The oxygen content of sulphide inclusions in diamonds and its use as a mantle geothermometer

Sumith Abeykoon, Daniel James Frost, Vera Laurenz, and Nobuyoshi Miyajima

Bayerisches Geoinstitut

Sulphide inclusions in diamonds are commonly used for determining both the timing and lithology of diamond formation. Most sulphide inclusions were trapped as melts which then crystallized as Fe-Ni rich monosulphide solid solutions (MSS). Upon cooling below ~1000°C the inclusions recrystallize to phases such as pyrrhotite, Fe_{1-x}S (x = 0 to 0.2), and pentlandite, (Fe,Ni)_{9}S_{8}, and sometimes pyrite (FeS_{2}) depending on the bulk composition. Previous experimental studies have shown that oxygen can also partition into sulphide melts. Moreover, measurements of natural sulphide inclusions in diamonds show measurable oxygen concentrations. A systematic parameterization of factors that control the oxygen concentration of sulphide melts in the mantle could be potentially used to understand formation conditions of diamonds.

We performed a series of high pressure (3-15 GPa) and high temperature (1373 - 2000 K) multi-anvil experiments to equilibrate a fertile peridotite (KLB-1) mixture with molten sulphide (FeS). The effects of pressure, temperature, oxygen fugacity and composition (both silicate and sulphide) on oxygen content in sulphide melt have been investigated. We also examined the effect of Ni content in sulphide on the oxygen concentration. Iridium was also added in some experiments in sufficient quantities to saturate the sulphides and produce Fe-Ir alloy, which was used to determine the oxygen fugacity of the experiments. Run products consisted of mantle silicate minerals and quenched sulphide melts. Chemical compositions were analyzed using the electron microprobe.

Our experiments show up to 16 mole% of FeO in the sulphide melts at relevant mantle conditions. Moreover, the oxygen content of the sulphides was found to be relatively independent of changes in fO_{2} or fS_{2}, which is in contrast with experimental studies conducted at ambient pressures. Results indicate that the oxygen concentration is primarily controlled by the FeO activity in coexisting silicate phases and the temperature.

By fitting the experimental data, we have developed a thermodynamic model using an end-member equilibrium between olivine, pyroxene and FeO in the sulphide melt. The standard state Gibbs free energy change (ΔG°) of the equilibrium is calculated using known activity composition relations for the silicates and by refining non-ideal interaction parameters for the sulphide melt in the system FeO-FeS-NiS system. The ΔG° is well determined as a function of temperature and shows no discernible dependence on pressure. The resulting relationship was used to calculate equilibrium temperatures of natural sulphide inclusions in diamonds. Using our new geo-
thermometer, previously measured oxygen concentrations in natural sulphide inclusions in diamonds from the Slave craton reveal temperatures for lithospheric diamond formation generally in the range of 1200 – 1300°C.