Pink color in Type I diamonds: Is deformation twinning the cause?

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ABSTRACT

Plastic deformation of diamond has long been associated with the generation of color, specifically brown and pink. Extensive previous optical and spectroscopic characterization of natural pink Type I (nitrogen containing) diamonds has revealed two clear groupings, with distinct geographical origins. Group 1 pinks, which have low concentrations of nitrogen and are relatively highly aggregated (IaA ≤ B), have only been found in the Argyle lamproite pipe (Australia) and Santa Elena alluvial deposits (Venezuela). Group 2 pinks, which have much higher nitrogen concentrations and exhibit low levels of aggregation, have been found in deposits from southern Africa, Canada, and Russia. Pink color is intimately associated with deformation lamellae on the {111} crystal planes, and understanding their formation and structure has been a priority with respect to defining the source of this geologically valuable color center. In group 2 pinks, these {111} lamellae have been characterized as deformation microtwins by both transmission electron microscopy and X-ray diffraction. Subsequently the {111} lamellae in group 1 pinks have been assumed to also be deformation microtwins. In this paper we report electron backscatter diffraction (EBSD) studies of three brown and six pink naturally deformed diamonds with varying nitrogen concentrations and aggregation states. The results show that there are no deformation microtwins in the group 1 pink or brown diamonds. The study also highlights the usefulness of orientation contrast imaging as a simple and rapid method for determining the presence of microtwins. Our results suggest that the color in the group 1 pink diamonds is not directly related to the presence of deformation twins. However, we propose that twins may have been present but subsequently removed by de-twinning, a process that utilizes the same Shockley partial dislocations involved in the original twinning event. Therefore, it may be the process of twinning (and de-twinning) that creates the defect responsible for pink color, as opposed to the actual structure of microtwins themselves. In addition, a large laboratory data set of pink diamond analyses reveals the occurrence of group 1 pink diamonds in the Namibian marine (secondary) deposits. This would appear to suggest an additional source of group 1 pink diamonds in southern Africa, but the antiquity of these diamonds means that a common source on the former Pangaea supercontinent cannot be ruled out.

Keywords: Shockley partial dislocations, plastic deformation, de-twinning, Argyle, electron backscatter diffraction (EBSD), nitrogen aggregation

INTRODUCTION

It has long been recognized that brown and pink colors in diamonds are associated with plastic deformation (Collins 1982). The color is often confined within {111} lamellae, while the bulk of the crystal is colorless (Collins et al. 2000), a phenomenon commonly referred to by gemologists as “graining”. Like other face-centered cubic (FCC) materials, diamond exhibits a {111}<110> slip system, meaning that the {111} planes are the active slip planes with movement in the <110> direction. Due to the high symmetry of diamond, the {111} planes are also twin planes. Twins in diamond are contact twins, where reflection in a {111} plane is the equivalent of a 60° rotation around a {111} axis (Fig. 1). Note that in a twin, lattice points in one crystal are shared as lattice points in another crystal, adding apparent symmetry to the crystal pairs; hence twinning adds symmetry to the crystal, decreasing the energy stored within it. They commonly occur as arrays of twins parallel to one another (i.e., polycrystalline twins). Twinning in diamond can occur during growth (e.g., Yacoot et al. 1998; Machado et al. 1998; Tomlinson et al. 2011) or during deformation (Buerger 1945; Hirth and Lothe 1982; Christian and Mahajan 1995; Niewczas 2007). Early work using indentation (Phaal 1964) and high-pressure high-temperature (HPHT) experiments (de Vries 1975) produced deformation microtwins, which were also observed in natural samples (Varma 1970). More recent studies using transmission electron microscopy (TEM; Shiryaev et al. 2007; Gaillou et al. 2010), X-ray diffraction (Titkov et al. 2012), electron backscatter diffraction (EBSD, Howell et al. 2012a) and atomic force microscopy (AFM; Gainutdinov et al. 2013), have shown these analytical techniques to be powerful tools for identifying some of these {111} lamellae as deformation microtwins.

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