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CITLALMITL: A DEVICE FOR METEORITE FABRICATION

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RESUMEN

Citlalmitl es un instrumento experimental construido para estudiar procesos de calentamiento en meteoritica. Citlalmitl ha operado desde 2014 y tiene la capacidad de reproducir historias térmicas programadas para simular procesos de calentamiento como los que crearon a los condros o la entrada de polvo interplanetario a la atmósfera. El aparato está siendo mejorado y tiene varias aplicaciones futuras como, por ejemplo, el estudio del destino del material orgánico durante su entrada a la atmósfera.

ABSTRACT

Citlalmitl is an experimental device designed and built in order to study the heating processes in meteoritics. Citalmitl has been operational since 2014 and is capable of reproducing programmed thermal histories to simulate heating processes such as those associated with the formation of chondrules, or with atmospheric entry of interplanetary dust. The experimental device is constantly being improved and has several future applications, for example, the study of the fate of organic materials during atmospheric entry.

Key Words: astronomical instruments — chondrules — meteorites — micrometeoroids

1. INTRODUCTION

Citlalmitl is an experimental device designed for simulating processes related to meteoritic bodies, such as chondrules and micrometeorites (MMs) formation, sublimation and burning of organic matter during the atmospheric entrance of extraterrestrial materials. This device is based on a laser which allows the melting of precursors relevant to these processes. Lasers have been used for simulating high energy processes such as lightning, shockwaves and atmospheric entry of micrometeoroids (Hernández-Reséndiz et al. 2020).

1.1. *History of Citlalmitl*

Meteorites have been studied in Mexico since the XIX century (Cervantes-de la Cruz et al. 2020). In 2003, a group led by Fernando Ortega Gutiérrez studied the age, source, and thermal processes involved in meteorites found in Mexico, particularly, chondrites (e.g. Hernández-Bernal & Solé 2010; Cervantes-de la Cruz et al. 2015). This group (Cervantes-de la Cruz 2009) reported experiments based on a Merchantek® MIR10 de CO_2 laser with 50W power used for melting olivine samples to simulate the processes that formed chondrules. These experiments inspired our own project to design and build an experimental device to study chondrule formation, that started in 2011. The first version of the experimental device was operational in 2014 and is still being improved.

1.2. *Citlalmitl team*

Meteoritics is a science that requires the expertise of several disciplines to analyze the samples, leading to an understanding of the their properties in regards to the origin and evolution of our Solar System, and other planetary systems. The Citlalmitl team includes experimental physicists, geologists, astronomers, biologists and chemists.

The core of our group is composed by the meteorite expert, geologist Karina Cervantes-de la Cruz who is in charge of the experiments planning and sample analysis, Alfred U’Ren and Héctor Cruz-Ramírez, experimental physicists who designed, built, and operate the experimental device with the collaboration of astronomer Patricia Hernández-Reséndiz who started working in the project as an undergraduate student, as well as astrobiologist Antígona Segura, who provides an astronomical perspective of the results obtained. In addition, students from different backgrounds have collaborated in the project.

2. CITLALMITL

The Citlamitl device (Figure 1a) was built in our laboratory, it permits the energy transfer to a sample through laser irradiation, in a user-defined intensity vs time profile, in such a manner that the ambient

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pressure may be controlled. During the irradiation of the sample simple – for simulating processes of chondrule formation and the atmospheric entry of micrometeorites –, the thermal history is recorded.

We used a CO_2 pulsed laser at 10.6 μm, linearly polarized, with a maximum power of 50 W. Power control is achieved through duty-cycle control (the ratio of time the laser is on, compared to the time the laser is off). The laser average output power is monitored by measuring, with a power meter (D), the power of a portion of the beam reflected from a beam splitter (BS). The beam splitter reflects 5 % and transmits 95 % of the energy of input beam. We used two lenses, L_1 and L_2, with focal length $f_1 =$ 50 mm and $f_2 =$ 200 mm respectively, to control the power per unit area on the sample (M). This control is achieved by placing L_1 on a motorized linear stage in such a way that the distance between the lenses can be changed. We can control the position of laser beam on the semispherical depressions of the sample holder (A) by tilting the mirror M with a high-precision motorized system. The sample holder contains 6 × 6 semispherical depressions with different diameters, see Figure 1b. The sample holder is located in the center of a vacuum chamber (VC) in which, by means of a vacuum pump, the pressure is controlled. The VC has eight portholes in which different types of diagnostic measurements can be implemented. The output power of the laser as a function of time is defined by the user, which allows us to implement any model, for example corresponding to shock-wave irradiation. In a VC portholes at 45∘ we located the pyrometer (P) and we measured the temperature as a function of time, which results in obtaining the thermal histories of the process. The pyrometer can measured in a range of 300∘ to 2000∘ and we corrected the measured temperature considering that the fluorescence is isotropic (Lambertian source), see Figure 1c. The device is fully automated.

3. APPLICATIONS

3.1. *General methodology*

The sample preparation for the precursor material starts with the chemical and petrological characterization and selection of mineral grains. Olivine and feldspar grains, as well as some organic material are used, in order to reach a realistic composition for chondrules and MMs (e.g. Hewins and Fox 2004; Brownlee et al. 1983; Jiménez-Bahamon et al. 2021).

The weight of each sample is measured before and after the irradiation to evaluate mass loss. We place the precursor material in each depression of the sample holder. Samples do not require any other preparation prior to being irradiated.

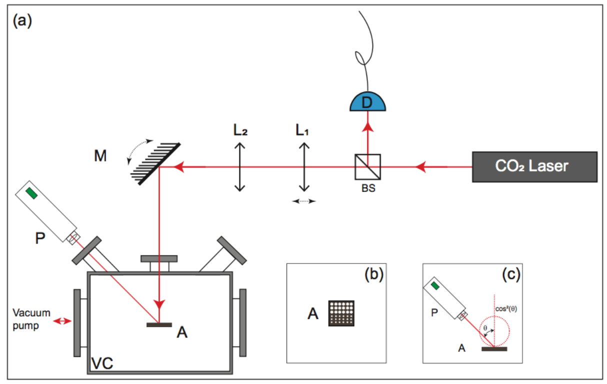

Fig. 1. Diagram of the Citlalmitl device. See text for description.

Analogs are fabricated with Citlalmitl by melting this material with previously-programmed irradiation profiles, while directly measuring sample temperature and irradiation power, essential parameters in the heating process. This data allows us to record the thermal histories of the samples in real time.

Once irradiated, the samples go through a series of analyzes in order to evaluate their similarity with real chondrules and MMs (Fig. 2). We perform petrologic, chemical, and textural analysis with a stereoscopic microscope, an electronic variable scanning microscope, and an electron probe microanalyzer, respectively.

3.2. *Chondrules*

Chondrules are the principal component of chondrites formed 4.56 Ga ago, together with calcium and aluminum inclusions are the oldest components formed in the Solar System. They are millimetric to sub-millimetric spherules of mafic minerals, such as olivine (O) and/or pyroxene (P), with accessory felspathic glass, Fe-Ni alloys, and troilite.

Chondrules' spheric form and textures suggest different melting grades, then, according to the grade of melting of the minerals, there are partial (porphyritic-like, such as PO, POP, and PP) and completely melted chondrules (barred olivine, BO; cryptocrystalline pyroxene, CP; radial pyroxene RP). However, the mechanism of chondrule formation is still unclear. Some flash mechanisms, such as shockwaves and giant nebular lighting, explain the preservation of volatile elements such as sodium and sulfur as suggested by Connolly Jr. & Jones (2016).

In the literature, several temperature profiles pretended to explain the melting of chondrule precursors (e.g. Hernández-Reséndiz 2021). We have tested different experimental conditions such as thermal profiles, from vacuum experiments to high-pressure

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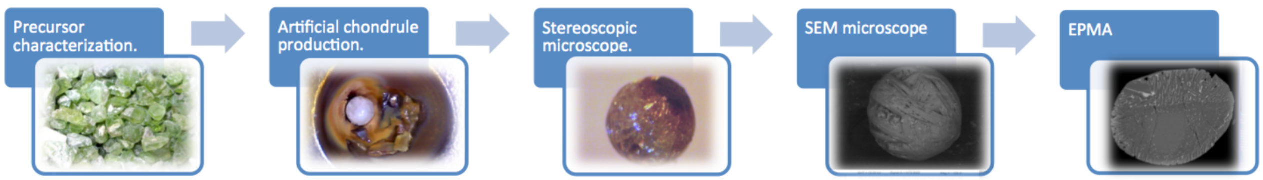

Fig. 2. Flowchart of the sample analysis methodology.

experiments, and different irradiation times. We observed that preservation of volatile elements occurs during high-pressure experiments, whereas the best temperature profiles are those that resemble the shockwave models.

3.3. *Micrometeorites*

In Suttle et al. (2021), micrometeorites are defined as small grains of asteroidal or comet material, ranging in diameter from 50 to 3000 μm. The composition of the precursor material of micrometeorites is chondritic, mafic minerals, silicates, organic matter, and metals. The classification of micrometeorites is according to the degree of melting, from non melted material, partially melted silicates called scoriaceous, to the completely melted spherules. The processes which a micrometeoroid may experience when entering the atmosphere are: heating, ablation, fragmentation, lighting effects, and collisions (Ceplecha et al. 1998; Chávez Bernal 2018).

Ablation refers to mass loss by phase transformations, from solid to liquid or liquid to solid-state. One of the effects of ablation in mafic silicates is iron loss if the material is completely melted. However, this iron could precipitate on the surface as magnetite when the material is partially melted (Suttle et al. 2021). This effect is successfully reproduced by Citlalmitl experiments (Hernández-Reséndiz et al. 2020). Recently, we have worked with a team including biologists and chemists; studying the sublimation capacity of amino acids to survive to high temperatures, such as occurred in the entry of micrometeoroids (e.g. Jiménez-Bahamon et al. 2021). This kind of studies have substantial implications for understanding the processes of prebiotic chemistry.

4. THE FUTURE OF CITLALMITL

Citlalmitl is an experimental device, constantly improved, that not only helps to understand the flash melting processes to simulate the chondrule formation and the MMs atmospheric entrance, but also to understand the formation of the glassy cover of meteorites – called fusion crust –, as well as sublimation and burning of organic matter (Jiménez-Bahamon et al. 2021), and the reproduction of laser-induced plasmas for the study of lightning in different atmospheres.

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