

FeAlO₃ phase at ultrahigh-temperature metamorphic conditions: experimental evidences from sillimanite–hematite and sillimanite–magnetite systems at 9 kbar and 1050 °C

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FeAlO₃ phase was first synthesized from sillimanite–hematite and sillimanite–magnetite systems at 9 kbar and 1050 °C under moisture condition. FeAlO₃ phase and corundum appeared with sillimanite, SiO₂-rich melt and vapour without hematite from a mixture of sillimanite and hematite (weight ratio of 95 : 5) within Pt capsule. Moreover, FeAlO₃ phase coexisted with magnetite–hercynite spinel, sillimanite, SiO₂-rich melt and vapour from sillimanite–magnetite mixture (weight ratio of 86 : 14) within AuPd capsule. These results indicate FeAlO₃ phase is stable at ultrahigh-temperature metamorphic conditions and FeAlO₃ phase could be found as a new index mineral of ultrahigh-temperature metamorphism.

1. Introduction

Previous works (Muan & Ge 1956, Muan 1958) on the Al₂O₃–Fe₂O₃ system at the atmospheric pressure in the air at temperatures 1085–1725 °C showed that (1) orthorhombic FeAlO₃ phase (space group *Pc2₁n*, isomorphous with GaFeO₃; Dayal et al 1965) is unstable below 1318 °C to decompose to corundum and hematite; (2) FeAlO₃ is stable between 1318–1380 °C as a single phase; (3) FeAlO₃ coexists with Fe–Al spinel at 1380–1410 °C; and: (4) FeAlO₃ is converted to Fe–Al spinel and Fe–corundum above 1410 °C.

Here, we would like to report the experimental evidence that FeAlO₃ phase is stable at ultrahigh-temperature metamorphic conditions, which was found in the course of the study on the Fe³⁺ solubility in sillimanite (Kawasaki 2017).

2. Experimental procedures

2.1. Starting materials

Mixtures of sillimanite and reagent-grade Fe₂O₃ (weight ratio of 95 : 5) and of sillimanite and magnetite (weight ratio of 86 : 14) were used as starting materials. Sillimanite was obtained from a ‘sillimanite-cumulated block’ within quartzite (Kawasaki et al 2011) at Rundvågshetta, East Antarctica.

Hand-picked sillimanite contains very tiny amount of micron-size apatite, biotite, diaspore, ilmenite, K-feldspar, muscovite, orthopyroxene, phlogopite, plagioclase, quartz, rutile, sapphirine, spinel, zircon as inclusion. Magnetite was megacryst (*ca* 3 cm × 5 cm) found within the K-feldspar dyke at Akarui Point, East Antarctica, containing of minor ilmenite, muscovite, rutile, spinel and zircon. Detailed petrographic descriptions of sillimanite and magnetite will be published elsewhere. The mixtures were pulverised in an agate mortar with ethyl alcohol for about one hour until the liquid is gone.

2.2. Experimental technique

Pulverised starting materials for sillimanite–hematite system and for sillimanite–magnetite system were packed into a Pt capsule and an Au₇₅Pd₂₅ capsule welded at one edge, respectively. Another edge of a capsule was sealed by welding after packing.

High pressure experiments were carried out at 9 kbar and 1050 °C for 31 h (Run nos. 171018A and 171018D) using the piston cylinder apparatus at Yamaguchi University, Japan. The furnace assembly used in the present experiments is same as that described by Kawasaki and Motoyoshi (2016).

The run products were mounted in epoxy resin and polished for analyses by a Raman spectrometer at Ehime University, Japan and electron microprobes at Ehime and Yamaguchi Universities, Japan.

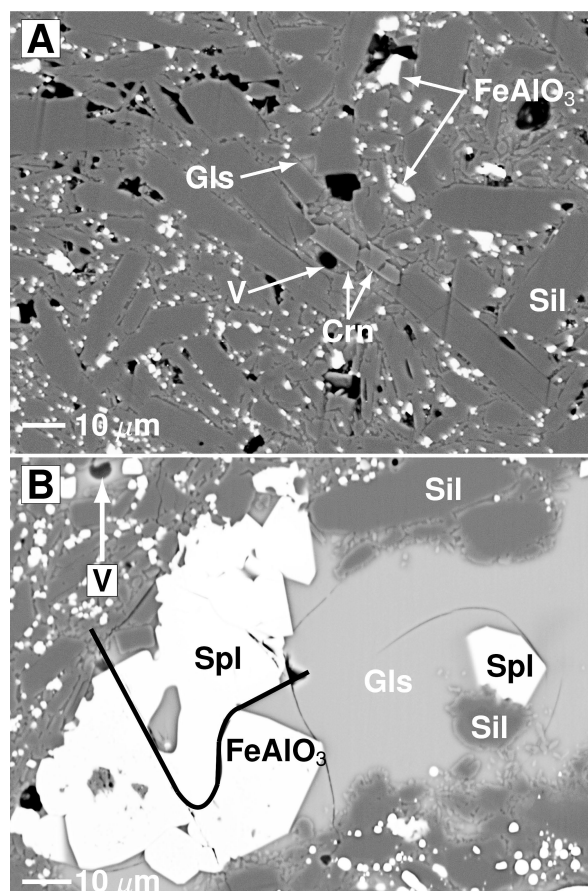
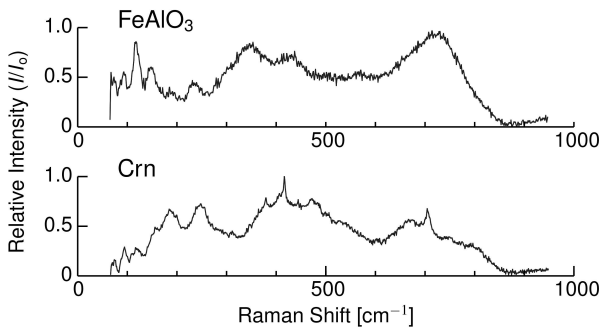


Fig. 1. Run products at 9 kbar and 1050 °C for 31 h under moisture condition. A, Sil–Hem system in Pt capsule (Run no. 171018A). B, Sil–Mag system in AuPd capsule (Run no. 171018D). Crn, corundum. FeAlO₃, FeAlO₃ phase. Gls, glass. Sil, sillimanite. Spl, spinel. V, vapour.

3. Experimental results

Figures 1 show the back-scattered electron images of run products at 9 kbar and 1950 °C. Figure 2 indicates the Raman spectrum of run products including FeAlO₃ phase, corundum and spinel. In the run products from the mixture of sillimanite and hematite (Run no. 171018A, weight ratio of 95 : 5), FeAlO₃ phase and corundum newly crystallised vanishing hematite (Fig. 1A). From sillimanite and magnetite (Run no. 171018D, weight ratio of 86 : 14), euhedral FeAlO₃ phase and magnetite–hercynite spinel are directly-contacted (Fig. 1B). In both, sillimanite is a dominant phase associated with SiO₂-rich melt (see Fig. 3) and vapour.

Sil–Hem system



Sil–Mag system

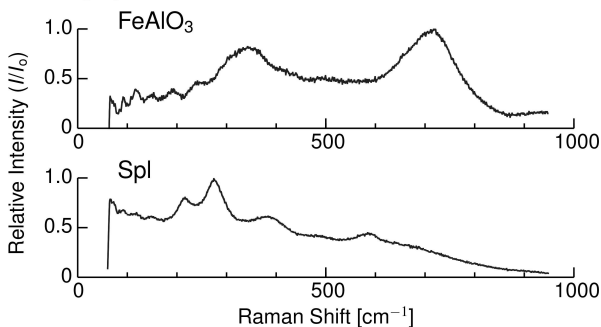


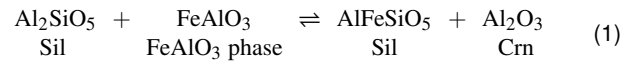
Fig. 2. Raman data of run products at 9 kbar and 1050 °C for 31 h under moisture condition in the Sil–Hem system (upper) crystallised in the Pt capsule (Run no. 171018A) and the Sil–Mag system (lower) in the AuPd capsule (Run no. 171018D). Crn, corundum. FeAlO₃, FeAlO₃ phase. Spl, spinel.

Chemical compositions of run products are plotted within the SiO₂–Al₂O₃–Fe₂O₃–FeO tetrahedron (Fig. 3). Here iron in FeAlO₃ phase, sillimanite, corundum and glass is assumed as ferric. Spinel in the sillimanite–magnetite system contains about 3 wt % TiO₂ component contaminated from inclusions ilmenite and rutile, resulting as ulvöspinel component. The ferric/ferrous ratio of iron in spinel is based on the stoichiometry. The heterogeneous glass in the sillimanite–magnetite system plots on the tie line connected sillimanite and homogeneous glasses.

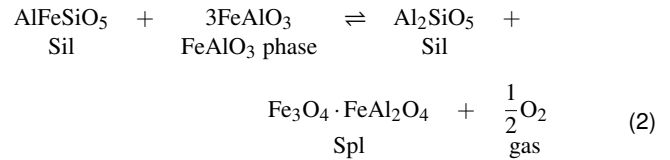
From the sillimanite–hematite system we obtained FeAlO₃ phase (0.544)^{*1} + corundum (0.023) + sillimanite (0.009) + glass (0.304) + vapour. The sillimanite–magnetite system resulted FeAlO₃ phase (0.514), magnetite–hercynite spinel (0.412), sillimanite (0.016), glass (0.230) and vapour.

4. Discussion and conclusion

Appearances of FeAlO₃ phase associating with sillimanite + corundum and sillimanite + spinel are constrained, respectively, by the following reactions:



and



Due to the experimental evidence that FeAlO₃ phase is stable at 9 kbar and 1050 °C, the volume change of Reaction (1), ΔV_1 , is positive, which means that

$$\Delta V_1 = V_{\text{AlFeSiO}_5}^{\text{Sil}} + V_{\text{Al}_2\text{O}_3}^{\text{Crn}} - (V_{\text{Al}_2\text{SiO}_5}^{\text{Sil}} + V_{\text{FeAlO}_3}^{\text{FeAlO}_3 \text{ phase}}) > 0 \quad (3)$$

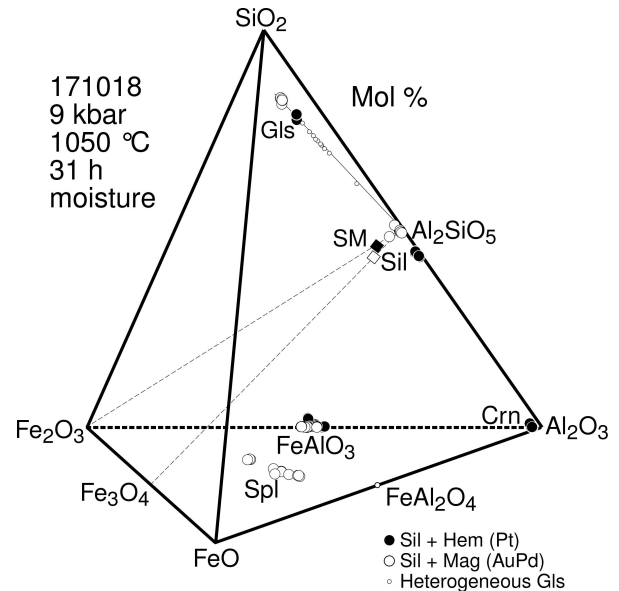


Fig. 3. SiO₂–Fe₂O₃–FeO–Al₂O₃ plot of chemical composition of run products recrystallised within Pt and AuPd capsules at 9 kbar and 1050 °C for 31 h under moisture condition. Black symbols, run products from a mixture of Sil + Hem in Pt capsule. White symbols, run products from a mixture of Sil + Mag in AuPd capsule. Small white circles, heterogeneous glass in Sil–Mag system. Crn, corundum. Gls, glass. Sil, sillimanite. SM, starting material. Spl, spinel.

This indicates FeAlO₃ is a stable phase at ultrahigh-temperature metamorphic conditions and FeAlO₃ phase could be found as a new index mineral of ultrahigh-temperature metamorphism.

5. References

- Dreval Zienert Fabrichnaya 2016 J Alloy Comp 657 192–214
- Feenstra Sämann Wunder 2005 J Pet 1881–1892
- Kawasaki T 2017 8th Symp Polar Sci OGP5
- Kawasaki Motoyoshi 2016 J Mine Pet Sci 111 226–240
- Kawasaki Nakano Osanai 2011 Gond Res 19 430–445
- Muan 1958 Am J Sci 256 413–422
- Muan Gee 1956 J Am Ceramic Soc 39 207–214

^{*1} Figure in parenthesis indicates as $X_{\text{Fe}} = \text{Fe}^{3+} / (\text{Fe}^{3+} + \text{Al}^{3+})$