

A novel high-resolution laser-melting sampler for discrete analyses of ion concentrations and stable water isotopic compositions in firn and ice cores

Y. Motizuki,^{*1} Y. Nakai,^{*1} K. Takahashi,^{*1} J. Hirose,^{*1} Y. V. Sahoo,^{*1} Y. Yano,^{*1} M. Yumoto,^{*2} M. Maruyama,^{*2} M. Sakashita,^{*2} K. Kase,^{*2} and S. Wada^{*2}

Ice cores preserve past climatic changes and, in some cases, astronomical signals. Here we present a newly developed automated ice-core sampler that employs laser melting (see Fig. 1). In our system, a hole in an ice core approximately 3 mm in diameter is melted and heated well below the boiling point by laser irradiation, and the meltwater is simultaneously siphoned by a 2 mm diameter movable evacuation nozzle that also holds the laser fiber. The advantage of sampling by laser melting is that molecular ion concentrations and stable water isotope compositions in ice cores can be measured at high depth resolution, which is advantageous for ice cores with low accumulation rates, such as ice cores drilled around Dome Fuji station in Antarctica.

This device takes highly discrete samples from ice cores, attaining depth resolution as small as ~ 3 mm with negligible cross contamination; the resolution can also be set at longer lengths suitable for validating longer-term profiles of various ionic and water isotopic constituents in ice cores.

The laser beam used to melt the ice is supplied through the wall of the freezer container by a continuous-wave operated Er-doped fiber laser (CEFL-TERA, Keopsys Inc.) through optical fibers (core/clad diameter = 200/220 μm). The laser wavelength is 1.55 μm (near infrared) and the maximum output power is 10 W. The 1.55- μm wavelength takes advantage of the strong absorption bands of ice and water from 1.4–1.6 μm . In addition, because 1.55- μm lasers are commonly used in optical communication technologies, suitable optical fibers are commercially available.

To check the stability of the sampler in the -20°C

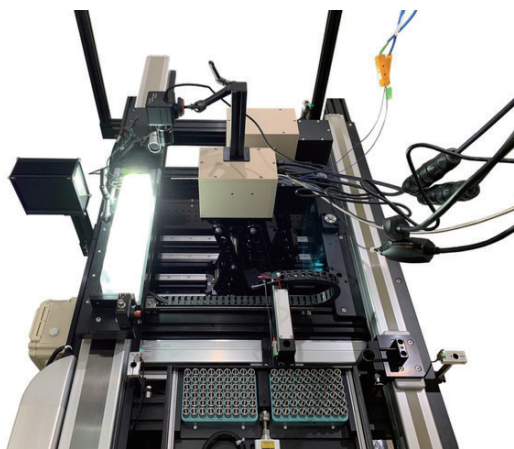


Fig. 1. Photo showing a newly-developed laser-melting ice core sampler.



Fig. 2. Photo showing an ice block after the continuous extraction of 100 meltwater samples in a stability test.

environment, we performed a continuous sampling test in which 100 vials were filled with a minimal volume (0.65 mL) of meltwater. In this test, the laser power was set at 1.9 W, the nozzle intrusion speed was 0.52 mm/s, the pumping speed was 5.5 mL/min, and the horizontal and vertical pitch of the nozzle was 2.5 mm. It took 8 hours 47 minutes to complete this test with no issues the $\sim -20^\circ\text{C}$ environment. Figure 2 shows a dummy ice block made up from ultrapure water (Milli-Q water) after this stability test. We conclude that the sampling rate will not be a bottleneck during high-throughput isotopic and ionic ice-core analyses.

We also conducted experiments to check whether there was any leaching of ions from inner components and to check the degree by which samples mixed with each other during continuous sample collection. We found a 2.4% “memory effect,” which is usually significantly less than the analytical accuracy (a few $\mu\text{g}/\text{L}$) of ion analyses by ion chromatography. We conclude that internal contamination and cross contamination are negligible with this sampler.

With this new sampler design, the analysis of the 2,000-year record embodied in the Dome Fuji firn core, which took us several years, could now be finished in about 30 working days by using two isotopic analyzers. For the first time, we can now realistically contemplate strategic plans for cores recovered from low-accumulation sites that include large numbers of repeated operations, such as compiling continuous 2,000-year profiles with annual resolution of ionic and water isotopic constituents. Finally, our sampler has the capability to profile ionic and isotopic constituents at monthly resolution to pursue intriguing transient signals, potentially by annual layer counting.

Reference

1) Motizuki *et al.*, submitted to Cold Reg. Sci. Technol.

^{*1} RIKEN Nishina Center

^{*2} RIKEN Center for Advanced Photonics