Although these growth methods are still in the development stage and it is difficult to grow high-quality single crystals, future progress is expected because they enable efficient material research that cannot be achieved by the conventional growth methods.

1.2.3.11 Heat-Exchange Method

The heat-exchange method (HEM) has been developed for crystal growth of sapphire and spinel-type $MgAl_2O_4$ single crystals as a gradient furnace technique [104–106]. Large bulk single crystal can be grown by the HEM using a large crucible, although the crystallinity is lower than crystals grown by the Cz and BS methods. As shown in Figure 1.41, crystal growth is performed from the interface between melt and seed crystal by gradual cooling after the starting materials and portion of the seed crystal are melted by the heating. The heat exchanger causes the seed and grown single crystal to be slightly lower in temperature than the melt, so that the crystal growth proceeds while extracting heat from them. However, it is difficult to control shape and moving speed of the solid–liquid interface during the crystal growth, and as a result, the grown single crystal tends to contain vacancies and defects.

Figure 1.42 shows the crystal growth method of fluoride and halide single crystals using the HEM. Initially, a single crystal fiber is pulled down from the capillary at the bottom of the crucible using a seed crystal and wire as in the general μ-PD method. After confirming that the single crystal fiber without cracks has been pulled down, stop pulling down the single crystal fiber. Then, the heating of the crucible is gradually lowered to the grown bulk single crystal inside the crucible from the grown single crystal fiber at the bottom of the crucible. In this method, the grown single crystal fiber serves as the heat exchanger and seed crystal.

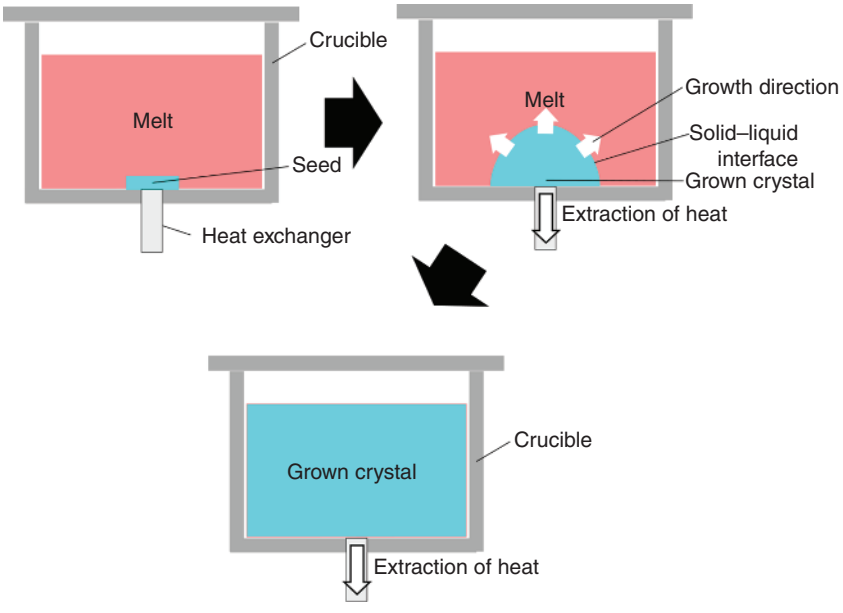

Figure 1.41 Schematic diagram of heat-exchange method.

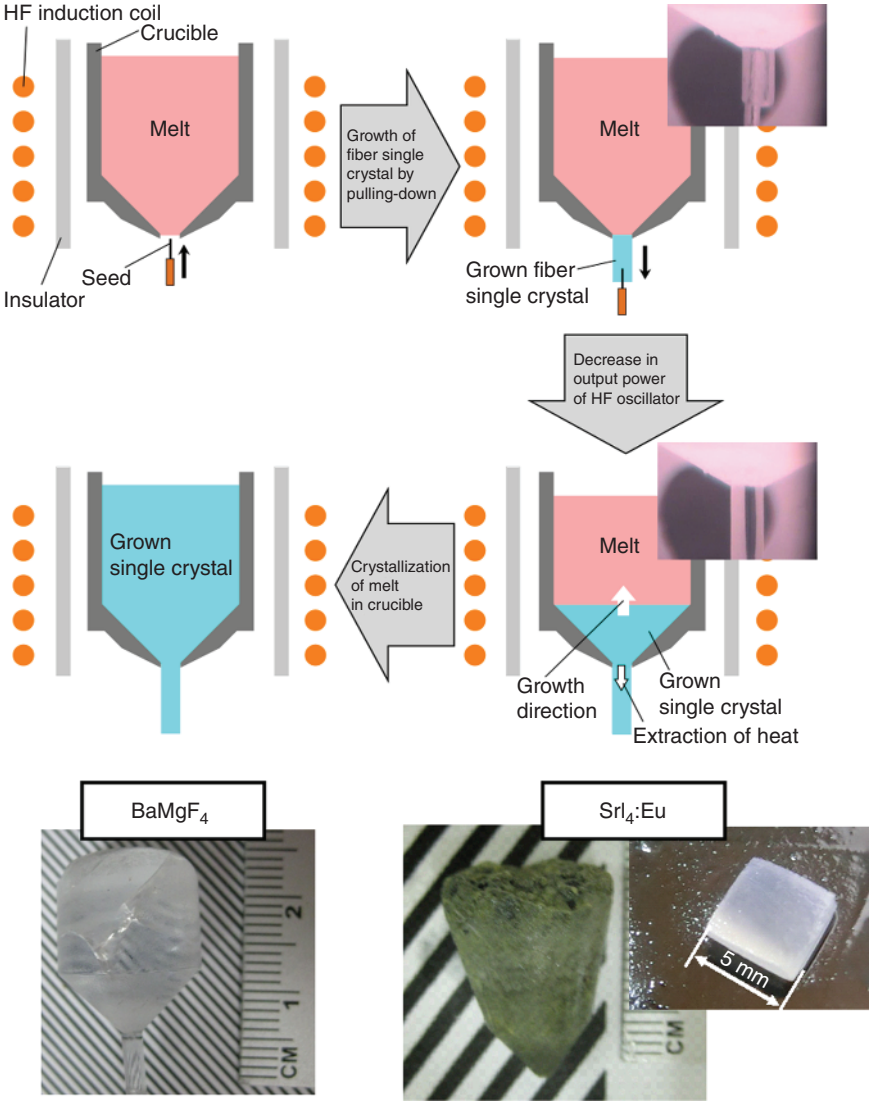

Figure 1.42 Schematic diagram of crystal growth method integrating μ-PD method and HEM, and $BaMgF_4$ and SrI_2:Eu single crystal grown by the method.

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