THE LARGE AREA MASS ANALYZER (LAMA) FOR IN-SITU CHEMICAL ANALYSIS OF INTERSTELLAR DUST PARTTICLES

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ABSTRACT

An instrument to analyze the chemical composition of dust particles in space has been developed. The large target area (0.2 m^2) makes this instrument suitable for detecting rare interstellar dust grains. The device is a reflectron type time-of-flight mass spectrometer that measures the ions from the impact-generated plasma due to hypervelocity dust impacts on the target surface. The SIMION ion optics software package has been used to investigate different potential field configurations and optimize the mass resolution and focusing of the ions. The final cylindrical configuration uses a set of six ring electrodes on the side and six annular electrodes at the top, biased to different potentials, to create the potential distribution of the reflectron. The laboratory model of the instrument has been fabricated and is undergoing preliminary testing. Dust impacts are simulated by using a frequency-doubled (532 nm) Nd:YAG laser with ~8 ns pulse length. The mass resolution is $m/\Delta m \geq 125$.

1. INTRODUCTION

The composition of cosmic dust can be studied by remote sensing [1-3], analysis of samples that survived atmospheric entry and were collected in the stratosphere [4] or from ice sediments [5], collection and sample return from space [6], and by *in-situ* measurement in space. The *in-situ* methods offer advantages in several cases. They allow long-term measurements of dust particles with low fluxes and the detection of volatiles that are or can be difficult with other methods to obtain. The recently developed *in-situ* time-of-flight (TOF) mass analyzing instruments for spacecrafts are the Cassini Cosmic Dust Analyzer [7] (CDA) and the STARDUST Cometary and Interstellar Dust Analyzer (CIDA) [8]. Both instruments work based on a similar principle utilizing the impact-generated plasmas. When dust particles impact on a solid surface with a high velocity, they evaporate and partially ionize. The produced atomic or molecular ions are analyzed using TOF mass spectrometry and these mass spectra are characteristic for the composition of the dust. The chemical analyzer subsystem of CDA is a linear TOF mass analyzer with a target area of approximately 0.02 m^2. Because the ions generated in the hypervelocity impact have a relatively wide energy distribution, the resolution power of CDA is $m/\Delta m \leq 50$. The CIDA instrument used an ion reflectron to compensate for the initial ion energy distribution achieving $m/\Delta m = 250$ in laboratory tests. The effective target area of CIDA is 60 cm^2.

In this paper we report the development of the Large Area Mass Analyzer (LAMA) instrument. The instrument is a chemical analyzer with a large sensitive area, approximately 0.2 m^2, and a mass resolution better than $m/\Delta m \geq 125$. The large target area is needed to measure the dust particles arriving from the local interstellar cloud with a low flux, approximately 1.5×10^{-4} $m^{-2}s^{-1}$ [9]. The laboratory prototype version of this instrument was constructed and calibrated. The instrument is described in Sec. 2. Mass spectra and the resolution power of the instrument are presented in Sec. 3. Section 4 is the conclusion.

2. THE LAMA INSTRUMENT

The schematic diagram of the cylindrically symmetric instrument is shown in Fig. 1. The LAMA instrument is a reflectron type TOF mass analyzer. The electrostatic field of the reflectron is generated by six ring electrodes and six annular disk electrodes. The electrodes' dimensions and bias potentials are summarized in Table I. The dimensions of the annular electrodes are measured from the cylindrical axis and the ring electrodes from the grounded grid.

The operational principle of the instrument is the following. The dust particle enters the instrument through the annular disk electrodes made out of highly transparent grid material. After passing another (grounded) grid, it impacts the target. The target is a 64

Proc. 'Dust in Planetary Systems', Kauai, Hawaii, USA. 26--30 September 2005 (ESA SP-643, January 2007)

cm diameter disc with an opening in the center for the ion detector. The ions generated from the hypervelocity impact are accelerated away from the target that is kept at +5kV potential. The distribution of the electric field within the instrument provides a temporal and spatial focusing of the ions onto the detector. Ions impact the detector in groups, according to their charge to mass ratio.

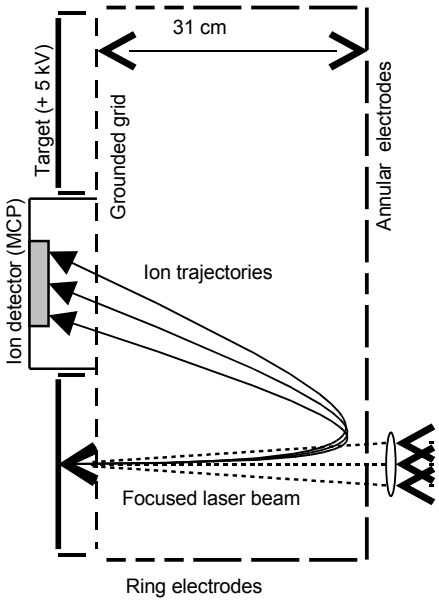

Figure 1. The schematic diagram of the LAMA instrument.

The LAMA instrument was designed using the SIMION ion optics package. The performance was optimized for mass resolution, spatial focusing of ions onto the detector and a minimum number of biased electrodes necessary for the operation. The simulations required an assumption of the initial energy and angular distributions of ions. Ion energies up to 50 eV and a cosine distribution for the emission angle were considered [10]. The simulated mass resolution is $m/\Delta m \approx 200$ with a weak dependence on the radial position of the impact. Most of the emitted ions are collected on a detector with 120 mm diameter.

Figure 2 shows the laboratory model of the LAMA instrument. The instrument was tested in a vacuum chamber of approximately 1 m^3 volume. The attainable base pressure is 2.5×10^{-6} Torr. The potentials required for the electrodes were distributed from a single 7 kV power supply using a series of voltage dividers. A microchannel plate (MCP) with a 30 mm sensitive diameter is used for the detection of the ions. According to the simulations, a detector of this size collects only a subset of generated ions that are emitted close to the normal direction or have a small initial energy. The anode of the MCP is connected to the input of a 350 MHz digital storage scope for data acquisition.

Annular electrodes	(r_{min}, r_{max}) [mm]	Bias potential [V]
1	(0, 27)	5416
2	(29, 85)	5438
3	(87, 143)	5492
4	(145, 201)	5591
5	(203, 259)	5745
6	(261, 318)	5965

Ring electrodes	(z_{min}, z_{max}) [mm]	Bias potential [V]
1	(2, 34)	1324
2	(36, 68)	2162
3	(70, 102)	2880
4	(104, 171)	3529
5	(173, 240)	4701
6	(242, 309)	5761

Table 1. The dimensions and the bias potentials of the electrodes.

In our laboratory, the dust impact-generated plasmas were simulated using the laser ablation technique. A frequency doubled Nd:YAG laser with 8 ns pulse length is used for this purpose. Laser desorption ionization produces conditions similar to those of impact plasmas [11]. The laser beam is focused to the target by a simple lens system. One of the lenses is outside of the vacuum

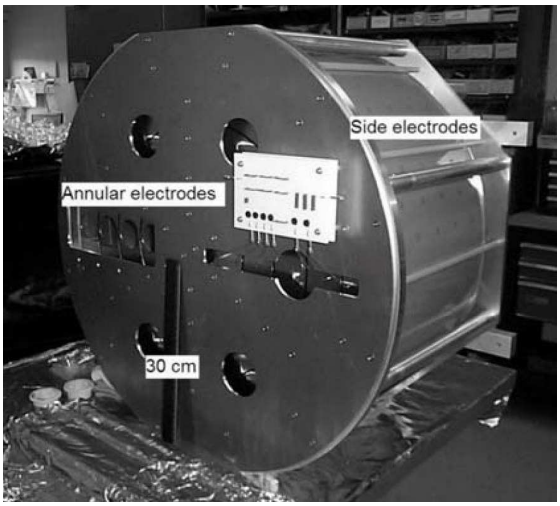

Figure 2. The laboratory model of the LAMA instrument shown from the front side. The annular electrodes are behind a cover plate. The side electrodes are etched on a flexible circuit board. The white panel in front is a voltage divider distributing the bias potentials onto the annular electrodes.

chamber, allowing a convenient adjustment of the laser focus. At the position of the focused laser beam, the material of the target is interchangeable. Three different

target materials have been used: silver, brass and graphite. The size of the laser spot was determined from the microscopic image of an exposed target. The diameter of the ablated crater on a silver target was smaller than 20 microns.

3. PERFORMANCE

Figure 3 shows a mass spectrum taken on a brass target. The spectrum contains the typical surface contamination elements of Na, K, and Ca, which are the largest peaks. Both isotopes of K at masses 39 and 41 are clearly visible in the spectrum and the relative peak heights are in agreement with their natural abundance of approximately 93% and 7%. The peak at 27 amu is likely to correspond to C_2H_3, although a contribution from contaminating aluminium is also possible [12]. The material of the target shows up as a series of peaks corresponding to the various isotopes of Cu and Zn. Again, the relative abundance of the naturally occurring isotopes is in good agreement with relative peak heights in the spectrum. It is, however, ambiguous to conclude the relative abundance of Cu and Zn in the brass sample from the measured spectra due to the likely different efficiency of the ablation and ionization processes. Small contributions from Fe (56) and Co (59) can also be identified in the spectra that are likely to be contaminants from machining the sample.

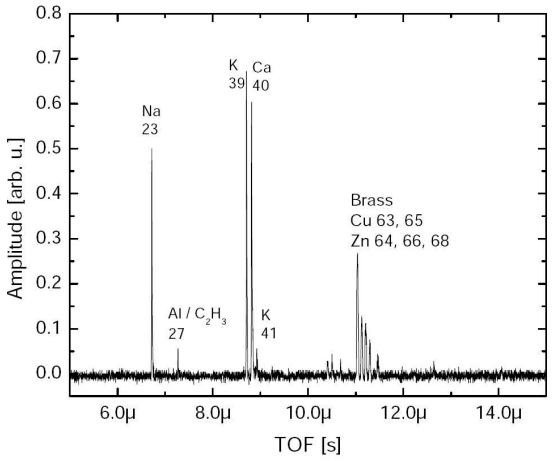

Figure 3. The mass spectrum from a brass target.

The large contribution from the surface contaminants to the mass spectrum may seem to be a bothersome problem. In the laboratory tests, however, no special attention was paid to the preparation of the target's surface that was wiped with acetone and ethanol prior installing into the vacuum. Srama et al. [13] have shown that specially prepared silver or gold targets can provide essentially contamination-free mass spectra. The laser intensity and irradiation history are the other factors that have a significant influence on the relative intensity of the mass peaks. At low laser intensities, the contamination peaks dominate the spectrum because of two reasons. First, the binding energy of the contaminants to the surface is lower than that in the bulk of the material. Second, species as Na, K or Ca can be ionized more effectively due to their lower ionization energy. The cleaning of the surface from contaminants can be achieved by an intense bombardment of the target by the laser. This procedure reduces the abundance of contaminants by evaporating many atomic layers from the surface.

In another set of experiments, graphite has been used as a target material. Similarly to observations on brass, the mass spectra were dominated by lines from contaminants at low laser energies. With increased laser energy, lines from carbon clusters emerge in the spectra. Figure 4 shows a spectrum obtained on a graphite target with a wide range of mass lines. Evident is the series of singly-charged carbon clusters from C_3 up to C_{16}. With a further increase of the laser intensity, the carbon monomer C^+ peak becomes the dominating line in the spectrum.

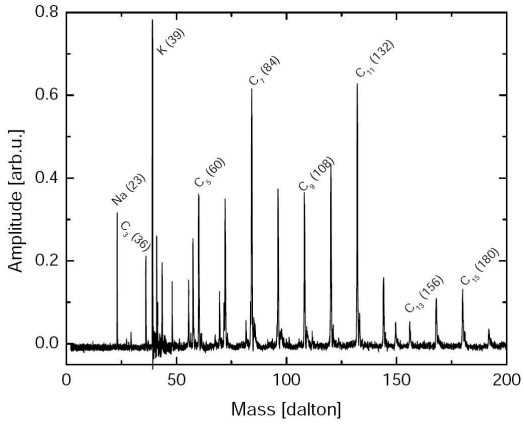

Figure 4. The mass spectrum from a graphite target shows a series of carbon cluster lines.

The mass resolution of the instrument is calculated from the width of the mass peaks (FWHM) Δt and the corresponding time of flight t from the following relation: $m/\Delta m = t/2\Delta t$. Figure 5 shows that the mass resolution from a series of measurements with a different laser intensity including all clearly recognizable peaks in the spectra. The large scatter in the mass resolution is likely due to the inconsistent initial conditions in the laser-produced plasmas. However, the important observation is that the performance of the instrument does not vary with the total amount of generated charge over the investigated

range. The mass resolution is always larger than $m/\Delta m > 125$, with a typical value approximately $m/\Delta m \approx 200$. This is in agreement with the value obtained from the simulations.

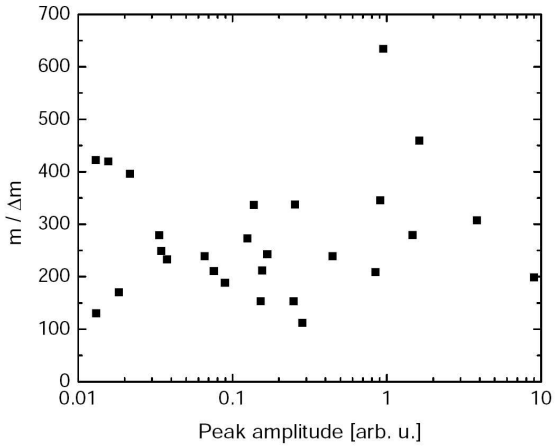

Figure 5. The mass resolution as a function of the peak amplitude.

4. CONCLUSIONS

An instrument with a 0.2 m^2 effective area has been developed that is suitable for the in-situ compositional analysis of interplanetary or interstellar particles with low fluxes. The laboratory model of the instrument was tested and the initial measurements confirmed the expected performance of the instrument. In the near future, experiments will continue using target materials similar to those expected in interstellar dust. The final calibration of the LAMA instrument will take place at the Heidelberg dust acceleration facility.

Acknowledgements

The research is supported by NASA. The authors thank Mark Lankton, Tracy Buxkemper and Charlie Bowen for their enthusiasm and help in the design and construction of the LAMA instrument.

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