FABRICATION, ASSEMBLY AND TESTS OF A MEMS BASED SAFE, ARM AND FIRE DEVICE

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Abstract: We propose a safe arm and fire device (SAF) that could constitute a real breakthrough for safe miniature fuzing device. On the one hand, it takes all the functions embodied in a conventional mechanical arm and fire system and integrates them in a single 1cm^3 package. On the other hand, for the first time, it combines a mechanical arming unit with electrical safety functionalities on the same pyrotechnical initiator's chip. It respects the STANAG 4187 norm (1A/W during 5 minutes of not fire) and requires 500mW for ignition.

Key words: MEMS, pyrotechnical micro initiator, safe arm and fire device, electrical protections.

1. INTRODUCTION

An innovative concept of micro actuation was proposed by LAAS-CNRS in 1995 for a medical application using pyrotechnical energy [1]. Since then, this concept has been applied into many fields: micro propulsion [2], micro fluidics [3] and weapons [4] (in both military and civil domains). In this context, the motivation of using microsystems is not only to reduce the systems dimensions but also to increase the system safety and reliability. The french military agency (DGA) in collaboration with NEXTER MUNITION is applying MEMS technology to fabricate smaller safe arm and fire systems. The main functions of a SAF device are to keep the device safe (a screen interrupts the explosive train), to arm it (the screen is removed from the safe position) 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.

The goal of this paper is to present the design and fabrication of a 1cm^3 MEMS SAF, integrating electrical and mechanical protections.

2. ARCHITECTURE AND PRINCIPLE OF OPERATION OF THE 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 device

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.

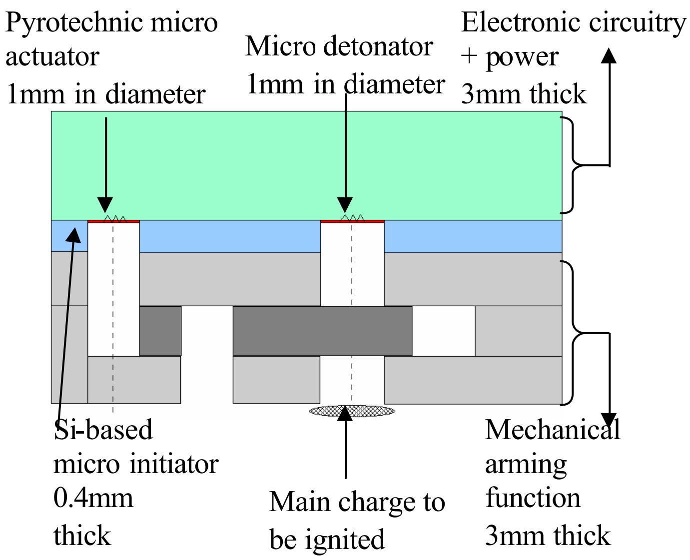


Fig. 1: Cut view of the SAF device made of stacked wafers.

This small size design with 50 000 hours of lifetime is supplied by a storage battery. In this application, our micro device needs 500mW to be operated, that corresponds to a hundred to thousand factor in comparison with traditional energetic consumption in autonomous systems. Furthermore, to supply this power for the device, we have to apply an important voltage (upper than 10V) which doesn't match with standards in low-power world.

As the system is embedded, the available energy is limited. The electronic has to have a maximal lifetime and has to provide 500mW to each of the five poly-silicon resistances.

The selected solution for energy storage is a pre-loaded supercapacity kept on load by button cell.

To maximize the lifetime, a low-consumption electronic is used and set on sleep mode until its use.

The waking is made by an external order. The system's lifetime reaches 30 000h. It's also planned to keep the embedded electronic on voltage during the stocking.

To provide the required power, the power supply voltage is raised by a DC/DC converter.

This power sending is driven by analog switches. Two kinds of fast switching (less than 200ns) and low on resistance components are used: a CMOS analog switch and MOSFET.

A microcontroller supervises all required stages for the Si-based safe initiator layer operation.

Small components and multilayer circuit fulfil size specification ($1cm^3$). The embedded electronic is composed of three double-side stages connected each other by vias, and connected with the Si-based safe initiator by conductive glue. The power supply is placed above the system and is the bulkiest element (Fig. 2).

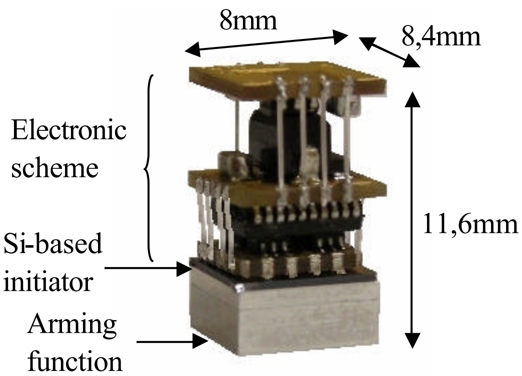


Fig. 2: Arm and fire device with its electronic circuitry.

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 MEMS switches protect the micro detonator of any external physical perturbations (lightning,…) and permit to respect the STANAG 4187 (1A/W during 5 minutes of not fire) military norms [5]. In safe mode, the detonator electrical pads are connected to the electrical ground until the system is ready to be fired. It is electrically armed just before firing. It can be disarmed once. The definitive annihilation of the fuzing capability is also possible. The detonator is constituted of a heating element made of polysilicon which initiates an energetic material by Joule effect.

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.

The electrical protections layout is presented in the Fig.3 below.

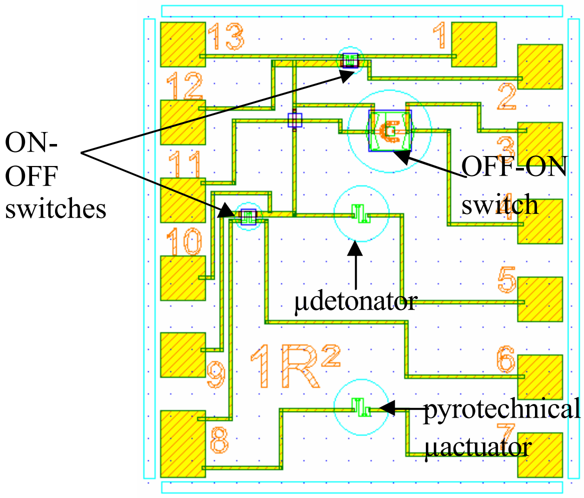
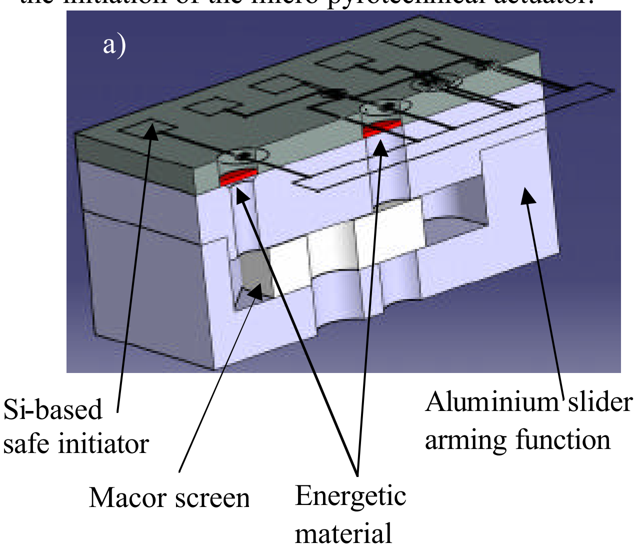


Fig. 3: Layout of the Si-based safe initiator layer (middle layer).

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 225°C, the pressure in the cavity increases up to 6.10^5Pa and pushes the screen to arm the SAF device.

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. 4 represents the arming function before and after the initiation of the micro pyrotechnical actuator.



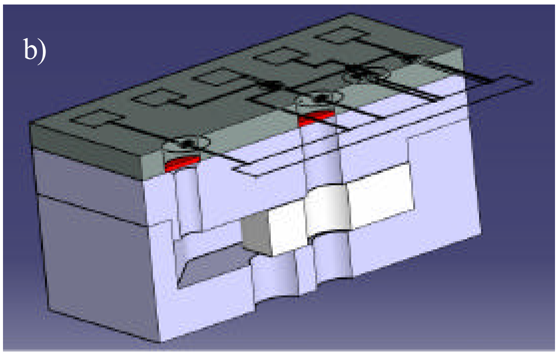


Fig. 4: Arm and fire device with its arming function before (a) and after (b) actuation.

First, the pyrotechnical actuator which contains 0.1mm^3 of bi-metallic energetic material [6] is simulated using Matlab/Simulink to predict the pressure and temperature increase in the cavity that pushes the screen. As shown in the Fig. 5, after the energetic material ignition, the pressure increases rapidly and reaches 6.43.10^{5}Pa when the screen is blocked in its final position. The maximal temperature is about 100°C. For this simulation, we assume that there is no gas leakage.

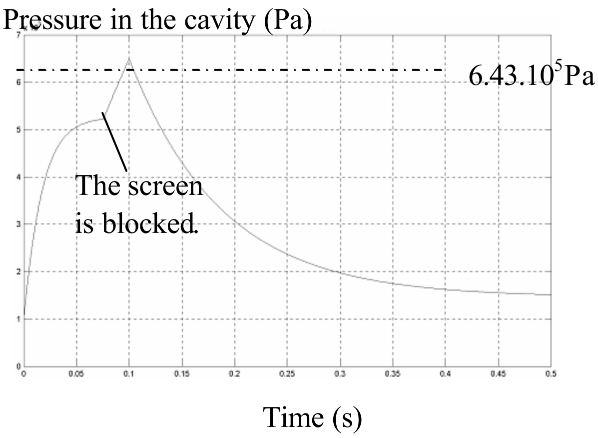


Fig. 5: Pressure evolution in the micro actuator cavity and slide containing the screen.

3. FABRICATION AND ASSEMBLY

3.1 Si-based safe initiator

For the fabrication process, we work with a 4" double side polished silicon wafer. The 400µm thick (100) oriented silicon wafer is thermally oxidized (1.4µm) at 1150°C. It is then coated with a 0.6µm thick silicon rich LPCVD (Low Pressure Chemical Vapor Deposition) nitride. These two layers will form the 2µm thick low stressed membrane. A 0.5µm thick polysilicon layer is deposited by LPCVD at 605°C and N doped by the diffusion of phosphorus.

Top side processing

The polysilicon layer is patterned using photolithography and etched away by Reactive Ion Etching (RIE) to define the heater resistors. Then, a 0.7 µm PECVD (Plasma Enhanced Chemical Vapor Deposition) thick layer of low stressed oxide is deposited and patterned using photolithography. This layer is then removed in a HF bath everywhere except on the heater resistance of the ON-OFF and OFF-ON switches. Then a 3µm thick copper layer is electroplated. A thin layer of gold (200nm) is finally flashed on the copper tracks to prevent them from oxidation. An other 0.7µm PECVD thick layer of low stressed oxide is deposited. And finally, 0.7µm of aluminium is evaporated for the fabrication of the ON-OFF switches.

Back side processing

The three thin back-side layers (Polysilicon, SiN_x and SiO_2) are removed by RIE. The silicon is then etched away by Deep Reactive Ion Etching (DRIE) to make the cavities closed on the top side by the SiO_2 / SiN_x membrane.

Post processing

The silicon chip is then cleaved to obtain a single MEMS based safe igniter. The first post-processing operation is the deposition of the rosin and solder ball on the ON-OFF micro switch heating platform. For that, the substrate is heated at 150°C and rosin is deposited between the two tracks of the switch by stamping. The ∅ 350µm Sn/Pb solder ball is then placed manually. Finally, the substrate is cooled down. The rosin solidifies and traps the solder ball.

The process is summarized in Fig. 6.

Fig. 7 shows the Si-based safe initiator layer (middle layer) with the micro igniters and the switches used as electrical protections.

3.2 Arming function

The aluminium structure of the arming function is made in 2 separated parts which are glued with an adhesive Epoxy H70E [7] as it can be seen on the following photo (Fig. 8).

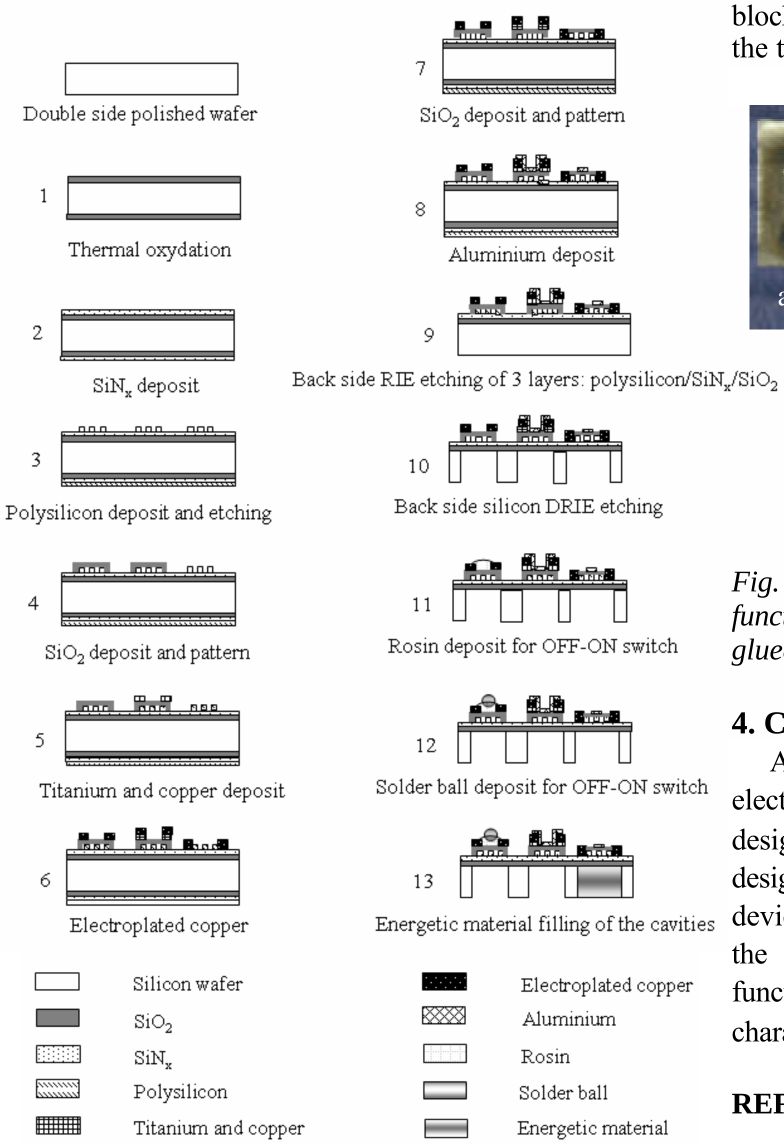


Fig. 6: Main steps of the Si-based safe initiator fabrication process.

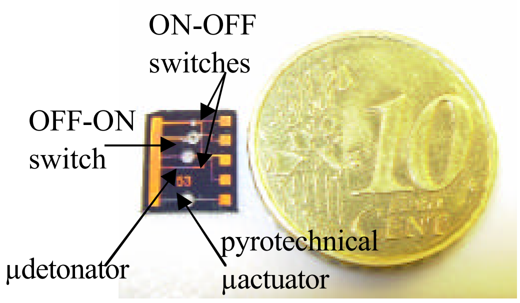


Fig. 7: Photo of the Si-based safe initiator (middle layer).

First validation tests have been carried out to calibrate the displacement of the screen in the aluminium slider. For that a pressure bench test generating pressurized N_2 gas is used and showed that 3 bars is required to move the screen of 1.43cm and block it in the slider. No failure was presented during the test.

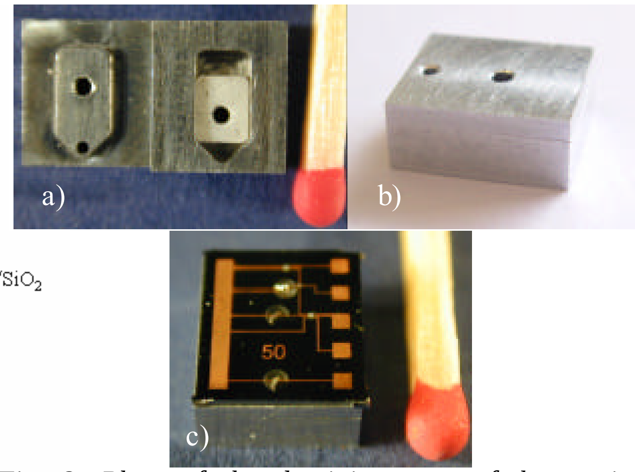


Fig. 8: Photo of the aluminium part of the arming function: a) opened with the MACOR screen inside b) glued c) assembly with Si-based safe initiator.

4. CONCLUSION AND PERSPECTIVES

A MEMS based safe, arm and fire device with both electrical and mechanical protections was proposed, designed and presented in this paper. The detailed design and the fabrication process of each part of the device were presented. Next steps are the assembly of the 3 layers (electronic circuitry, Si-layer, arming function) and the electrical and mechanical characterizations.

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