Synchrotron micro-X-ray fluorescence analysis of natural diamonds: First steps in identification of mineral inclusions in situ

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ABSTRACT

Diamond inclusions are of particular research interest in mantle petrology and diamond exploration as they provide direct information about the chemical composition of upper and lower mantle and about the petrogenetic sources of diamonds in a given deposit. The objective of the present work is to develop semi-quantitative analytical tools for non-destructive in situ identification and characterization of mineral inclusions in diamonds using synchrotron micro-X-ray Fluorescence (μSXRF) spectroscopy and micro-X-ray Absorption Near Edge Structure (μXANES) spectroscopy at a focused spot size of 4 to 5 micrometers. The data were collected at the Pacific Northwest Consortium (PNC-CAT) 20-ID microprobe beamline at the Advanced Photon Source, located at the Argonne National Laboratory, and yielded the first high-resolution maps of Ti, Cr, Fe, Ni, Cu, and Zn for natural diamond grains, along with quantitative μSXRF analysis of select chemical elements in exposed kimberlite indicator mineral grains. The distribution of diamond inclusions inside the natural diamond host, both visible and invisible using optical transmitted-light microscopy, can be mapped using synchrotron μXRF analysis. Overall, the relative abundances of chemical elements determined by μSXRF elemental analyses are broadly similar to their expected ratios in the mineral and therefore can be used to identify inclusions in diamonds in situ. Synchrotron μXRF quantitative analysis provides accurate estimates of Cr contents of exposed polished minerals when calibrated using the concentration of Fe as a standard. Corresponding Cr K-edge μXANES analyses on selected inclusions yield unique information regarding the formal oxidation state and local coordination of Cr.

INTRODUCTION

The exceptional chemical and physical properties of diamond allow it to store and preserve information about the deep mantle from which it originates. Diamond crystals often incorporate grains of other minerals as they grow, and shield these mineral inclusions from later destruction. These diamond inclusions (DIs) record information about the mineralogy, composition, and thermal regime of the ancient Archean-Proterozoic lithospheric mantle, thus providing constraints on processes that lead to stabilization of proto-continent. In addition, diamonds and DIs provide valuable information for diamond exploration programs, allowing determination of diamond parent paragenesis (eclogitic or peridotitic; Gurney 1989) and leading to prioritization of exploration targets.

Historically, DIs have been studied by destructive methods in which the diamonds are crushed (Sobolev et al. 1970; Gurney et al. 1984; Gurney 1989) or ablated (Seitz et al. 2003), thereby destroying all smaller inclusions and extracting only parts of larger inclusions. The recovered inclusions are then mounted on a slide, polished, and analyzed using electron microprobe techniques. This complicated and time-consuming process requires 2–3 days to study major mineral inclusions in just one diamond.

Synchrotron micro-X-ray Fluorescence (μSXRF) spectroscopy is an established method for non-destructive extraction of important chemical and mineralogical information from fluid and solid inclusions in minerals (Frantz et al. 1988; Mavrogenes et al. 1995). The utility of the synchrotron micro-techniques is enhanced by the high brightness and energy of the third-generation synchrotron sources (Sutton et al. 2002), such as the Advanced Photon Source (APS) and the Canadian Light Source (CLS), and by the high spatial resolution of the associated microprobe beamline and end-station. It takes only minutes to collect a fluorescence spectrum from a high intensity X-ray beam produced by synchrotron radiation and, due to its substantial penetration depth, synchrotron μXRF can probe inclusions in situ. Moreover, with recent advances in micro-focusing techniques, one can collect a meaningful μSXRF signal from 5–10 μm inclusions (Vincze et al. 2004) that previously could not be characterized.

Mineral inclusions in diamonds have been studied with the μSXRF technique qualitatively (Ohigashi et al. 2002; Meng et al. 2003) and, most recently, quantitatively (Vekemans et al. 2004; Vincze et al. 2004). Quantification of the μSXRF data

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