SCANNING TRANSMISSION ION MICROSCOPY (STIM): A NEW TECHNIQUE FOR DENSITY MAPPING OF MICROMETEORITES

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Introduction:

The density of a cosmic dust particle is an important parameter in calculating the orbital evolution timescale and temperature profile on atmospheric deceleration. Sutton and Flynn [1] inferred the densities of 12 stony micrometeorites from the stratospheric dust collection using synchrotron x-ray fluorescence. This method used iron mass determinations to infer the particle mass and optical microscope measurements to determine volumes. These results coupled with density measurements by others [2,3] suggest that stony micrometeorite densities fall into two distinct density groups, with mean values of 0.6 and 1.9 g/cm^3. Such a bimodal distribution has dramatic implications for natural segregation of dust by gravitational resonances [4] and interpretation of degree of heating in terms of proportions of asteroidal and cometary populations [5,6].

The synchrotron-inferred densities have estimated uncertainties of $\pm$ 25% due largely to the difficulty in determining the volumes of these irregular objects. We are presently exploring the value of the Scanning Transmission Ion Microscope (STIM) for directly mapping the density distribution in individual stratospheric particles and other micrometer-sized objects. In this approach, the energy loss experienced by protons as they traverse the specimen is used to produce 3-dimensional microtomographic images of the internal structure of objects. One of the key advantages of this technique is the ability to focus this charged particle beam to below 100 nm [7] and thereby attain extremely high resolution tomographic images.

Analytical Methods:

The proton beam was obtained with the University of Melbourne 5U Pelletron accelerator and Microprobe, a description of which is given in [8]. The beam was focussed to a 200 nm spot and was continuously scanned over the specimen in a random unclosed path by magnetic deflection with a pair of scan coils placed between the lens and target changer. A 2.5 MeV H^+ beam was used for two reasons. Firstly, the ions must penetrate the target whilst energy loss must be sufficiently large to give good energy loss contrast and show features at submicron resolution. Secondly, the angle scattering from thicker parts of the micrometeorite must be small enough that a significant portion of transmitted events from these regions fall within the solid angle subtended by the detector to minimize count times. Data were processed using the VIEW image software from Lawrence Livermore National Laboratory which allows regions or planes of interest to be examined in detail.

As an exploratory experiment, we have imaged a 40 micrometer fragment of Allende matrix. The "micrometeorite" was mounted with adhesive on the end of a 80 μm diameter glass fiber. The sample was rotated in consecutive steps of 1.9° over 180°. Ninety parallel, 256 x 256 pixel images (a total of 6 million pixels) were obtained in about 2 hours.

Results:

Figure 1 shows the density distribution from one of these slice images through the fragment. The accuracy of a density measurement is estimated to be about ± 50% for a single pixel with better sample-integrated accuracy. The overall mass and volume of the object were determined to be 21 ng (± 20 %) and 8800 μm^3 (± 10 %), respectively. These results give a reasonable density of 2.4 ± 0.7 g/cm^3. Several submicrometer-sized regions with density of about 5 are apparent in the image presumably indicating the positions of sulfides, metal, etc.

These initial results are promising for potential application to interplanetary dust particles (IDPs) and other minute specimens. We anticipate that eventually the uncertainties in this technique will be reduced to 10 % or below. To accomplish this goal, additional measurements on standards of known density and composition need to be made.

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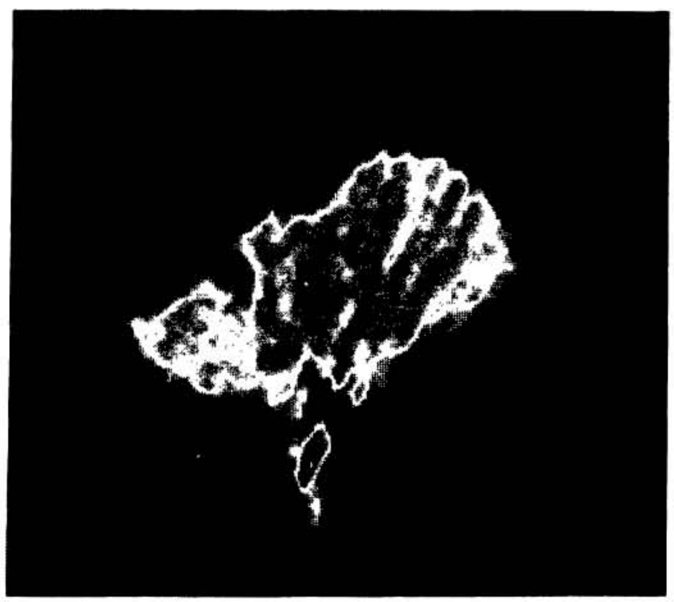

Figure 1: Scanning Transmission Ion Microscope (STIM) image of the density distribution through the interior of a 40 μm fragment of Allende matrix.