THE ION NANOPROBE: A NEW INSTRUMENT FOR STUDYING THE ISOTOPIC AND ELEMENTAL COMPOSITION OF THE SOLAR SYSTEM AND BEYOND AT THE FEW-NANOMETER SCALE.
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We are now constructing the ion nanoprobe, a new instrument designed for isotopic and chemical analysis at the few-nm scale. The new instrument will combine a recently developed high resolution liquid metal ion gun (LMIG), tunable solid state lasers for laser resonant ionization, a molecular fluorine excimer laser for UV ionization, and high transmission, high resolution time-of-flight mass spectrometer. The instrument is intended to provide a significant decrease in spot size and increase in sensitivity compared to the current state-of-the-art SIMS instrument, the Cameca NanoSIMS-50.

The ion nanoprobe is the next step in the development of microbeam resonant ionization mass spectrometers and builds on the success of two instruments of similar design, CHARISMA [1] and SARISA [2]. CHARISMA pioneered isotopic measurement of trace elements, such as Cr, Sr, Zr, Mo, Ru, and Ba, in individual presolar grains [3–8]; SARISA is now being used to measure trace element abundances in Genesis solar wind collectors by depth profiling [e.g., 2]. All three instruments share a number of characteristics, including release of atoms from samples with focused ion beams or lasers, use of laser resonant ionization to ionize specific elements, and time-of-flight mass spectrometers to mass-analyze and count ions.

Ion nanoprobe components: In designing the ion nanoprobe, the availability of new technology permits analytical goals beyond the capabilities of the current instrument. We now go through the major components of the ion nanoprobe and discuss these developments.

Sample stage. In CHARISMA and SARISA, the size of sample mounts is limited to 5–10 mm diameter. In order to make the ion nanoprobe more versatile, we have designed a new sample holder that will accept samples as large as 1 inch in diameter, which is the worldwide standard for polished thin sections. This has been done by making the stage a part of the ion extraction system. Fig. 1 shows the sample holder mounted on a four-axis (X, Y, Z, rotation) nanomotion stage. This stage uses piezoelectric motors with position encoders and is bakeable and UHV compatible.

Releasing atoms from samples. This will be done in several ways. First, following the example of CHARISMA, a UV ablation laser can be used to efficiently desorb atoms, but the diffraction limit to spatial resolution is ~0.5 µm. The instrument will be equipped with a high current, low energy Ar ion gun for surface cleaning and depth profiling. The new instrument gets its name, however, from Ga liquid metal ion gun that can be focused to a few nm. The development of these guns has been driven by focused ion beam (FIB) sample preparation devices for electron microscopy. Ga is not widely used in SIMS, because sputtering with Ga provides a relatively low yield of ions. (TOF-SIMS instruments use Ga ion beams, but get around the sensitivity problem by presputtering, which amorphizes a few monolayers of sample and enhances ion yield.) In the ion nanoprobe, it is desirable to sputter neutral atoms and then use lasers to ionize them, so the low ionization efficiency of Ga sputtering is actually an advantage.

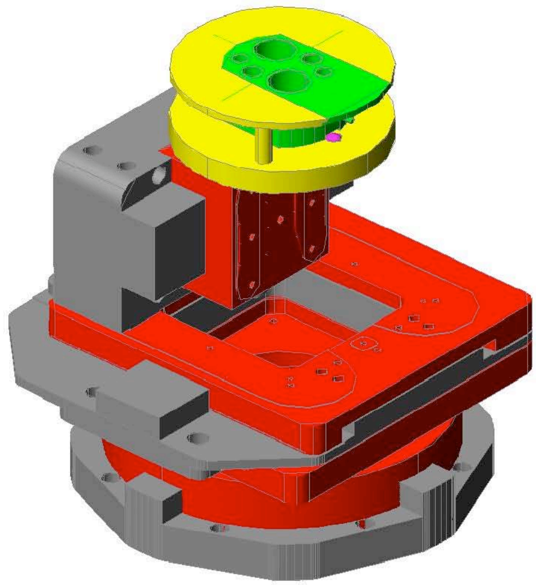

Fig. 1. Sample stage (red and gray) with removable sample holder (green) inserted into sample mount position (yellow).

Laser ionization. Following current practice on CHARISMA and SARISA, we will use tunable Ti:sapphire lasers for laser resonant ionization. We will initially have four such lasers, which should make it possible to analyze two elements at once. The sample chamber and mass spectrometer for the ion nanoprobe will be mounted on a large laser table, for vibrational stability and to allow more ionization lasers to be added in the future. The ion nanoprobe will also be equipped with a F_2 excimer laser. This laser puts out light with a wavelength of 157 nm, which corresponds to an energy of 7.9 eV. This is sufficient to ionize a large number of elements. Fig. 2 shows the elements that can be ionized in a single step with a F_2 laser and those that can be ionized by resonant ionization with tunable visible and UV lasers. The F_2 laser would be used for surveying samples and measuring trace element abundances, an application were isobaric interferences are less important and can be corrected for. Resonant ionization would be used for measurement of isotopic compositions of individual elements. Finally, Fig. 2 shows that a few elements, mostly in the upper right part of the periodic table cannot be ionized by either method, because their first excited levels are in the vacuum ultraviolet. For these, we are investigating element specific lamps, which may allow us to reach the first excited state, from which we could ionize using UV and visible tunable lasers.

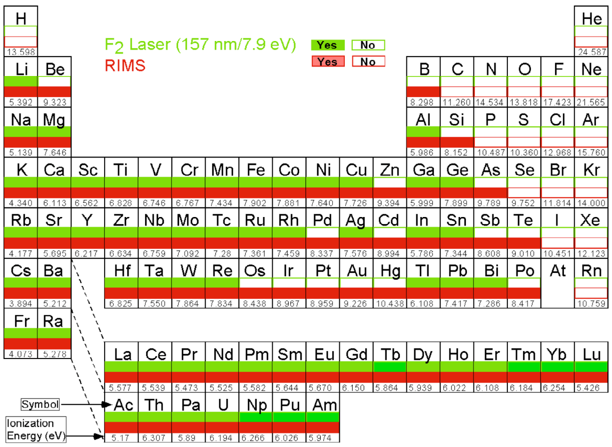

Fig. 2. The periodic table of the elements, showing elements that can be resonantly ionized with laboratory visible and UV lasers and those that can be ionized in a single step with an F_2 excimer laser.

Ion extraction and mass spectrometry. A major effort in ion optical design was undertaken when SARISA was built, which resulted in about a 10-fold improvement in the efficiency of extraction of photoions from the region above the target. In the new instrument, the ion extraction optics are simpler than in SARISA, in that the sample and sample holder comprise a large flat surface (see Fig. 1). The only other major change from SARISA is to increase the accelerating voltage from 1 to 9 kV for the ion nanoprobe. This will allow a three-fold improvement in mass resolution and improve the detection efficiency of the ion detectors. Finally, the flight tube will be mounted vertically above the sample chamber and both will sit in the center of a large H-shaped vibration-compensate laser table.

Ion counting. Current instruments are limited to precisions no better than a few tens of permil, primarily because current detectors can count no more than one ion of the most abundant isotope of an element per pulse, and typically are held to less than one count per 10 pulses. Ion detection is usually accomplished with a microchannel plate with a single anode. We are developing a multianode microchannel plate detector that will be able to count multiple ions per pulse, increasing throughput. Increasing the repetition rate of photoionization lasers from 1 to 10 kHz, will also improve counting statistics.

Useful yield. The useful yield, which is the percentage of ions counted in the detector per atom removed from a sample, is usually less than a percent in a SIMS instrument, depending on the ionization efficiency of the element analyzed. In CHARISMA, the useful yield is ~2%; in SARISA, recent measurements have approached 25%. The goal for the ion nanoprobe is 40–50%, to be achieved by modest improvement in ion optics compared to SARISA and by improved detector technology.

Environment. Recent experience with CHARISMA and SARISA [9] have shown that the wavelengths of tunable lasers are quite temperature sensitive. The entire ion nanoprobe will be installed in a new thermally stabilized, low vibration, draft-free, room that is now under construction (Fig. 3).

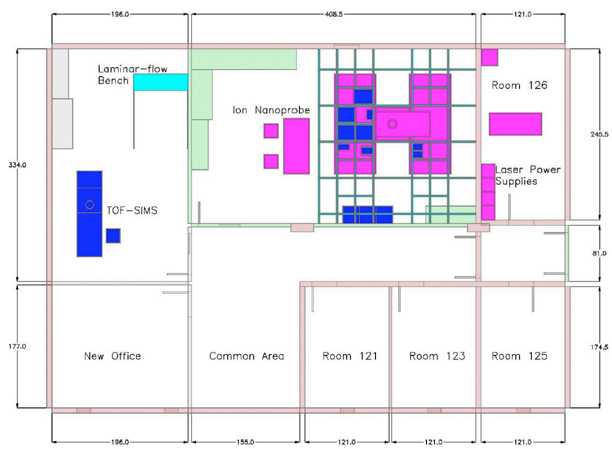

Fig. 3. The ion nanoprobe laboratory. The instrument is mounted on the purple H-shaped laser table; electronics boxes are in blue. Power supplies and pumps, which generate heat, noise and vibration, will be located in the next room (126).

Applications: The ion nanoprobe will be applied to a broad range of problems in cosmochemistry. Contemporary interstellar grains collected by the Stardust mission are just now being extracted and, if found, will be a high priority for the ion nanoprobe, as will be small presolar SiC and subgrains in presolar graphite that are beyond current analytical technology. The high sensitivity of the ion nanoprobe may allow investigation of the ^{26}Al-^{26}Mg system is Wild 2 cometary dust.

References: [1] Savina M. R. et al. (2003) *GCA* **67**, 3215–3225. [1] Davis et al. (2007) *GCA* **71**, A205. [2] Veryovkin et al. (2008) *LPS* **39**, #2396. [3] Nicolussi G. et al. (1997) *Science* **277**, 1281–1283. [4] Nicolussi G. et al. (1998) *GCA* **62**, 1093–1104. [5] Nicolussi G. et al. (1998) *Phys. Rev. Lett.* **81**, 3583–3586. [6] Savina M. R. et al. (2003) *GCA* **67**, 3201–3214. [7] Savina M. R. (2004) *Science* **303**, 649–652. [8] Levine J. et al. (2009) *LPS* **50**, this volume. [9] Levine J. et al. (2008) *LPS*. **39**, #1661.