Available online at www.sciencedirect.com
SCIENCE DIRECT®

Sensors and Actuators A 120 (2005) 297–310

SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

Review

Micropyrotechnics, a new technology for making energetic microsystems: review and prospective

C. Rossi *, D. Estève

LAAS-CNRS, 7 avenue du colonel Roche, 31077 Toulouse cedex 4, France

Received 5 November 2004; received in revised form 21 January 2005; accepted 21 January 2005
Available online 23 February 2005

Abstract

A review of the micropyrotechnics related works is done. Micropyrotechnics is the integration of an energetic material into microsystem, for which the thermal, mechanical and chemical energy released by decomposition can be exploited. After a state-of-the art of micropyrotechnics and its application to microsystems, authors try to identify obvious difficulties and insufficiencies that may require future work, particularly in terms of the development of new materials, new modelling tools and new processes for integration into microsystems. A section is dedicated to the current micropyrotechnic applications including emerging ones. In conclusion, the perspectives of this discipline are discussed and the authors try to give some guidelines for future investigations.

Keywords: Microsystem; Micropyrotechnic; Microactuation; Gas generator; Microthruster; Energetic material

Contents

* Corresponding author. Tel.: +33 5 61 33 63 01; fax: +33 5 61 33 62 08.
E-mail address: rossi@laas.fr (C. Rossi).

0924-4247/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2005.01.025

Nomenclature

a^2	section of energetic material in combustion
$a_{critical}$	quenching diameter
C_p	heat capacity of the energetic material
$C_{p,g}$	heat capacity of the combustion gas
DP	over pressure
h	convection coefficient
h_s	convection coefficient between combustion gas and the surrounding material
k_p	thermal conductivity of the energetic material
k_s	thermal conductivity of the surrounding material
L	thermal loss in the environment
P_{elect}	input electrical power over the time
Q	heat release
S	surface area over which the electrical flux is applied
t	time
t_{ic}	critical ignition time
$T_{ambient}$	ambient temperature
T_f	flame temperature
T_i	temperature of initiation
T_s	surface temperature
T_0	initial temperature
V_{MAX}	maximal combustion rate
V_p	energetic material volume
V_r	rate of combustion of the energetic material
V_0	initial volume

Greek letters

ρ_p	density of the energetic material
τ	time step
ϕ	input electrical flux
ϕ_c	critical ignition flux

1. Introduction

Obtaining an integratable, compatible, low cost energy source providing a sufficient quantity of easily accessible energy within a miniaturised system has been an ongoing challenge for decades. The urgency and interests of such systems will continue to increase with the development of portable microsystems [1–3], distributed microsystems [4–7] as the smartdust type [8] and monitoring systems. The most reasonable option in the next few years is to distribute energy needs between multiple onboard sources adapted to specific needs. Naturally, a large amount of scientific work is being done on miniature electrical sources [9–12]. A similar effort is being done to find solutions to mechanical and/or thermal actuation problems [13,14]. This is the context of our analysis.

The conventional approach to mechanical actuation is based on electromagnetic machines. This option is very efficient but difficult to integrate at microscopic scales [15]. Actuation making use of electrostatic forces [16–18] became widespread starting from the 1990s, and this is an important step forward for microsystems since it is very easy to integrate, it is relatively powerful and easy to use. However, its use is limited to small displacements. Obviously it does not satisfy all needs, and there is still a real one to be satisfied for integrated and high power actuation.

About 1995, the use of energetic materials began to attract interest in the scientific community since they are a very attractive source of onboard energy. For example, combustion of these materials is an attractive means of obtaining a large quantity of energy from a small volume. Typically, the combustion of hydrocarbon materials produces 50 MJ/kg, combustion of propellant produces 5 MJ/kg, while a modern chemical lithium battery used in new laptops only stores 0.4 MJ/kg. Thus, even with a conversion efficiency of 10%, propellants are still attractive in terms of available energy density. To return to mechanical actuation applications, it would be better to use the actuation pressure parameter, which is defined as the ratio between the energy and the volume of the system. Table 1 compares actuation pressures for different actuation methods developed in microsystem technology. It shows that propellants are capable of accessing to the most attractive actuation pressures.

If these materials could be integrated into functional microsystems in a manner compatible with microsystem technologies, then micropyrotechnics could help to make considerable progress in the field of power microactuation and energy micro storage.

In this context in which LAAS-CNRS initiated micropyrotechnics in 1997 for medical applications by proposing and making micropyrotechnics actuators [19,20]. It then applied the concept to micropropulsion for space [21]. Since then, other teams have initiated large amounts of work in micropyrotechnics by integrating energetic materials (propellants or explosives) into microsystems to generate microthrusts [22,31–38], gases for actuation [40], for microinitiation [24,41] or simply to act as energy sources to modify surfaces, and for heating and welding [42]. This large number of applications suggests that approaches should be coded. We can talk about a new discipline called “micropyrotechnics”. This term includes various orientations presented in the specialised literature as “explosives technology” [44] or “mi-

Table 1
Comparison of different actuation available in terms of actuation pressure

Type of actuation	Actuation pressure (J/m^3)
Piezoelectric (PZT)	10^5
Electrostatic	10^3
Electromagnetic	10^5
Thermomechanic	$\sim 10^5$
Thermopneumatic	10^6
Shape memory alloy (SMA)	10^7
Solid-liquid phase change	10^6 (acetimine) to 10^7 (paraffin)
Energetic material combustion	10^7 to 10^8