HAL open science

Miniaturized Pyrotechnic Systems Meet the Performance Needs While Limiting the Environmental Impact

Carole Rossi, Ruiqi Shen

▶ **To cite this version:**

Carole Rossi, Ruiqi Shen. Miniaturized Pyrotechnic Systems Meet the Performance Needs While Limiting the Environmental Impact. Micromachines, 2022, 13 (3), pp.376. 10.3390/mi13030376 . hal-03598671

HAL Id: hal-03598671

https://laas.hal.science/hal-03598671v1

Submitted on 5 Mar 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Miniaturized Pyrotechnic Systems, meet the performance need while limiting the environmental impact

Dr. Carole Rossi,

LAAS-CNRS, University of Toulouse, 7 Avenue du colonel Roche, 31400 Toulouse, France

Prof. Ruiqi Shen

School of Chemical Engineering, Nanjing University of Science and Technology, Nanjing 210096, China

Pyrotechnic systems also termed pyrotechnics refer of a broad family of sophisticated single use devices able to produce heat, light, smoke, sound, motion and/or combination of these thanks to the reaction of an energetic material (primary and secondary explosives, powders/propellants and other pyrotechnic substances). Most pyrotechnics utilize a simple hot wire or bridgewire for initiating the energetic material reaction and are used to perform a large variety of functions in large equipment such as release, cutting, pressurization, valving, ignition, switching, and other mechanical works. Their applications are expanding in defense, civil engineering, demolition, fireworks, automotive and space industries and are enjoying good safety records.

Two decades ago, the concept of micro pyrotechnics has emerged with the idea to reduce the manufacturing cost by applying collective microelectronic processing with the goal to lower the ignition energy costs while improving both vulnerability and safety requirements by replacing the simple hot wire by a sophisticated arm and fire electronic unit.

At this stage, it was only a very early thinking about how to manufacture new performing pyrotechnically actuated micro systems. The concept was just thought “technically feasible” and researchers hoped to provide a cogent view that a new era in pyrotechnics was upon us, wherein the micro-nanotechnologies and simulation would allow entirely new capabilities to be developed with exciting advancements in the fields of propulsion, actuations and thermic. Consequently, an active research effort was born internationally on both the design and elaboration of new nano-energetical materials (nano-energetics[1,2]), and, the demonstration of new functionalities such as micro-actuators[3-5], micro-thrusters[6-11], tunable initiation of secondary explosives[12-15], joining, brazing and sealing[16].

Two decades later, in years 2022s, advancements in energetic materials and micro-pyrotechnics are considerable and the opportunity for new capabilities for industries built on micro-pyrotechnics is upon us.

This special issue does illustrate some of the works of the groups engaged in it. A first paper by Pouchairet and coworkers [17] presents the development of a miniaturized smart infrared (IR) electronically controllable flare combining a microinitiation stage integrating low-energy addressable pyroMEMS (pyrotechnical micro-electro mechanical systems) with a structured IR pyrotechnical loaf connected. Not only the miniaturization is a key point of this work but also the choice of technologies and materials that are environmental benign. Another series of papers presents innovating research on energetic composites that can be integrated on miniaturized devices for initiation. Liu and co-workers [18] develop a new composite energetic film ($Cu(N_3)_2$) on MEMS chip which presents highly reactivity while being safer. Yu and coworkers

[19] give a new generic synthesis route for $CoFe_2O_4$/Al nanothermite films via an integration of nanoparticles of Al with $CoFe_2O_4$ nanowires. Interestingly this route, this method totally compatible with MEMS technologies, can be applied diverse thermite systems such as $MnCo_2O_4$ and $NiCo_2O_4$. He and coworkers [20] develop an explosive ink that can be printed layer by layer, each single layer printing being ~ 10 μm. The critical detonation size of the sample can reach 1 mm × 0.01 mm or less and the detonation velocity can achieve 8686 $m \cdot s^{-1}$, which exhibits excellent micro-scale detonation ability. Finally, two last papers consider miniaturized initiation devices. Wang and coworkers [21] present exploding foil microinitiators totally fabricated by MEMS based engineering that can be triggered by Metal-Oxide-Semiconductor Controlled Thyristor. And Lei and coworkers [22] integrate Cu/Ni Multilayer Exploding Foil on MEMS chips by Magnetron Sputtering and Electroplating.

It is only a snapshot but may encourage readers to investigate further. One important requirement for future miniaturized pyrotechnical systems is to meet the performance need within the cost limits with the need to minimize the environmental impact. It can appear difficult to claim minimal impact for a device that involves the combustion of fuel with subsequent emission of gaseous and unburnt products. However, the choice of ingredients such as environment-friendly thermite and the design of the system can reduce that impact significantly.

1. Zachariah, M. R. NanoEnergetics: Hype, Reality and Future, *Propell Explos Pyrot*, **2013**, *38* (1), 7-7.
2. Glavier, L.; Taton, G.; Ducere, J. M.; Baijot, V.; Pinon, S.; Calais, T.; Esteve, A.; Djafari-Rouhani, M. D.; Rossi, C. Nanoenergetics as pressure generator for nontoxic impact primers: Comparison of Al/Bi2O3, Al/CuO, Al/MoO3 nanothermites and Al/PTFE, *Combust Flame*, **2015**, *162* (5), 1813-1820.
3. Rodriguez, G.A.A.; Suhard, S.; Rossi, C.; Esteve, D.; Fau, P.; Sabo-Etienne, S.; Mingotaud, A.F.; Mauzac, M.; Chaudret, B. A microactuator based on the decomposition of an energetic material for disposable lab-on-chip applications: Fabrication and test. *J. Micromech. Microeng.* ***2009****, 19, 015006.*
4. De Koninck, D.A.; Lopez, F.M.; Briand, D.; de Rooij, N.F. Foil-Level Fabrication of Inkjet-Printed Pyromems Balloon Actuators. *In Proceedings of the 2012 IEEE 25th International Conference on Micro Electro Mechanical Systems (Mems), Paris, France, 29 January–2 February* ***2012****.*
5. Nicollet, A.; Salvagnac, L.; Baijot, V.; Estève, A.; Rossi, C. Fast circuit breaker based on integration of Al/CuO nanothermites, *Sensors and Actuators A: Physical*, **2018**, *273*, 249-255.
6. Larangot, B.; Rossi, C.; Camps, T.; Berthold, A.; Pham, P.; Briand, D.; Puig-Vidal, M.; Miribel, P.; Esteve, D.; Rooij, N.D.; et al, Solid Propellant Micro Rockets - Towards a New Type of Power MEMS. *In NanoTech 2002 - "At the Edge of Revolution"; AIAA: Houston, TX, USA, 2002.*
7. Larangot, B.; Conedera, V.; Dureuil, P.; Do Conto, T.; Rossi, C. Solid propellant microthruster: an alternative propulsion device for nanosatellite. *2002 Aerospace Energetic Equipment Conference (Avignon, France).*
8. Zhang, K. L.; Chou, S. K.; Ang, S. S.; Tang, X. S. A MEMS-based solid propellant microthruster with Au/Ti igniter, *Sensor Actuat a-Phys*, **2005**, *122* (1), 113-123.
9. Staley, C. S.; Raymond, K. E.; Thiruvengadathan, R.; Apperson, S. J.; Gangopadhyay, K.; Swaszek, S. M.; Taylor, R. J.; Gangopadhyay, S. Fast-Impulse Nanothermite Solid-Propellant Miniaturized Thrusters (vol 29, pg 1400, 2013), *J Propul Power*, **2015**, *31* (1), 483-483.
10. Tanaka, S.; Hosokawa, R.; Tokudome, S.; Hori, K.; Saito, H.; Watanabe, M.; Esashi, M. MEMS-based solid propellant rocket array thruster with electrical feedthroughs, *T Jpn Soc Aeronaut S*, **2003**, *46* (151), 47-51.
11. Ru, C.; Wang, F.; Xu, J.; Dai, J. ; Shen, Y.; Ye, Y.; Zhu, P.; Shen, R. Q. Superior performance of a MEMS-based solid propellant microthruster (SPM) array with nanothermites, *Microsystem Technologies*, **2016**, 1-14.

12. Glavier, L.; Nicollet, A.; Jouot, F.; Martin, B.; Barberon, J.; Renaud, L.; Rossi, C. Nanothermite/RDX-Based Miniature Device for Impact Ignition of High Explosives, *Propell Explos Pyrot*, **2017**, *42* (3), 307-316.
13. Staley, C. S.; Morris, C. J.; Thiruvengadathan, R.; Apperson, S. J.; Gangopadhyay, K.; Gangopadhyay, S. Silicon-based bridge wire micro-chip initiators for bismuth oxide-aluminum nanothermite, *J Micromech Microeng*, **2011**, *21* (11).
14. Fu, S.; Shen, R. Q.; Zhu, P.; Ye, Y. H. Metal-interlayer-metal structured initiator containing Al/CuO reactive multilayer films that exhibits improved ignition properties, *Sensor Actuat a-Phys*, **2019**, *292*, 198-204.
15. Zhu, P.; Shen, R. Q.; Ye, Y. H.; Zhou, X.; Hu, Y.; Wu, L. Z. Energetic Igniters Based on Al/CuO/B/Ti Reactive Multilayer Films, *Theory and Practice of Energetic Materials (Vol Ix), Proceedings of the 2011 International Autumn Seminar on Propellants, Explosives and Pyrotechnics*, **2011**, 756-760.
16. Dombroski, D. M. B.; Wang, A. Q.; Wen, J. Z.; Alfano, M. Joining and welding with a nanothermite and exothermic bonding using reactive multi-nanolayers - A review, *J Manuf Process*, **2022**, *75*, 280-300.
17. Pouchairet, J.L.; Rossi, C. PyroMEMS as Future Technological Building Blocks for Advanced Microenergetic Systems, *Micromachines (Basel)*, **2021**, *12* (2).
18. Liu, X; Hu, Y; Wei, H; Chen, B; Ye, Y; Shen, R. Energetic Films Realized by Encapsulating Copper Azide in Silicon-Based Carbon Nanotube Arrays with Higher Electrostatic Safety, *Micromachines (Basel)*, **2021**, *12* (2).
19. Yu, C; et al. A Facile Preparation and Energetic Characteristics of the Core/Shell CoFe2O4/Al Nanowires Thermite Film, *Micromachines (Basel)*, **2021**, *12* (2).
20. He, Y; et al. Inkjet Printing of GAP/NC/DNTF Based Microscale Booster with High Strength for PyroMEMS, *Micromachines (Basel)*, **2021**, *12* (2).
21. Wang, K; Zhu, P; Xu, C; Zhang, Q; Yang, Z; Shen, R. Firing Performance of Microchip Exploding Foil Initiator Triggered by Metal-Oxide-Semiconductor Controlled Thyristor, *Micromachines (Basel)*, **2021**, *12* (2).
22. Lei, F; Ye, Q; Yang, S; Fu, Q. Study on Electrical Explosion Properties of Cu/Ni Multilayer Exploding Foil Prepared by Magnetron Sputtering and Electroplating; *Micromachines (Basel)*, **2021**, *12* (2).