Resistive Products	Application Note

EPIC

For more than 15 years, Vishay has been very successful in the field of electro-pyrotechnic initiators used in automotive safety devices: airbags, pre-tensioners, etc. To address the booming demand for safety devices in new cars (more than 20), the auto industry has focused on the development of microjoules-energy and fast-firing initiators linked by one central "intelligent" bus system encircling the vehicle. The EPIC resistor fits these requirements. Among several other military and civilian applications the EPIC has proven its efficiency as the heating element of an initiator for use in the promising new generation of digital-controlled blasting systems.

In this paper we will show how the EPIC's thin film construction is unique in providing pyrotechnic engineers with outstanding performances in terms of firing energy, firing time, reproducibility and reliability, easy set up, no fire/all fire ratio, assembly, versatility, etc.

PRINCIPLE OF OPERATION

1. **Definition**
   An electro-pyrotechnic chip initiator is a resistor which is designed to use the electro-thermal heat developed within it to ignite an energetic material

2. **Properties**
   It must respond to a specific energy input with a specific period of time. It must be immune to electro-magnetic environmental pollution

3. **Mounting**
   Usually within a sealed chamber called a "squib"
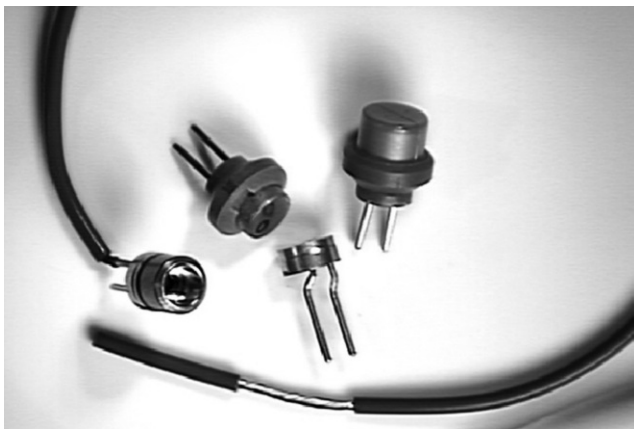
Example of squip assemblies

APPLICATION REQUIREMENTS

1. Automotive Safety Devices

There are more and more safety devices in new cars: Dual stage airbags, seatbelt pre-tensioners, side curtain airbags, knee bolsters, headrest bags, side bags, inflatable seatbelts, rear seat bags, roll bars on convertibles, battery cable cutters, etc…

With more than 20 "squib" activated devices per car, the energy level required to initiate the ignition of the pyrotechnic has become a very serious cost consideration.

Consequently, the auto industry has focused on the development of low energy systems, in the microjoule area, linked by one central "intelligent" bus system encircling the vehicle. The traditional bridge wire technology is no longer valid to make the low energy squibs. Such devices would require wire of very small diameter, less than 7.5 µm.

The wire is too weak, the ohmic value of the weld wire is incontrollable, the contact area of the wire with the pyrotechnic material is too small to effect efficient heat transfer, the no fire/all fire ratio becomes out of control in addition to that the heater top surface must be lapped very flat at very high cost etc...
The bridge wire technology is also questionable in terms of mechanical shocks and high acceleration withstanding.

An other heating element, the semiconductor bridge, over-powering back-biased diodes to generate heat, is in the right energy ranges but the temperature profile curves are undefinably inconsistent. Manufacturers are using them but they are not completely satisfied because the electrical engineers do not know the precise power configuration to deliver to the squib.

The EPIC fits exactly the requirements of these low energy and fast firing time squibs dedicated to automotive safety devices.
It's thin film technology contributes to the stability of the heating element, the precise electro-thermal response profile and the ability to design a precise activation energy.

APPLICATION NOTE

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2. Mining Applications

The unique features of the EPIC are also ideally adapted to the new generation of blasting systems which are digital controlled system, it allows a complete control of blasting operations.

The introduction of the high accuracy detonator is reinforcing proper timing as a fundamental element of efficient blast design. The controlled sequence of hole-detonation is one of the more critical parameters having a direct effect on overall blast performance in many ways. The measure of potential effectiveness that the available explosives energy has to both break and displace the rock mass is directly proportional to the effective burden that energy must overcome. Any variation in-hole detonation timing will result in burden to energy relationships that can have adverse impacts on the performance of a blast. The results of these impacts have been witnessed in the past as: Poor rock fragmentation - high ground and air vibration levels - fly-rock incidents - increased need for secondary blasting and increased excavation and crushing costs.

Research has shown that the standard pyrotechnic delay elements that are currently being utilized throughout the world do not provide the accuracy's necessary to consistently and measurably mitigate impacts.

In the contrary, digital blasting systems equipped with EPIC resistors have proved that accurate hole detonation would provide the explosives using industry with the potential to effectively minimize these adverse timing related impacts.

3. Other Applications

Numerous others applications:

Military pilot seat ejection systems, explosive bolt disengagement of airborne missiles, chaff dispensers, artillery projectile activators, anti-tank mines, deconstruction.

Are also taking benefits of the EPIC unique features:

- Low Firing energy

- Fast Firing time

- Compatibility with various pyrotechnic composition even with no primer

- Joule effect ignition or flash ignition for very fast firing

- Easy set up by design of firing levels

- No fire/all fire ratio up to 70 %

- Very predictable, reproducible and reliable behavior

- Harsh environment withstanding: Mechanical shocks, very high acceleration, high spin rates

EPIC CONSTRUCTION
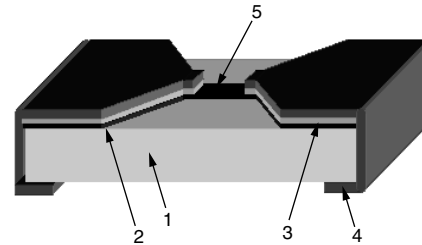
Three layers, respectively resistive (2), barrier of diffusion and conductive (3), are vacuum deposited on a special and proprietary alumina based substrate (1). Then the layers are selectively patterned in order to match very precisely the heating resistor (5). Then the end the terminations (4) are sputtered, plated and coated.

Technology Overview

The proprietary substrate (1) is a an alumina based material. The resistive material (2) is preferably Ta_2N which is very convenient in terms of:

- Resistivity, around 400 $\mu\Omega$ x cm

- Thermal coefficient of resistance, TCR, less than 200 ppm/°C

- Thermal conductivity 57 W/(m x °C)

- Specific heat ,C, 0.14 J/(g x °C)

- Resistivity, around 400 $\mu\Omega$ x cm

- Chemical resistance

It could also be NiCr, PtW or more exotic material for special applications, for example flash ignition.

The inner conductive (3) layer is gold and the terminations (4) are preferably dipped SnAg over a nickel barrier.
Solder reflow is the most standard assembly process but for special applications plated gold over nickel barrier terminations are also available.

The standard size is 0603 but other sizes, down to 0302, might be produced.

Thin Film Construction and Ensuing Benefits

Vishay's Thin Film technology is very well adapted to the mass production of high reliability, miniaturized, high precision and high stability products.
At a first glance the EPIC does not look like such a component but our 25 years of experience in Thin Film is of premium importance to give the EPIC all its unique features. This is what we will examine here below.

EPIC

The Substrate

is specially designed and built in such a way that:

- The whole firing pulse energy is transferred to the pyrotechnical material to heat it up, almost no energy from this very short pulse is going through the substrate.

- The electrical energy ,other than the firing pulse energy, is transferred preferably to the ambient through the substrates and the end terminations.

This is a key point to make low energy and fast firing time heating resistor.
This is also the reason of the high ratio NF/AF, up to 70 % which of paramount importance for automotive safety devices.

The Heating Resistor

is a very precisely patterned Ta_2N block which dimensions are:

Length L, width W and thickness T.

The ohmic value is controlled by the resistivity of Ta_2N and by L, W and T.

$$R = (r \times L)/(W \times T) \ (1)$$

The electrical energy is also controlled through R

$$E = R \times I \times I \times t \ (2)$$

The electrical energy is transformed into heat and the adiabatic heating of the resistor comes from the following equation:

$$E = m \times c \times \Delta T = L \times W \times T \times d \times C \times \Delta T \ (3)$$

density d and specific heat C are Ta_2N physical constants, providing Ta_2N deposition is perfectly under control.

Let us consider standard dimensions L = W = 50 μm, T = 2 μm, then per equation (1) R = 2 Ω

Assuming that we want a 400 °C adiabatic heating of the resistor the electrical energy E can be obtained from equation (3).

E = 0.005 x 0.005 x 0.0002 x 16 g x 0.14 J/(g x °C) x 400 = 4.5 μJ

As a matter of fact and from some figures we have got back from customers the actual electrical energy which is necessary to fire up a critical mass of pyrotechnical material is about 2 to 10 times the level of energy which is necessary to heat up the resistor alone by 400 °C.

In our case, and in the worst case, a 50 μJ energy firing pulse will be convenient.

From equation (3) one can calculate the combinations R, I, t.

With R = 2 Ω
I = 1 A, t = 25 μs
I = 0.7 A, t = 50 μs
I = 0.5 A, t = 100 μs

This is to illustrate how the low energy and fast firing time relevant to the EPIC are obtained.

Ta_2N Deposition and Patterning

The resistive layer and the inner conductive layer are vacuum deposited and heat treated through the high precision and stability process line.
This means that the thickness and the structure of the Ta_2N layer are precisely controlled, so are the density d, the specific heat C, the resistivity r and the thermal stability TCR of the Ta_2N heating resistor.
The patterning is done per our μm line definition processing. This means that L, W are very tightly controlled, so are the ohmic value and the mass of the heating element.
From equations (1), (2) and (3) and summing up the process fluctuations one can get a total error budget less than 10 %.

This is why the thermal behavior of the EPIC is so predictable, reproducible and reliable.

Firing Levels Set Up by Design

The predictable and reproducible behavior makes simpler the firing levels set up by design.
From the "EPIC design guide", which is filled up by customer, we know about all firing and no firing conditions, ohmic value and temperature range.
From there and using equations (1), (2) and (3) we can calculate the mass of the filament and define a set of (L, W, T) combinations.

It is important to notice that using a thin film resistive layer it is possible to work within a very large range of thickness, T, from 50 nm up to 5000 nm.

This means that one can choose among a lot of (L, W, T) combinations, this is very useful to cope with the "No fire"/"All fire" specifications.

Figure (#) shows how "All fire" and "No fire" values depend respectively on the mass and the surface of the heating resistor.

Fuses: NF and TF = f (s)
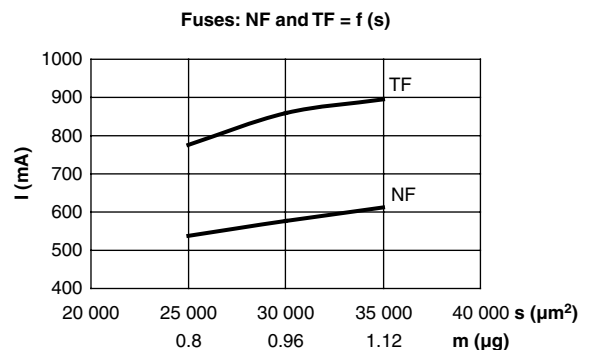
For our standard size 0603 we have a lot of opened tools, most of those are multi-images masks.
Using these masks we will be able to provide the customer with evaluation samples, generally three different ones, close to his needs.

Then equipping squibs with these samples the customer will know what is the right model for his application or at least he will help us defining more precisely the characteristics of the heating resistor.

Then we will be able to produce Initial Samples with a final set of masks.

These is why a new EPIC application set up can be fast and non expensive .

TESTING AND RELIABILITY DATAS: BRUCETON TEST

A prerequisite to valid reliability estimation of an electro-explosive device (EED) is a sensitivity test program carefully chose and properly performed. The Bruceton Method (or up and down method) of sensitivity testing was developed specifically for ordinance testing. (For more information, please refer to SAE/USCAR document).

**Bridge Resistor
(In Squib)**
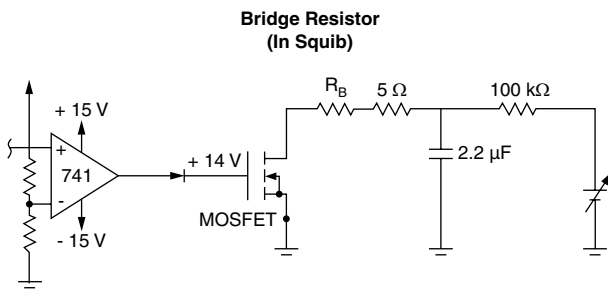
Test circuit bruceton reliability test

The here below example of Bruceton test results summary shows how Vishay/Sfernice design approach is efficient.

Two different customers, working on airbags, have tested squibs of their own which have been equipped by three different heating resistors, each one is a specific (L, W, T) combination, called "variant".

HEATING ELEMENT	CUSTOMER A		CUSTOMER B	
	NF (in mA)	AF (in mA)	NF (in mA)	AF (in mA)
Variant 1	546	766	538	776
Variant 2	571	839	577	859
Variant 3	619	891	612	875

Their Bruceton test results are self explanatory, they show that the electro-thermal behavior of the EPIC is predictable, precise and reproducible.

Assembly

The Wraparound terminations get the assembly very easy. The quality and the robustness of the inner and end terminations layers together with the stability of the resistive layer are preventing any drift during the assembly or the use of the squib.
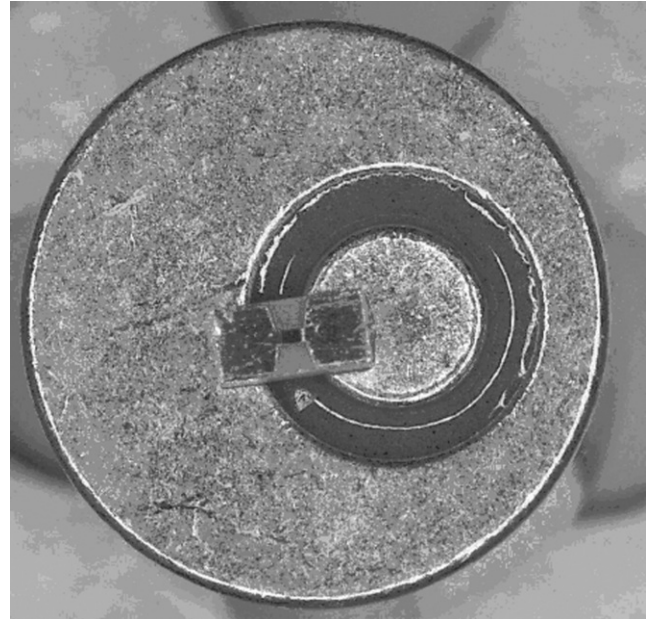
Example of an EPIC glued on a squib

Recommendations

Vishay/Sfernice recommends to use Electrovac squibs which are well adapted to the EPIC.
Example of suitable reference:
Electrovac web site: http://www.electrovac.com
E1.177202, C0.302200 or E1.177201
Both report processes: Silver epoxy or lead free soldering pasta (standard reflow process) are giving excellent results with this type of squib, the contact resistance is so small that it does not affect the overall value of the resistor.

Conclusion

In this paper we have shown how the thin film technology contributes to the stability of the heating element, the precise electro-thermal profile and the ability to design a precise activation energy.
All these features are perfectly controlled on high production volumes.