ISSN 2395-1621

Pyro-MEMS Based Safe, Arm and Fire (SAF) Device: A Review

[#1]Abhijit Kolhe, [#2]Virendra Kumar, [#3]Dhananjay Panchagade

[1]abhijitklh5@gmail.com
[2]dvkverma25@gmail.com
[3]panchagade@gmail.com

[#13]Department of Mechanical Engineering, DYPCOE Akurdi Pune, SPPU
Armament Research & Development Estt, Pashan Pune, India

ABSTRACT

This paper deals with Pyro-MEMS Based Safe, Arm And Fire Device used in Munitions. It takes all the functions in a mechanical arm and fire system and integrates them in a single $1cm^3$ package. It also combines a mechanical arming unit with electrical safety functionalities on the same pyrotechnical initiator's chip. In comparison to prior art safe and arm devices, the current work aims to achieve as much as reduction in volume and cost.This paper explores micropyrotechnics to fabricate a miniature Safe Arm and Fire device (SAF). The main functions of a SAF device are to keep the detonator safe (a screen interrupts the explosive train), to arm it (the screen is mechanically removed from the safe position) and to initiate one primary explosive necessary for initiating the munition (secondary explosive). Due to advancement in the micro scale manufacturing techniques it is possible to design and achieve the MEMS based safety and arming device with a high reliability level. Here in this paper a review of Carole Rossi's SAF device is given.

The features of the SAF device combine both 'sense' and 'actuate' functions in a single $1cm^3$ package, that mechanically arms the fuse by moving a microscale initiator in-line with other fire train components

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

Keywords- Pyrotechnics, MEMS, SAF.

I. INTRODUCTION

Safe Arm & Fire (AF) device is a safety device that provides electrical and mechanical interruption of an ignition train in order to prevent the unintended functioning of Munitions. Fuzing mechanisms are devices used to 'safe', 'arm' and detonate explosive military munitions. SAF devices incorporate a fail-safe mechanism that enables the device to remain armed only while power is applied. MEMS technology has matured to the state where compact and reliable SAF device designs can be created using well established and demonstrated MEMS manufacturing processes.

1.1. Microelectromechanical Systems (MEMS):

MEMS is the technology of very small devices. It merges at the nano-scale into nano electromechanical systems (NEMS) and nanotechnology. MEMS are also referred to as micro machines (in Japan), or micro systems technology – MST (in Europe).

MEMS are separate and distinct from the hypothetical vision of molecular nanotechnology or molecular electronics. MEMS are made up of components between 1 to 100 micrometers in size (i.e. 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometers (20 millionths of a meter) to a millimeter (i.e. 0.02 to 1.0 mm). They usually consist of a central unit that processes data (the microprocessor) and several components that interact with the surroundings such as micro sensors. At these size scales, the standard constructs of classical physics are not always useful. Because of the large surface area to volume ratio of

MEMS, surface effects such as electrostatics and wetting dominate over volume effects such as inertia or thermal mass.

1.2. Safe Arm and Fire Device (SAF)

These devices are used to prevent accidental or inadvertent ignition of rocket motors during flight or in any usage which could cause an extreme hazard to personnel or facilities. Arm and Fire (AF) devices incorporate a fail-safe mechanism that enables the device to remain armed only while power is applied. When power is removed from the device, they return to the safe position. Safe and Arm (S&A) device is a safety device which can be fail-safe or which can incorporate a latching mechanism which enables the device to remain armed after power is removed and can typically be returned to safe position by applying power. Latching S&A devices are commonly used to initiate system destruct in the event of a test failure. Fail-safe S&A devices are typically used for launch vehicle initiation and for rocket motor stage separation during flight. S&A devices commonly use an Explosive Train (ET) to transfer energy to another device from the S&A. A
SAF device should ensure that the missile has been launched, has traveled a minimum safe distance, and is operating properly before the Warhead or Warheads are armed or fired. If the missile has multiple Warheads, the ESAF device should fire the Warheads at delayed intervals. The missile launcher has to be confident that the Warhead or Warheads will detonate at the proper time.

S&A and AF devices are essential elements of today's complex launch vehicles, missiles and weapons systems. These devices must be compact, highly reliable and satisfy stringent performance requirements. Using traditional manufacturing methods, current S&A devices are precision electromechanical systems that are typically 4 inches by 4 inches by 3 inches and weigh 3.7 pounds. Today's advanced S&A designs are 2.25 inches by 2.25 inches by 2 inches and weigh 1.25 pounds. An innovative design for S&A and AF devices that is based on MEMS (micro-electromechanical systems) propulsion technology could reduce the size by a factor of ten and reduce the weight to grams.

The main functions of a SAF device are to keep the device safe, to arm it and to contain one energetic material necessary for initiating the munition. A MEMS SAF is not a “sensor” or a miniaturized pyrotechnical initiator, but it combines both sensing and actuation functions in a very tiny volume and must operate with a high reliability level.

1.3. Pyrotechnics

Pyrotechnics is the science of using materials capable of undergoing self-contained and self-sustained exothermic chemical reactions for the production of heat, light, gas, smoke and/or sound. Pyrotechnics include not only the manufacture of fireworks but items such as safety matches, oxygen candles, explosive bolts and fasteners, components of the automotive airbag and gas pressure blasting in mining, quarrying and demolition. Individuals responsible for the safe storage, handling, and functioning of pyrotechnic devices are referred to as pyrotechnicians.

Micropyrotechnics can be defined as the integration of an energetic material into a multi-functional microsystem, for which the thermal, mechanical and chemical energy released by decomposition can be exploited. The chemical energy can be released by sublimation, or combustion, or detonation conditions.

Also the point is to be able to insert the energetic materials into the global microsystem depending on the application. These lead to the following challenges:
1. Optimization of initiation is a crucial point for the progress of this technology. The objective is to minimize the energy to be supplied to trigger the initiation such that these systems are compatible with microsystem constraints.
2. The reduction of the dimensions towards the limits of micropyrotechnics, to make further progress in the integration level, mass and cost reduction.
3. The choice of energetic materials to be integrated. The energetic material is at the heart of the technology. It must be selected and formulated precisely as a function of the application and as a function of the expected performances in terms of initiation and actuation.
4. The choice of architecture and the development of a simple, integratable, robust and reliable manufacturing and assembly technology.

The airbag is the most well-known application of micropyrotechnics, followed by the generation of forces which is the most researched use of micropyrotechnics: more than half of the research papers addressing the applications of micropyrotechnics focus on micropropulsion.

II. Architecture and Principle of Operation of MEMS SAF

As illustrated in Fig.1, the architecture of the SAF MEMS device consists in a multilayer stacked-wafer:

2.1 Electronic circuitry and power supply de vice
The top layer contains the electronic circuitry and power supply device. It is composed of a multi layer circuit using a DC/DC converter and a fast switching scheme driven by a low consumption micro controller.

2.2 Si-based safe initiator
The middle layer is a Si-based safe initiator layer. The main component is one resistive igniter (micro detonator) with a highly energetic material and three bistable electro-thermal MEMS switches (ON-OFF and OFF-ON switches). The Si-based safe initiator layer contains also one resistive igniter with a bi-metallic gas generator energetic material to form a pyrotechnical micro actuator.

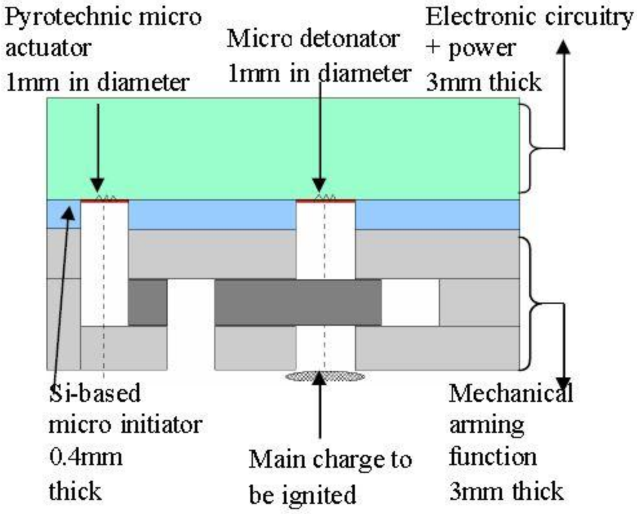
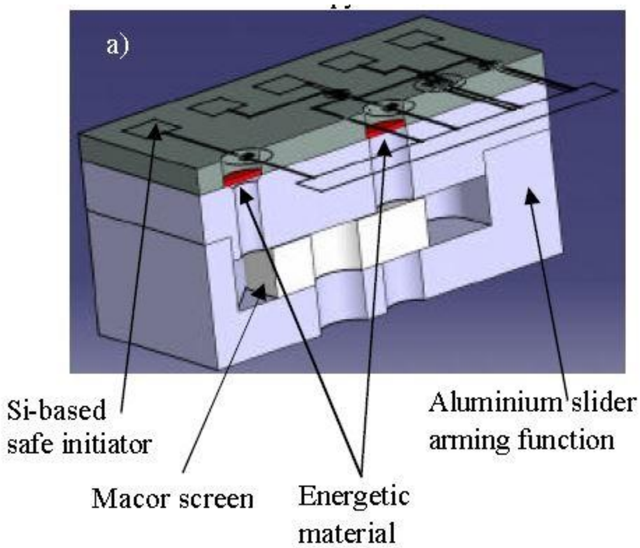


Fig. 1: Cut view of the SAF device made of stacked wafers.

2.3 The arming function

The bottom layer constitutes the arming function which consists in des-interrupting the main pyrotechnical chain by moving a ceramic (MACOR) screen. In safe mode, the screen avoids the spreading of the detonation if the micro detonator blazes despite of the electrical securities. To arm the SAF device, the electronic circuitry sends a current impulse into the pyrotechnical micro actuator resistance. When the gas generator energetic material reaches to a certain temperature, the pressure in the cavity increases and pushes the screen to arm the SAF device. To prevent that a shock unlocks the mechanical screen, an inertial pin can be inserted into the device to block the screen.

This screen moves in a slide made out of aluminium which is a light metal of similar density to that of silicon and which is used in assemblies subjected to the high thermal gradients and pressure. Fig. 2 represents the arming function before and after the initiation of the micro pyrotechnical actuator.



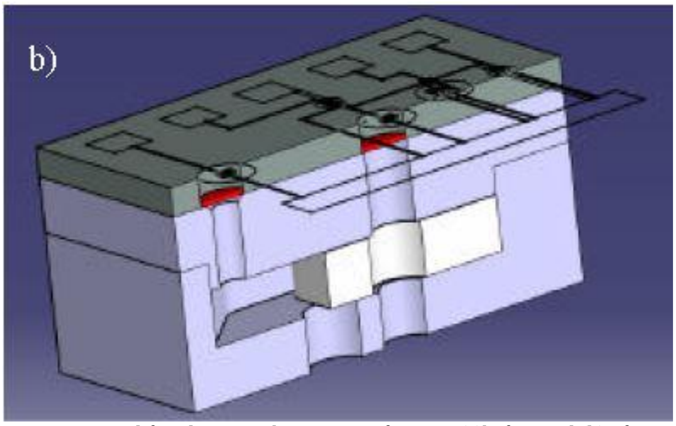


Fig. 2: Arm and fire device with its arming function (a)before and (b) after actuation.

The SAF device operations procedure is illustrated in Fig. 3: The MEMS SAF is stored in safe mode: the screen is locked and the initiator pads are both connected to the electrical ground (Fig. 3a). The first order is for the mechanical arming (Fig. 3b): the inertial pin is removed by the acceleration; then the microcontroller sends an electrical order to the microactuator resistance. The gas generated by the pyrotechnical actuator moves the screen in armed position. Then, the SAF is electrically armed, that is to say the microinitiator electrical short-circuit to electrical ground is cut (Fig. 3c). At this stage, if the operator does not send an order to stop the procedure, the microcontroller sends an electrical order to the initiator to ignite the primary explosive located in

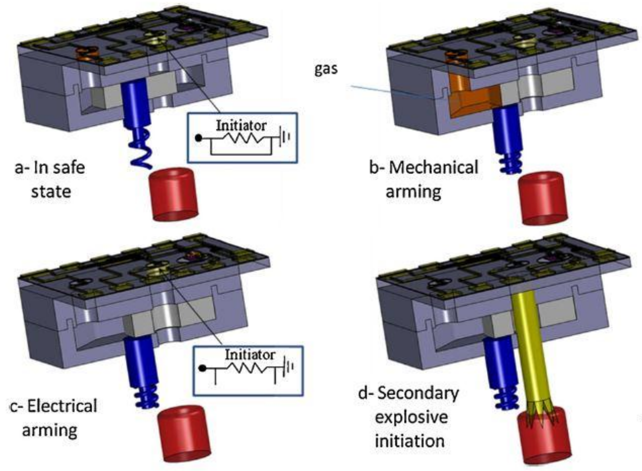


Fig 3: Operations procedure of the MEMS SAF device (a) in safe mode, (b) mechanically armed, (c) electrically armed and (d) secondary explosive initiation by initiator.

its cavity (Fig. 3d), and the secondary explosive can be initiated. If there is a failure during the sequences, it is possible to disconnect definitively the microinitiator from its power supply by breaking its electrical connections.

III. FABRICATION AND ASSEMBLY

3.1. Arming functions

The aluminum has been chosen for the arming function case because it presents good mechanical properties and a good longevity so it is used in assemblies subjected to high thermal gradients and pressure. The MACOR has been chosen for the movable mechanical screen: it is a ceramic which can support high thermal gradients (800–1000 ◦C). It is a rigid material featuring high resistance to wear effect like climatic or chemical aggressions and a very low thermal conductivity. The thermal dilation coefficient α like its physical properties as Young modulus approaches those of silicon. Both materials, aluminum and MACOR, can be machined precisely by traditional way.

The MACOR piece corner radius of curvature is slightly larger than the one of the slide corners in which it moves. It is thus able to achieve its end of course in force in the slider and to remain thus blocked in armed position.

The aluminum case is divided in two parts: the cap and the base, as it can be seen of. These two parts are machined in a complementary way. Indeed, the base has a 400μm height step in periphery of the cavity. And the cap has the complementary print as a crenel shape. The objective of this geometry takes all its direction during the assembly of the base and the cap by gluing. It prevents any glue flow inside the cavity. External dimensions of mechanical safety are the same ones as those of the Si-based safe initiator chip (8.4mm×7.4 mm).

3.2 SAF final assembly

Assembly is done with the Epotek H70E glue to assemble the arming function parts. It has good mechanical properties and in particular a rigidity modulus of μ= 1.35·107 Pa and a very good thermal dissipation. Surfaces to be stuck are cleaned in an ethanol bath. And a 99% ethanol and 1% promoter of adherence Epotek AP100 solution is deposited on surfaces to be assembled. Then the glue is dispensed on the part to be assembled using a calibrated syringe (Ø 250_m) and then the assembly is realized with a calibrated force (5000 g) and a reticulation is done at 150 ◦C during 300 s. After the arming function is glued, the silicon chip is glued with the same epoxy on the arming function part and is reticulated at 80 ◦C during 90 min. The temperature of reticulation has been reduced to prevent rosin to evaporate.

IV. CONCLUSION

This review gives an overview of detailed study of MEMS based SAF devices used in munitions & missiles, based on which the current work is defined. Very innovative Pyro-MEMS based safe, arm and fire device has been discussed. It is a multilayer stackedwafers: the bottom layer is the mechanical arming function made of Aluminum and MACOR. The intermediary layer is a silicon chip integrating electrical resistances and microswitches to realize the electrical arming and disarming functions. The top layer is the electronic and power circuitry with one supercapacitor.

REFRENCES

[1] .Carole Rossi, Marjorie Sancheza, Fabrice Mathieu, Xavier Dollata, Samuel Charlot, Ludovic Salvagnac, Véronique Conédéra, Integration of a MEMS based safe arm and fire device, Sensors and Actuators A 159 (2010) 157–167

[2] Hélène Pezous, Marjorie Sanchez, Fabrice Mathieu, Xavier Dollat, Samuel Charlot, Carole Rossi, Fabrication, Assembly And Tests Of A Mems Based Safe, Arm And Fire Device, Proceedings of PowerMEMS 2008+ microEMS2008, Sendai, Japan, November 9-12, (2008).

[3] C. Rossi, D. Estève, Micropyrotechnics, a new technology for making energetic microsystems: review and prospective, Sensors and Actuators A120/2 (2005) 297–310..

[4] C. . Rossi, D. Briand, M. Dumonteuil, T. Camps, P.Q. Pham, N.F. de Rooij, Matrix of 10×10 addressed solid propellant microthrusters: review of the technologies, Sensors and Actuators A: Physical 126 (1) (2006) 241–252.