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Microphysics and Spectroscopy of Europa water-ice analogs: effects of grain size, temperature, and sintering

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Abstract

The near-term understanding of Europa's habitability and future exploration relies on our current ability to assess ocean chemistry by evaluating candidate sites of fresh extruded materials. Our objective is to determine how grain size, salt content, and radiation influence the spectroscopic/optical properties of materials, and to identify these "fresh" sites, using laboratory simulations and Galileo NIMS modeling. To address this objective, we developed protocols for preparation of pristine Europa ice analogs in the lab. Here, we experimentally demonstrate how water ices and their spectra evolve at different grain sizes and temperatures relevant to Europa's surface, and quantify the sintering observed in our lab samples.

1. Introduction

Jupiter's moon, Europa is one of NASA's key targets for exploration of habitable worlds. Measurements reveal several distinct, absorption bands of water ice (and salts) in the near-infrared spectrum of Europa, whose presence, shape, and positions are functions of temperature, radiation, microphysics of ices, and mixing with non-ice components. Sintering is predicted to be an important temperature-dependent process on Europa, leading to a significant change in the microphysical structure and spectra of surface materials over short timescales [2,3]. Predicting the level of sintering and corresponding exposure age/thermal history, requires knowing the surface composition and ice grain size distribution (estimates vary from 5 µm to few mms). The Europa Clipper Mapping Imaging Spectrometer for Europa (MISE) could help reveal this distribution of water ice phases, organics, salts, and other materials. However, we are limited by a lack of experimental data of the optical, spectral, and mechanical properties of ices under Europa-relevant conditions (and timescales) to accurately interpret these measurements. We present a laboratory-based pathway [4] designed to obtain these critical optical and spectroscopic measurements of candidate ices in the UV-VIS-NIR spectral range, at Europan conditions. Our hypothesis is that sites of recently emplaced oceanic material can be identified by determining the spatial attributes of albedo, grain size, composition, degree of sintering, and ice crystal structure. In the first step discussed here, our experiments explore how ices and their spectra evolve under relevant conditions, and investigate their dependence on grain size and thermal cycling.

2. Methodology

At the Ice Spectroscopy Laboratory (ISL) at JPL, we have developed state-of-the-art infrastructure for studying spectral, optical-imaging & compositional properties of ices under Europa's radiation conditions. This facility includes an ice deposition/sieving drybox with continuous N_2 purge, a high-vacuum chamber ($<10^{-9}$ mbar), a closed-cycle helium cryostat (10–300 K), UV-VIS-NIR reflection spectrometers, a remote microscope (2 µm), and tunable electron gun sources (<100 keV) (Fig. 2A) [4]. We have developed protocols for ex-situ preparation of ice grains of controlled size (5 µm to >200 µm), with varying ice composition (ice+salts like $MgSO_4$, NaCl) at 77-150 K (Fig. 2B-D). Grain size is controlled by misting ultrapure H_2O into a dewar filled with liquid nitrogen (LN), followed by sieving in dry N_2 [1]. Ice grains are transferred to a sample holder inside the chamber and cryogenically cooled to 100 K to replicate Europa's equatorial dayside conditions. Reflectance spectra of these ice grains are collected using NICOLET 6700 FTIR spectrometer with MCT detector. We perform quantitative analysis by calculating band depth & ratio at 1.5, 1.65, and 2 µm, and compare with spacecraft/lab data. We also collect optical data of ices using INFINITY K-2 DistaMax Microscope and Zeiss Axiocam camera (resolution: 10 µm), to obtain secondary assessment of average grain size, and evaluate the evolution of size and morphology. Finally, we perform two control experiments: (1) in-situ deposition of water-ice at 10 K and (2) ex-situ deposition of ice block at ~170K.

3. Results

We successfully collected reflectance spectra of water-ice grains with sizes ranging from 25-212 μm. Our samples display spectral signatures of crystalline water ice (1.65, 3.1 μm), with an observed increase in band depth of NIR absorption with grain size, which is consistent with theoretical models (Fig. 1A) – we can use this trend to determine Europa's surface particle size, and relative surface age. The spectra for high temperature ice block are also consistent with predictions. Thermal cycling of samples (100 K to 170 K) leads to an increase in 1.65 μm band depth (Fig. 1B) – we observe a potential transition from amorphous to crystalline ice. This is potentially due to (a) contamination of samples during transfer by frosting (however, no evidence of frosting in images), or (b) sample preparation in LN (at 77K) resulting in amorphous ice formation, which turns crystalline upon annealing. (c) A scattering effect has also been suggested due to scale of interaction with ice grains. Additionally, we observe a change in grain size and morphology (small, spherical to larger, angular) through ice sintering (Fig. 1C-D), which follows expected results from recent modeling [2, 3]. There is an associated shift in collected spectra and band depth (towards crystalline ice), which demonstrates the need to understand sintering effects.

We will present the findings of (50+) grain size and temperature experiments, discuss plans for delivering our measurements to the community, and describe upcoming experiments with salt content and radiation.

4. Figures

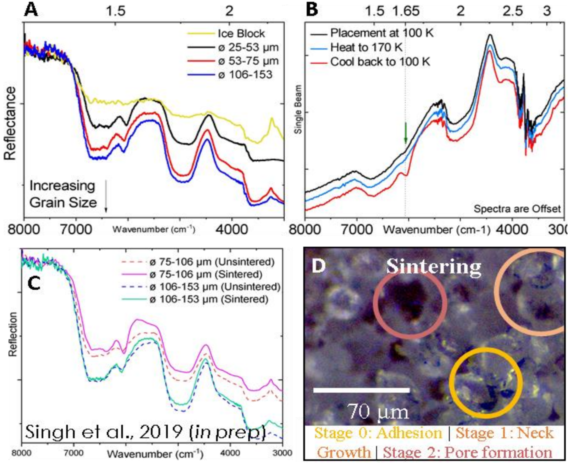

Figure 1: We successfully collected spectroscopic data in ISL: (A-C) illustrate grain size, temperature, sintering effect on spectra. (D) shows sintering stages.

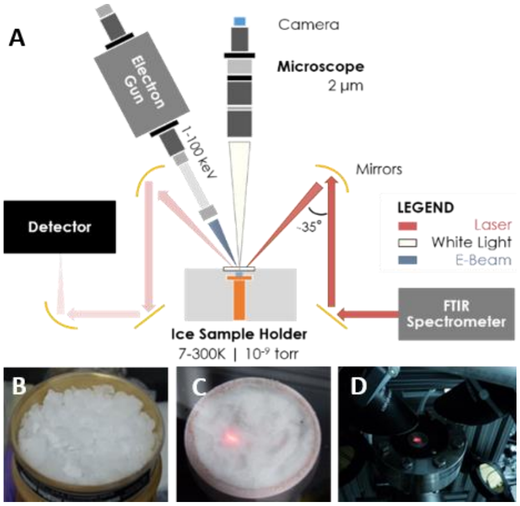

Figure 2: (A) ISL enables experiments at Europan conditions. (B-D) We deposit ices and collect spectra.

5. Summary and Conclusions

Our study will for the first time allow us to determine how the combination of grain size, salt content, and high-energy electron radiation together influence spectral/sintering properties of Europa ice-analogs under relevant conditions. In future years, the collected spectra will allow us to accurately model Europa NIMS/MISE datasets, which can enhance our interpretation of icy surface, and inform site selection for in-situ sample collection on ocean worlds.

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