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Highly miniaturized FEEP propulsion system (NanoFEEP) for attitude and orbit control of CubeSats

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ABSTRACT

A highly miniaturized Field Emission Electric Propulsion (FEEP) system is currently under development at TU Dresden, called NanoFEEP [1]. The highly miniaturized thruster heads are very compact and have a volume of less than 3 cm^3 and a weight of less than 6 g each. One thruster is able to generate continuous thrust of up to 8 μN with short term peaks of up to 22 μN. The very compact design and low power consumption (heating power demand between 50 and 150 mW) are achieved by using Gallium as metal propellant with its low melting point of approximately 30 °C. This makes it possible to implement an electric propulsion system consisting of four thruster heads, two neutralizers and the necessary electronics on a 1U CubeSat with its strong limitation in space, weight and available power. Even formation flying of 1U CubeSats using an electric propulsion system is possible with this system, which is shown by the example of a currently planned cooperation project between Wuerzburg University, Zentrum fuer Telematik and TU Dresden. It is planned to use the NanoFEEP electric propulsion system on the UWE (University Wuerzburg Experimental) 1U CubeSat platform [2] to demonstrate orbit and two axis attitude control with our electric propulsion system NanoFEEP. We present the latest performance characteristics of the NanoFEEP thrusters and the highly miniaturized electronics. Additionally, the concept and the current status of a novel cold neutralizer chip using Carbon Nano Tubes (CNTs) is presented.

1. Introduction

More and more small satellites, like CubeSats [3], are launched these days as they become more attractive not only for universities and research institutes to test and qualify new space technologies and give on-hands experience to students or researchers but also for commercial companies to enable new space applications. Though, the fields of application of CubeSats are still quite limited. One reason for that is the strong limitation in volume, weight and power available on a CubeSat which makes it difficult to implement larger payloads and consequently to enable more complex applications.

One way to render it possible to enhance the spectrum of applications on a CubeSat may be the approach of distributed networks of CubeSats. Several CubeSats could be used in a network to accomplish the same mission objectives, like for example the interferometrical use of data of each CubeSat. To enable such autonomous networks, constellations or even formations (actively controlled distances) of satellites will be needed. To build such a formation of satellites, very precise attitude and orbit control systems are necessary.

Besides attitude and orbit determination, a precise and efficient propulsion systems are mandatory to achieve formation flights of CubeSats.

Facing the challenges of operating a propulsion system on a CubeSat with its very limited budget in power and volume, we are currently developing a highly miniaturized electric propulsion system, consisting of thrusters, neutralizer and electronics, called NanoFEEP. All the components of this propulsion system will be introduced in this paper and the current status of development will be presented.

For the first demonstration mission of the NanoFEEP propulsion system, a cooperation project between TU Dresden and the University Wuerzburg is planned. The NanoFEEP propulsion system will be integrated in the highly reliable and modularly designed 1U CubeSat UWE (University Wuerzburg Experimental) platform developed by the University Wuerzburg [2]. Two axes attitude control and orbit control will be demonstrated in the planned mission using four NanoFEEP thrusters, integrated in the mandatory CubeSat bars.

1.1. Working principle of FEEP

The technology of Field Emission Electric Propulsion (FEEP) thrusters

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in general is based on the field emission effect. The working principle of a FEEP thruster using very sharp needles is illustrated in Fig. 1.

By applying a high electric potential of several kilovolts between a sharp needle tip which is wetted with the liquid metal propellant and a ring shaped extractor electrode, an ion beam is formed. Due to the interplay of the surface tension of the metal propellant and the applied electrostatic force, a so called Taylor Cone forms on top of the needle tip. If the electric field strength on the jet of the Taylor Cone reaches the field evaporation strength of the metal propellant in the order of 10^{10} V/m, the metal propellant is evaporated, ionized and accelerated in the very same electric field. The emitting metal ions exit the thruster through the extractor aperture with velocities of up to 100 km/s. This and the fact that the ionization rate especially at lower emitting currents and thus lower thrusts is high, make it possible to reach a very high specific impulse of up to 6000 s [1].

1.2. NanoFEEP propulsion system

The NanoFEEP propulsion system consists of the actual NanoFEEP thruster heads (see section 2), the neutralizer chips to control the spacecraft floating potential (see section 3) and the power processing unit (HV PPU, section 4) which controls thrust and provides high voltage power to the thrusters and the neutralizer.

The first in orbit demonstration is planned on the 1U UWE (University Wuerzburg Experimental) CubeSat platform developed by the University Wuerzburg to demonstrate two axes attitude and orbit control. In this planned demonstration mission four NanoFEEP thrusters will be integrated in the four obligatory CubeSat rails [3], like shown in Fig. 2. The four NanoFEEP thrusters and up to two neutralizer chips will be powered and controlled by two very compact CubeSat boards. The two boards will require a space of only $90 \times 87 \times 20\ \text{mm}^3$ inside the CubeSat.

Besides this demonstration mission on the UWE CubeSat, another mission on a 3U CubeSat, SNUSAT-2 from the Seoul National University, is planned. In this mission two thrusters, one neutralizer and one HV PPU board will be integrated in the CubeSat to demonstrate a deorbiting maneuver after operation phase. This mission will demonstrate the capabilities of the NanoFEEP propulsion system as a deorbiting device to actively control the lifetime of a CubeSat and to fulfill international regulations for opposing the increase of space debris.

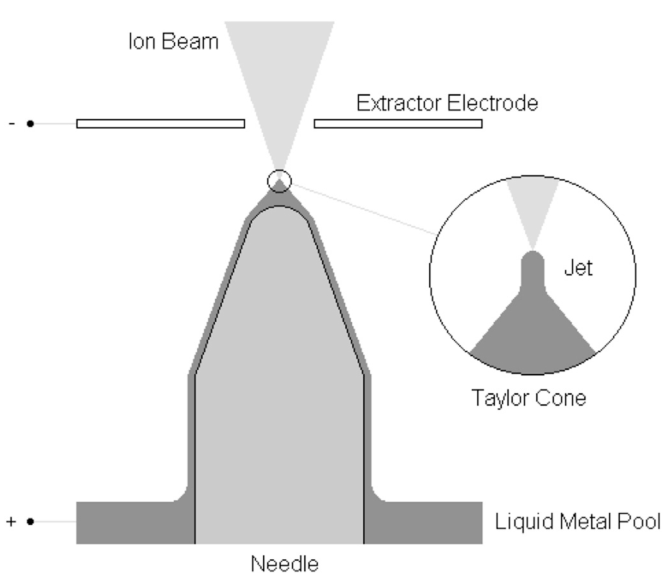

Fig. 1. Basic principle of Field Emission Electric Propulsion (FEEP), needle type [4].

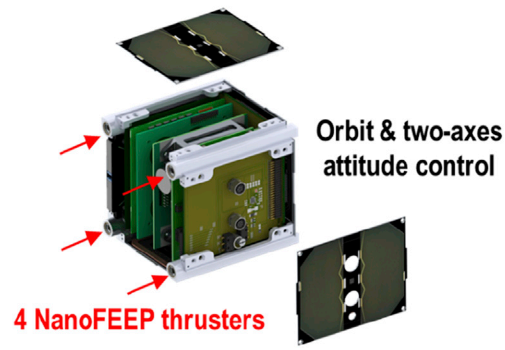

Fig. 2. Operation scenario of NanoFEEP propulsion system for attitude and orbit control of a 1U CubeSat, using the example of the UWE CubeSat platform [5].

2. NanoFEEP thruster heads

The NanoFEEP thrusters are designed to face the strongly limited volume, weight and power available on a 1U CubeSat. Therefore, the main objective of the thruster design is power efficiency, the optimum use of space and the aim to achieve a light-weight propulsion system. The design of the thruster, performance data and a possibility of a space-saving mechanical integration using the example of the UWE CubeSat mission will be presented in the following subsections.

2.1. Design of thruster heads

To achieve a highly efficient and stable ionization of the propellant, the NanoFEEP thrusters use our novel porous Liquid Metal Ion Sources (LMIS) [6]. This LMIS consists of a very sharp porous tungsten needle with an open porosity wetted with the metal propellant (see Fig. 3) and a reservoir filled with the propellant. Due to capillary action of the open porosity of the tungsten needle, the propellant is hold on the needle and a self-feeding propellant flow from the reservoir to the needle tip is provided. With this passive propellant feeding no valves or propellant feeding devices are necessary.

In order to reduce the power demand for liquefying the metal propellant, the metal gallium with its low melting temperature of approximately 30 °C is used as propellant in the NanoFEEP thrusters. The use of other metal propellants like e.g. Indium with a melting temperature of 157 °C would lead to a much higher heating power demand and would consequently be not feasible for a FEEP propulsion system on a 1U CubeSat with its strong power limitations.

Besides the choice of the propellant material to reduce the heating power demand, the design of the NanoFEEP thruster itself is optimized

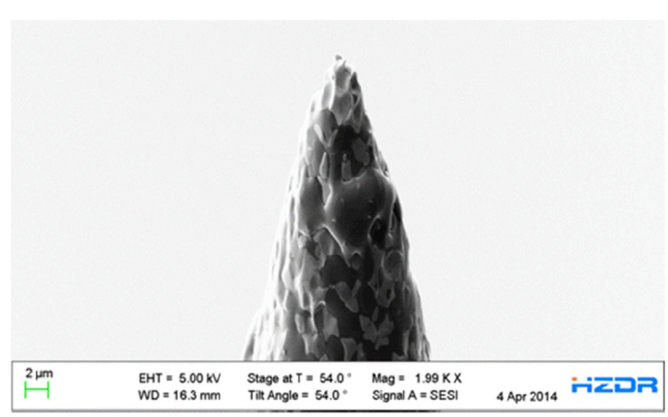

Fig. 3. SEM image of a porous tungsten needle wetted with the metal propellant Gallium [1].