Origin of milky optical features in type IaB diamonds: Dislocations, nano-inclusions, and polycrystalline diamond

TINGTING GU¹*,†, HIROAKI OHFUJI², and WUYI WANG¹

¹Gemological Institute of America (GIA), 50 W. 47th Street, New York, New York 10036, U.S.A.
²Geodynamics Research Center (GRC), Ehime University, Matsuyama, 790-8577, Japan

ABSTRACT

The milky appearance shown by certain type IaB diamonds has been subjected to several recent studies, but the origin of this feature is not fully understood. Here several type IaB diamonds with a milky appearance have been studied by cathodoluminescence (CL), electron backscatter diffraction (EBSD), and transmission electron microscopy (TEM). CL of several hazy type IaB diamonds shows scattered or orientated micro-sized spots or short linear luminescence features. TEM observation revealed that those spots and linear features are caused by dislocation loops that are likely responsible for the hazy appearance of the host diamonds. It is also shown that type IaB diamonds with a cloudy appearance contain nano-sized inclusions with negative crystals of octahedral shape. Some of these negative crystals contain a precipitate that can be explained by a compressed disordered cubic δ-N₂ phase observed by high-resolution TEM. In one of the milky IaB diamonds with platelet defects, polycrystalline areas composed of columnar diamond crystals elongated radially in [110], similar to ballas diamond, were revealed by EBSD. Taking into account these observations, it is suggested that the dislocation loops, nano-sized inclusions (negative crystals) and/or characteristic grain boundaries of the radiating fibrous crystals would be the origins for the milky appearance of the type IaB diamonds studied here. Those results add a complementary explanation that accounts for the milkiness of type IaB diamonds studied before.

Keywords: Type IaB diamonds, milky, dislocations, voidites, polycrystalline diamond; Nanominerals and Mineral Nanoparticles

INTRODUCTION

The origin of milky diamonds is enigmatic. Unlike diamonds with intense fluorescence that creates an “oily” appearance, milky diamonds contain areas with distinct textures, scattering light and resulting in a hazy or cloudy appearance. With dense “clouds” inside, they can be termed “fancy white” diamonds. The exact cause of their opacity is not fully understood. In previous studies, the term “cloudy” has been used to refer to fibrous diamonds or describe diamonds with submicroscopic internal inclusions. Extensive studies have shown that those frosted zones are filled with disk-shaped crack-like graphite inclusions (Rakov et al. 2014) or high-density fluids (HDFs) from a deep origin, with compositions ranging between carbonatitic and saline end-members (Navon et al. 1988; Izraeli et al. 2001; Klein-BenDavid et al. 2007; Tomlinson et al. 2009; Logvinova et al. 2011). However, cloudy inclusions filled with HDFs usually appear gray or black, while the milky diamonds are generally white in color, suggesting a different filling.

It has been noticed that milky white diamonds are most often type IaB (Fritsch 1998), with nitrogen in B-aggregates (four nitrogen atoms around a single vacancy, Loubser and van Wyk 1981). The development of B centers is usually accompanied by the formation of platelets, planar defects in {001} planes that measure a few nanometers to a few micrometers in diameter (Clack et al. 1999; Speich et al. 2017). In some pure type IaB diamonds, that have been termed “irregular” (Woods 1986), platelets have experienced degradation and may be absent completely. Platelet degradation is often accompanied by the formation of voidites (e.g., Barry et al. 1987). Previous studies have confirmed that voidites and nano-inclusions can be found in type IaB diamonds with milky zones (Rudloff-Grund et al. 2016; Navon et al. 2017). However, the composition of those nano-inclusions is still a subject of debate. Electron energy loss spectroscopy (EELS; Bruley and Brown 1989) and energy-dispersive X-ray spectroscopy studies (EDX; Rudloff-Grund et al. 2016) reveal the presence of nitrogen in the voidites. Based on moiré patterns, the material filling the voidites has been identified as NH₃ (Barry 1986; Hirsch et al. 1986a) or a tetragonal N₂ phase (Luyten et al. 1994; Navon et al. 2017). If such voidites are the products of platelet degradation, elements that constitute the platelets should be present in the voidites or alongside the dislocation loops. However, the structure and composition of the platelets are still unclear. In previous studies, the structural model of platelets with a nitrogen double layer (Lang 1964) was excluded because EELS investigations have shown that the concentration of nitrogen within the platelets is too low to fit with this model (Berger and Pennycook 1982). The generally accepted platelet model is that of a pentagonal interstitial carbon arrangement in the {100} planes as proposed by Humble (1982). Theoretical studies have indicated that the strain associated with...