Comparison of AlB_{12} synthesis process

The comparative performance of the proposed vacuum aluminothermic reduction process against traditional and recent AlB_{12} synthesis routes is summarized in Table 1. Unlike the high-temperature halide salt method or the prohibitively expensive powder metallurgy route, the current methodology utilizes a low-cost $NaBF_4$ and operates at a significantly reduced temperature of 1100 ℃. The core advantage lies in the integration of vacuum distillation, which exploits vapor pressure differentials to achieve in-situ purification. This synergy allows for a superior boron recovery rate of approximately 90% and an exceptional purity level (Na < 0.03 wt. %), while simultaneously addressing the issues of oxygen contamination and compositional instability prevalent in SHS.

Table 1 Comparison of AlB_{12} synthesis process

Process/Feature	Traditional Halide Salt Process	Powder Metallurgy	SHS	This Work
Raw material	KBF_4	High-purity B powder	B_2O_3	$NaBF_4$
Process Type	Molten salt reaction	Solid-state sintering	Exothermic combustion	Vacuum reduction-distillation
Reaction Temperature	>1200 ℃	>1300 ℃	>2000 ℃	1050~1200 ℃
Boron Recovery	Low (<60%)	High	Fluctuating	High (~90%)
Issues	High raw material cost	High raw material cost	Oxygen contamination	Vacuum maintenance

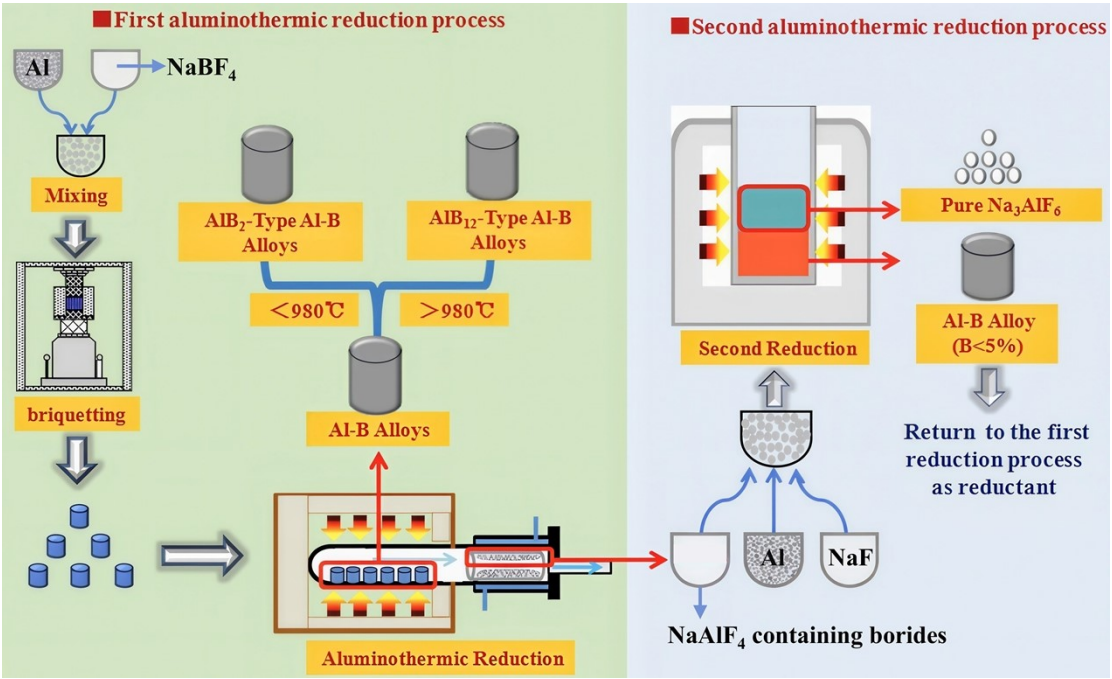

Fig. S1 Overview of the two-step vacuum aluminothermic reduction process to produce Al-B alloy

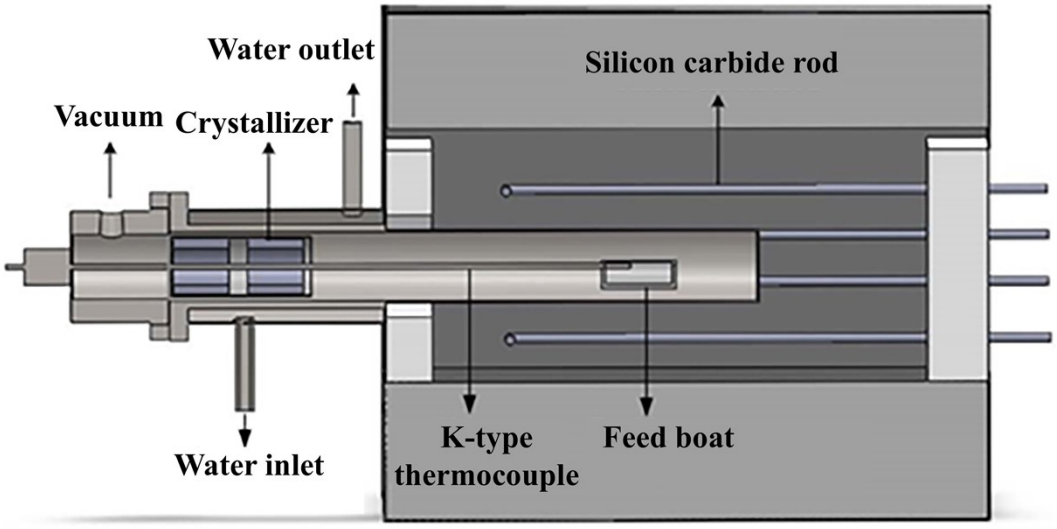

Fig. S2 Schematic diagram of the vacuum reduction equipment.