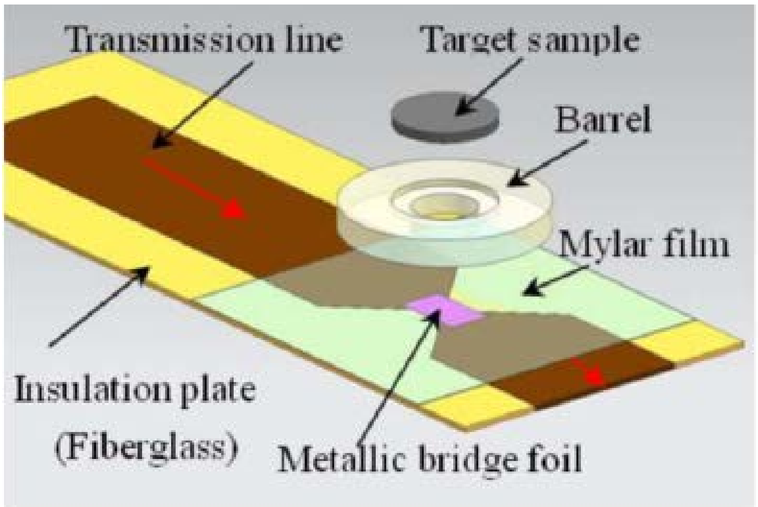
1) Accumulation stress;

2) The appearance of apophysis;

3) The nucleation with apophysis;

4) The growth of nanowires

Reactive Materials for Exploding foil initiator (EFIs)-Al/CuO



Influence of Al/CuO reactive multilayer films additives on exploding foil initiator

Xiang Zhou, Ruiqi Shen, Yinghua Ye, Peng Zhu, Yan Hu, and Lizhi Wu
School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, China

(Received 19 June 2011; accepted 12 September 2011; published online 3 November 2011)

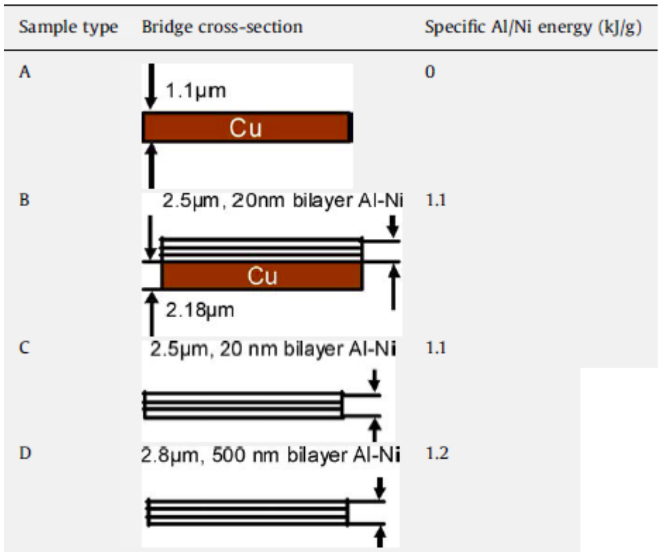
An investigation on the influence of Al/CuO reactive multilayer films (RMFs) additives on exploding foil initiator was performed in this paper. Cu film and Cu/Al/CuO RMFs were produced by using standard microsystem technology and RF magnetron sputtering technology, respectively. Scanning electron microscopy characterization revealed the distinct layer structure of the as-deposited Al/CuO RMFs. Differential scanning calorimetry was employed to ascertain the amount of heat released in the thermite reaction between Al films and CuO films, which was found to be 2024 J/g. Electrical explosion tests showed that 600 V was the most matching voltage for our set of apparatus. The explosion process of two types of films was observed by high speed camera and revealed that compared with Cu film, an extra distinct combustion phenomenon was detected with large numbers of product particles fiercely ejected to a distance of about six millimeters for Cu/Al/CuO RMFs. By using the atomic emission spectroscopy double line technique, the reaction temperature was determined to be about 6000–7000 K and 8000–9000 K for Cu film and Cu/Al/CuO RMFs, respectively. The piezoelectricity of polyvinylidene fluoride film was employed to measure the average velocity of the slapper accelerated by the explosion of the films. 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, and some probable reasons were discussed with a few suggestions put forward for further work. *© 2011 American Institute of Physics.* [doi:10.1063/1.3658617]

Traditonal metallic materials : Copper aluminum, gold and so on

Al/CuO multilayer: did not improve flyer velocity

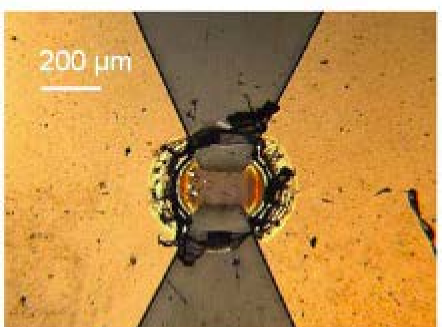
Disadvantage: low power transduction efficiency

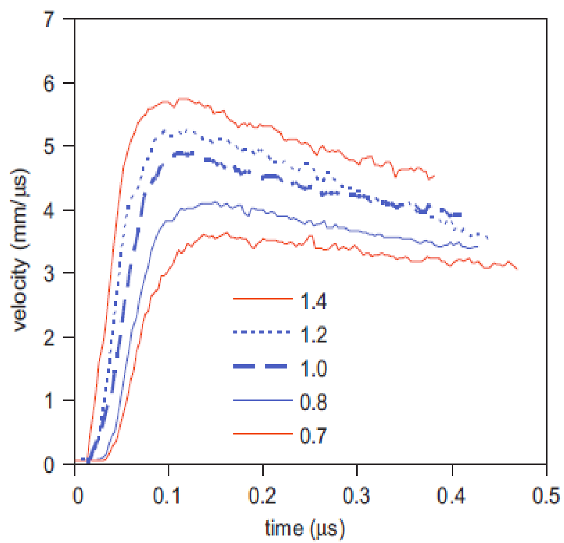
Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni

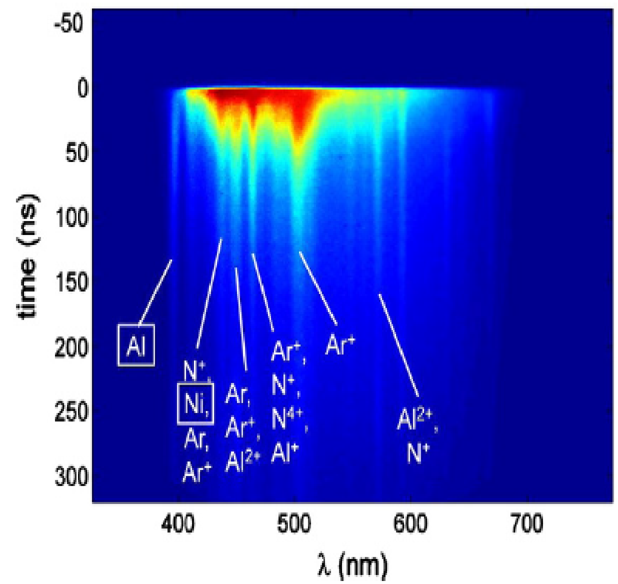


Sample type	Bridge cross-section	Specific Al/Ni energy (kJ/g)
A	1.1μm; Cu	0
B	2.5μm, 20nm bilayer Al-Ni; Cu; 2.18μm	1.1
C	2.5μm, 20 nm bilayer Al-Ni	1.1
D	2.8μm, 500 nm bilayer Al-Ni	1.2

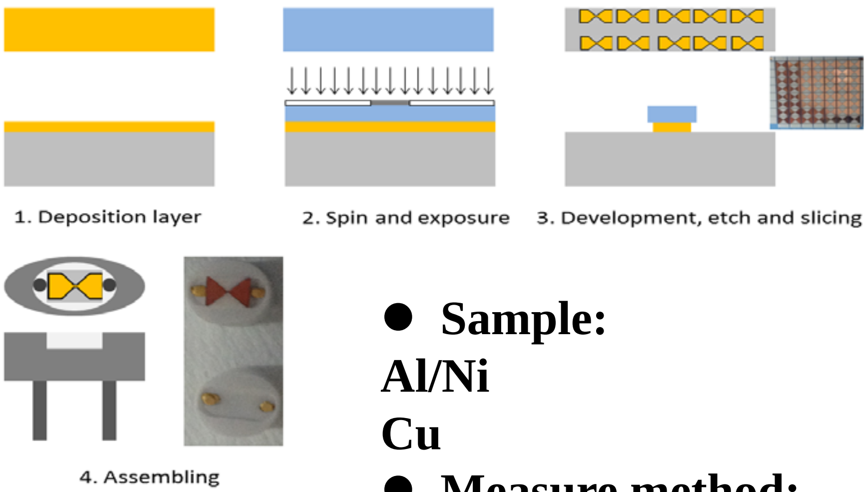
application of a large electrical current. We observed flyer plate velocities in the 2–6 km/s range, corresponding to 4–36 kJ/g in terms of specific kinetic energy. Several samples containing Ni/Al films with different bilayer thicknesses were tested, and many produced additional kinetic energy in the 1.1–2.3 kJ/g range, as would be expected from the Ni–Al intermetallic reaction. These results provide evidence that nanoscale Ni/Al layers reacted in the timescale necessary to contribute to device output.







Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni



- **Sample:**

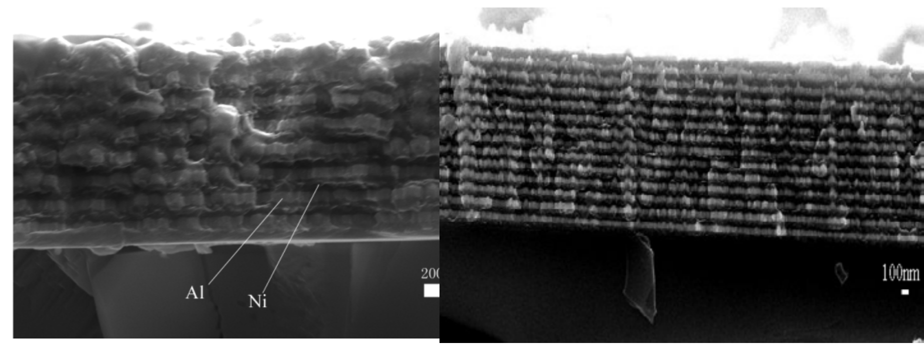
Al/Ni

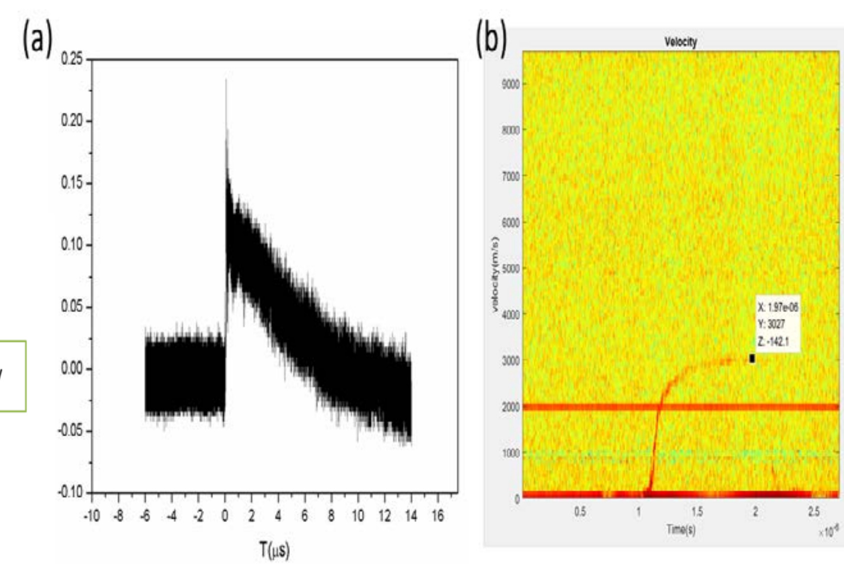
Cu

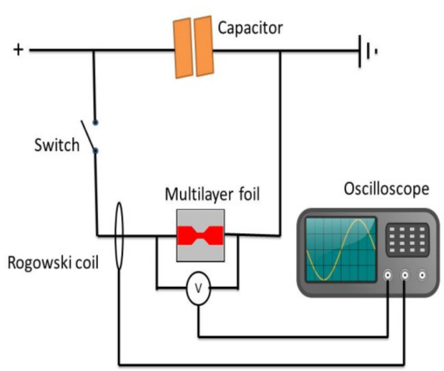
- **Measure method:**

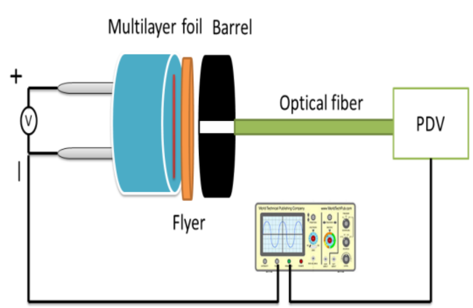
PDV

U/I









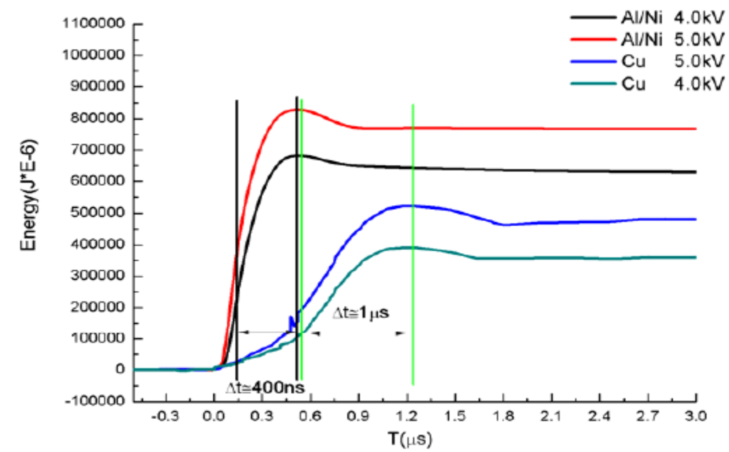
Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni

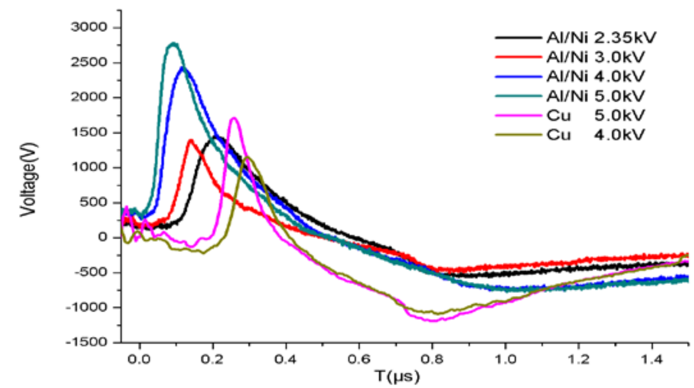
Fig. 5 (a): Current histories for Al/Ni and Cu film, (b): Voltage histories for Al/Ni and Cu film

Table.1 Results of exploding foil

No.	Material	Resistance of foil mΩ	Input voltage V	Peak voltage V	Time of peak voltage ns	peak current A	Time of peak current ns	Peak energy mJ	Maximum energy mJ	Input energy mJ	Energy efficiency	△t ns
1	Al/Ni	110	2350	1456	204	1203	201	110	340	610	18%	337
2	Al/Ni	104	3000	1500	140	1395	239	66	300	990	6.7%	346
3	Al/Ni	105	4000	2416	120	1498	261	170	650	1760	9.7%	366
4	Al/Ni	103	5000	2768	103	1760	273	240	780	2750	8.7%	376
5	Cu	26.2	5000	1717	260	3014	240	160	690	2750	5.8%	1245
6	Cu	26.5	4000	1157	275	2489	235	45	470	1760	2.6%	1180

△t: The time of maximum energy minus time of peak voltage



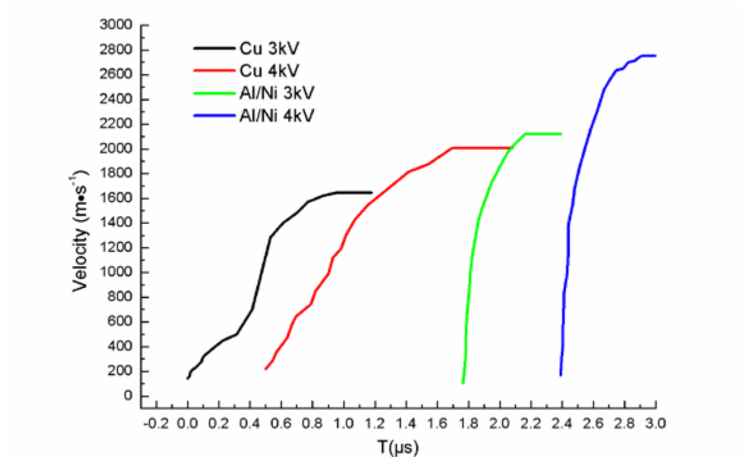


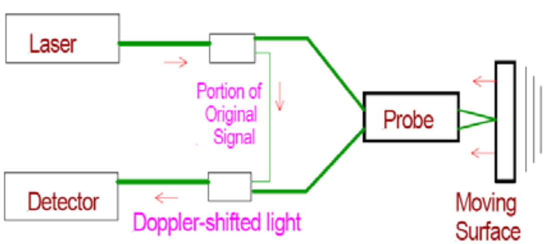
Reactive Materials for Exploding foil initiator (EFIs)-Al/Ni

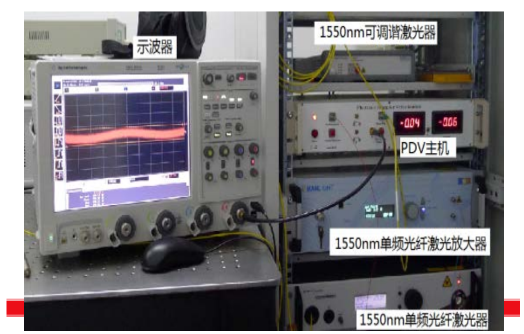
D. Photonic Doppler velocimetry (PDV)

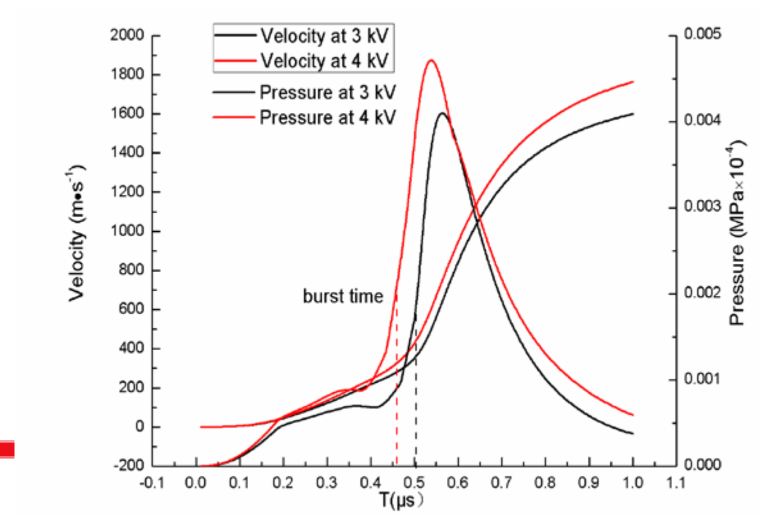
In a separate set of tests with identical samples, we used PDV to measure the resulting velocities of the flyer material when connected to the same high voltage firing circuit used in the streak spectroscopy measurements. This technique quantified the Doppler shift in frequency $\Delta f(t)$ of light reflected off a moving target—in this case the flyer—relative to the light emitted from the end of a fiber optic probe.[38] The measured difference in frequency $\Delta f(t)$ is related to the flyer velocity $u_f(t)$ according to

$$\Delta f(t) = 2\frac{u_f(t)}{\lambda_0}, \qquad (6)$$









Thank you for your attention