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A COSMIC DUST COMPOSITION ANALYZER WITH A SPARK ION SOURCE

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ABSTRACT

Simulated iron micrometeoroids were fired unto a capacitor-type micrometeoroid detector which responded to an impact with a spark. Large ion currents were extracted from the spark and analyzed in a crude ion time-of-flight mass spectrometer. The mass spectra show the elements of both detector and particle materials. They do not, however, show the alkali metals which have been a problem with prior composition analyzers.

*Patent Pending

A COSMIC DUST COMPOSITION ANALYZER
WITH A SPARK ION SOURCE

Analyzing the chemical composition of cosmic dust particles is presently one of the most attractive goals of the physics of interplanetary and interstellar matter, particularly of cometary physics. A prior composition analyzer (Auer and Sitte, 1968, Friichtenicht et al., 1973, Dietzel et al., 1973) makes use of the plasma that is emitted when a dust particle hits a solid surface. Ions can be extracted from the plasma and analyzed in a time-of-flight mass spectrometer with respect to their mass-to-charge ratios. That analyzer has one major disadvantage: a mass spectrum taken of the ions represents the elemental species in proportions different from those of the original dust particle; alkali metals, particularly, are overrepresented whenever the impact velocities are below about 20 km/s.

A new method is announced in this letter which offers the advantages of a spark ion source combined with the sensitivity, reliability, and simplicity of a capacitor-type meteoroid detector. The basic difference from the prior method is in the fact that a large amount of external electric energy is added to the kinetic energy of the dust particle in order to vaporize and ionize the atoms in the particle with a high efficiency.

A spark ion source is known (see, e.g., Inghram, 1954) to have the following major advantages:

1. It ionizes any element present in the sample, i.e., it handles both volatile and involatile substances;
2. It has no blind spots, i.e., within one order of magnitude all elements ionize with equal efficiency;
3. There is little fractionation of elements.

A major disadvantage of a spark ion source is that large spreads of energy are always present and recourse to double focusing mass analyzers is necessary. Another disadvantage is the flow of high currents with short rise times in the spark which can result in conducted and radiated electromagnetic interference with other equipment. Both disadvantages can be met with carefully designed instrumentation.

Capacitor-type micrometeoroid detectors have been used on many spacecraft. A very reliable metal-oxide-silicon (MOS) version is described by Kassel (1973). Its construction is schematically shown in Figure 1. The detector is made from a 51-mm-diameter, 0.5 mm thick wafer of low resistivity, p-type (boron doped) silicon which forms the inner electrode of the capacitor. A 1 μm thick layer of silicon dioxide is grown on the wafer by thermal oxidation to form the dielectric of the capacitor. A 0.1 μm thick aluminum coating is then vapor deposited on top of the SiO_2 to form the outer electrode. An electric field with the strength of the order of 10^6 v/cm is applied across the SiO_2 dielectric. An impacting dust particle can trigger a spark between the electrodes, giving rise to a voltage drop across the capacitor that can readily be detected and counted. According to Kassel (1973), an MOS detector with an SiO_2 thickness of $0.4\mu m$ is sensitive to iron projectiles with diameters as small as $d = \frac{2.81}{v^2}$ $(m^3 s^{-2})$, where v is the particle velocity. For example, at $v = 10 km/s$ a particle with a diameter of $0.028\mu m$ or larger would normally trigger a spark. The detector is sensitive to particles with low velocities, at least down to about 1km/s and probably lower. Such low velocities have always been a problem with prior plasma detectors. Capacitor-type detectors have until now only been used to count dust particles, never to analyze them. The idea behind this work was to make use of the inherent properties of the spark as a very efficient ion source and to inject the ions into a mass spectrometer for analysis.

Experiments were carried out with iron microspheres from the hypervelocity dust accelerator at the Goddard Space Flight Center. Most particles had sizes of several μm and velocities of several km/s. A MOS capacitor-type micrometeoroid detector, kindly provided by J. Alvarez and P. Kassel of the Langley Research Center, was exposed to impacts of dust particles, one at a time. As shown in Figure 1, the polarity of the bias voltage on the detector was such that ions were accelerated from the back to the front electrode. An additional electric field was applied by means of a grid in front of the detector in order to extract ions from the spark and to accelerate them further (total acceleration voltage $U = 265$ volt). Some ions hit this grid, giving rise to a short and intense current pulse (about 100 ns wide, 1 Ampere peak current) which provided the zero-time reference for a time-of-flight mass spectrum to be recorded on an oscilloscope. Other ions passed through the grid, were deflected in a transverse electric field and collected at a distance $l = 47$ cm from the detector. The deflection was necessary in order to prevent neutral ejecta from hitting the ion collector. Note that this very simple arrangement has all essential parts of a time-of-flight mass spectrometer - ion source, accelerating field, drift space, and ion collector. Correspondingly, the current flowing onto the ion collector and being measured on an oscilloscope as a function of time represented the time-of-flight mass spectrum of the ions that were extracted from the spark. One example of about 40 essentially identical spectra is shown in Figure 2. According to the equation of energy balance,

$$\frac{m_A}{2} v_A^2 = eU, \qquad (1)$$

Figure 2 also shows the nominal arrival times $t_A = l/v_A$ for mass numbers $A = 16$ (O^+), $A = 27$ (Al^+), $A = 28$ (Si^+), $A = 56$ (Fe^+), and $A = 60$ (SiO_2^+). A large peak can be seen around mass numbers 27/28 which is probably aluminum and silicon. Another large peak around mass number 56 is probably due to iron and/or silicon dioxide. Oxygen is only weakly indicated if at all. Alkali metals which have been a severe problem with the prior composition analyzer were not detected at all. The first large signal should be disregarded; it was caused by crosstalk between adjacent pins on the common vacuum feedthrough and essentially disappeared when different pins were used. Clearly, the mass resolution is poor. A better resolving mass spectrometer should be used for future experiments in this area.

The total charge of the extracted ions can be estimated from the grid current to be of the order of 10^{-6} As or 6×10^{12} elementary charges. If half of them were ions from the projectile and half of them ions from the detector material, the projectile must have had a radius of at least $2\,\mu m$, which does not seem unreasonable. If half of the ions were from a dust particle, with a radius of approximately $2\,\mu m$, it must have been vaporized and ionized by the spark with a very high efficiency.

The method needs further development in three areas:

1. Experiments with different dust materials should be performed in order to verify that all elements are ionized with essentially equal efficiency; of particular interest are probable meteoritic materials such as graphite or silicates.
2. Detectors should be made of materials which are normally not found in meteoroids; particularly silicon and silicon dioxide should be avoided as detector material in order to avoid an ambiguity with meteoritic silicon.
3. The mass spectroscopic resolution should be improved over that of the very simple arrangement of Figure 1 such that at least major meteoritic elements can be identified with certainty and discriminated against ions of the detector material.

In summary, it seems that a cosmic dust analyzer with a spark ion source will be able to provide, for the first time, mass spectrograms which represent the true proportions of elements and isotopes of which cosmic dust particles are composed. It is expected that the method is applicable to dust particles with high as well as low velocities (as low as 1km/s) while the prior method was severely limited at low impact velocities.

ACKNOWLEDGMENTS

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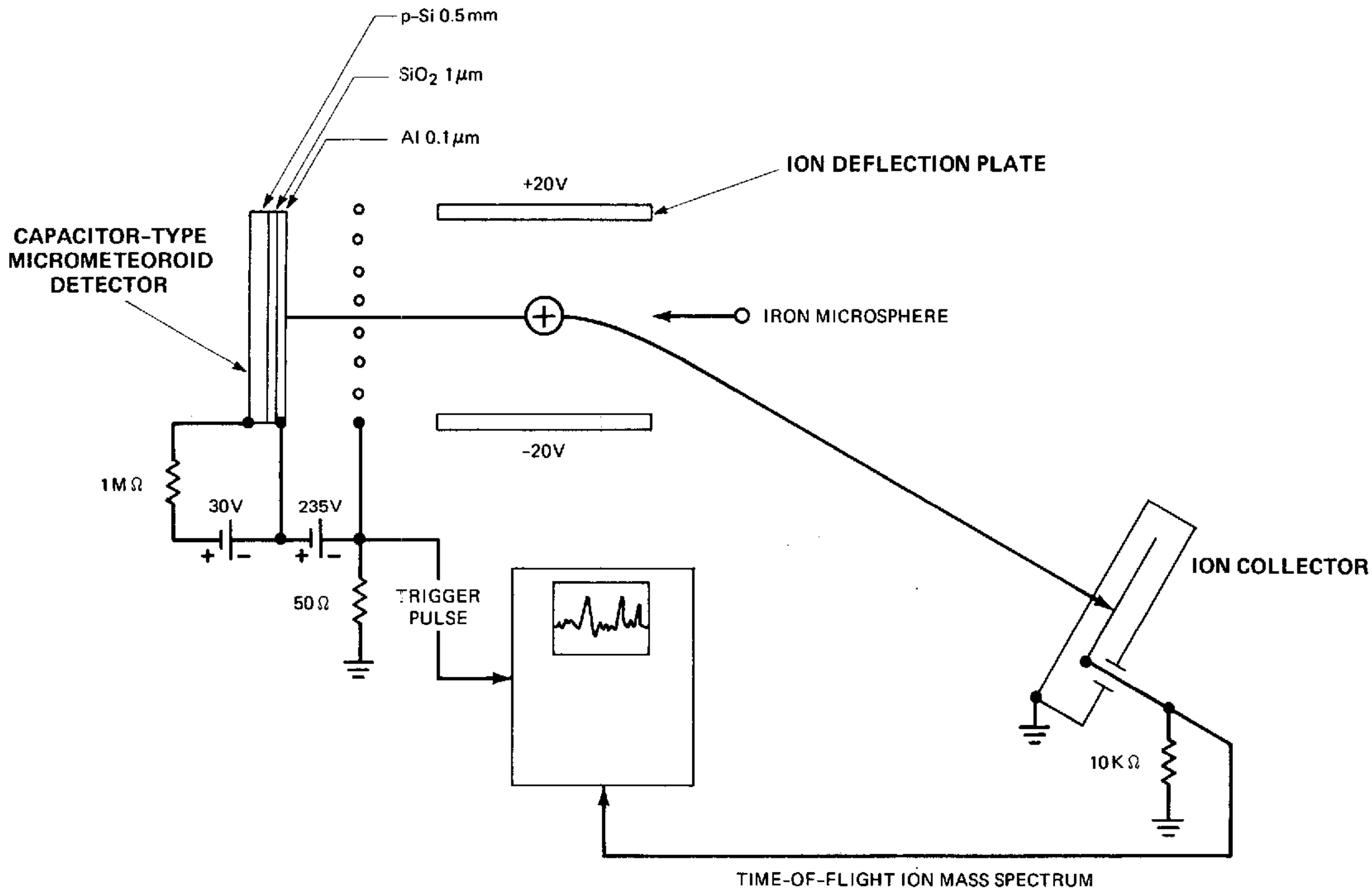

Figure 1. Schematic Diagram of the Experimental Arrangement

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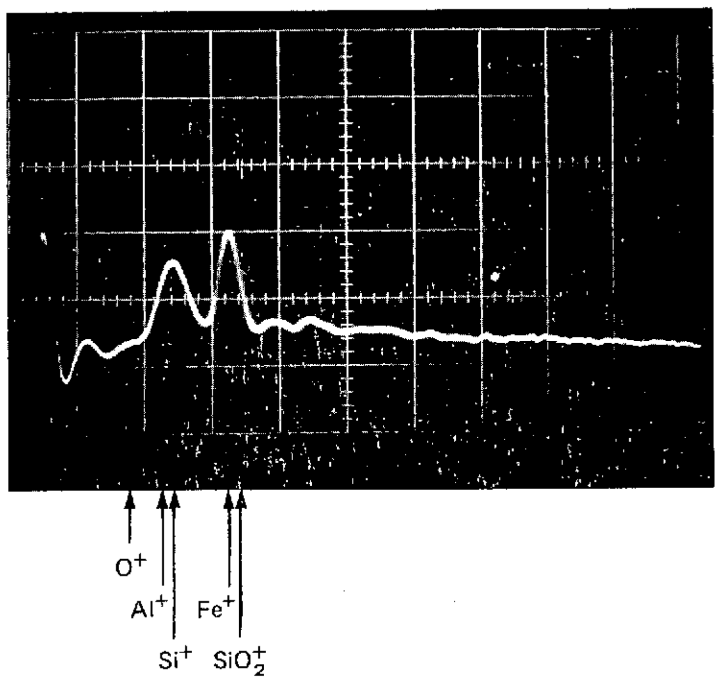

Figure 2. An Ion Time-of-Flight Mass Spectrum, 50 mV, 5 μs/div