# SOLIDIFICATION PROCESS OF α(Al)-$Mg_2Ge$ PSEUDOBINARY EUTECTIC ALLOYS①

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**ABSTRACT** Solidification process of α(Al)-$Mg_2Ge$ pseudobinary eutectic alloys in Al-Mg-Ge system has been studied by directional solidification and electron microscopy techniques. It was demonstrated that the morphology of the primary crystal of phase $Mg_2Ge$ is octahedron enclosed with {111} planes and $Mg_2Ge$ is the favored nucleating phase during eutectic solidification of this alloy. The branching process during solidification fits the mechanism of branching in the preferred growth direction. First, the primary branching occurs in the [110] direction of the primary crystal of $Mg_2Ge$, and then the second branching appears in the [110] direction of the primary branch. It progresses in this way till stable growth.

**Key words** eutectic solidification mechanism branching preferred growth direction nucleation

## 1 INTRODUCTION

The eutectic solidification occurs by a nucleation and growth process in common with other solidification processes. Growth process of the eutectic grain during solidification mainly displays branching, and the characteristics of branching directly influence the morphologies of the eutectic phases and the property of the materials, which has made the study on the branching characteristics of the eutectic phases an important aspect in the research field of eutectic composite materials[1-3].

In recent years, work in this direction has been carried out widely by electron microscopy. The eutectic branching is normally believed to be by the defects mechanism[4-6], i. e. branching occurs on the defects such as twins and dislocations. This opinion is inconvincible because the probability of obtaining the specimen for transmission electron microscopy with branching face of the strengthening phase is minimum. In a study on binary Al-Si eutectic, Li *et al*[7] presented the preferred growth mechanism of the eutectic solidification. In this paper, we verified its accuracy in the solidification process of α(Al)-$Mg_2Ge$ pseudobinary eutectic.

## 2 EXPERIMENTAL

Alloy ingots were prepared by melting pure Al, Mg and Si with purity above 99.99% in a resistance furnace under protection of molten LiCl. Directional solidification was performed by an electron-beam zone melting technique using a ring electron gun as heater working in a vacuum of ~ $10^{-3}$ Pa with the specimen remaining still, which has a narrow melting region and a rather constant temperature gradient. Specimens for directional solidification were placed in a graphite tube with an inner dimension of $d$ 8 mm × 110 mm and were naturally cooled. Temperature gradient ahead of the solid-liquid interface in the melt was measured to be $6.3 \times 10^{-3}$ ℃/μm.

Investigation on the microstructures was carried out on Neophot-21 optical microscope and S-4200 scanning electron microscope, and Hitachi-700 transmission electron microscope was used to analyse orientation of the phases.

## 3 RESULTS AND DISCUSSION

### 3.1 Nucleation

Fig. 1 illustrates the morphology of the primary crystal of phase $Mg_2Ge$ in the α(Al)-

① Received Mar. 21, 1997; accepted Jun. 26, 1997

$Mg_2Ge$ hyper-eutectic alloy, which is an octahedron enclosed with {111} planes, and we can primarily decide that the preferred growth direction may be [100] or [110] at this time[8]. From the regularity of the morphology of the primary $Mg_2Ge$ crystals, it can be concluded that $Mg_2Ge$ is the leading nucleation phase in the α(Al)-$Mg_2Ge$ eutectic. If α(Al) nucleates preferentially and $Mg_2Ge$ nucleates on the basis of phase α(Al), it is impossible to observe the primary crystals of $Mg_2Ge$ with a regular morphology.

### 3.2 Branching

After the nucleation of the eutectic solidification completes, coupled growth and branching occur immediately. Fig. 2 shows the structures on the transversal and longitudinal sections of α(Al)-$Mg_2Ge$ eutectic after directional solidification at a rate of $1.1 \times 10^{-2}$ mm/s (Figs. 2(a), (b)), and the orientation analysis result of phase $Mg_2Ge$ by transmission electron microscope (Fig. 2(c)).

It can be seen from Fig. 2 that the preferred growth direction of $Mg_2Ge$ is [110], which is corresponding to the morphology of its primary crystal. Besides, the symmetry of the aligned $Mg_2Ge$ fibre is equal to that of the crystal structure in the preferred growth direction. This phe-

**Fig. 1 Morphology of primary crystal of $Mg_2Ge$ in α(Al)-$Mg_2Ge$ hypereutectic alloy**

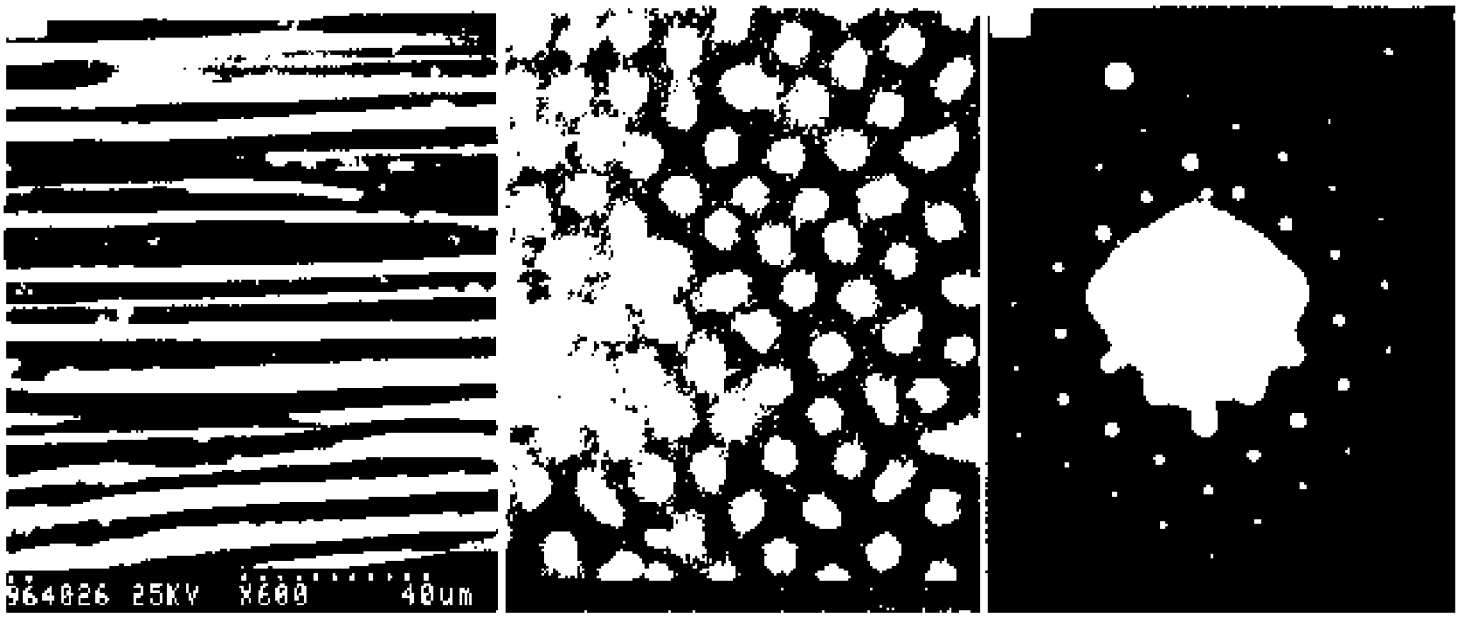


**Fig. 2 Structures of directionally solidified α(Al)– $Mg_2Ge$ eutectic and orientation analysis**

(a) —On transversal section; (b) —On longitudinal section;
(c) —Orientation analysis of eutectic phase $Mg_2Ge$

nomenon is just the result of branching of $Mg_2Ge$ in the preferred growth direction. This process can be explicated as follows (Fig. 3).

After the nucleation of $Mg_2Ge$ completes, the eutectic $Mg_2Ge$ will start to grow. Because the edge of the octahedron is the most facile point for losing of heat, this is the place where eutectic $Mg_2Ge$ will form preferentially. As $Mg_2Ge$ grows, the coupled growth of α(Al) occurs simultaneously. The request of coupled growth with α(Al) will result in the primary branching of eutectic $Mg_2Ge$ in the direction of [110], and then the second branching appears in the [110] direction of the primary branch. It progresses in this way till stable growth. During the stable growth of the directional solidification, the fibre of the eutectic $Mg_2Ge$ usually comes from one (or several limited) primary

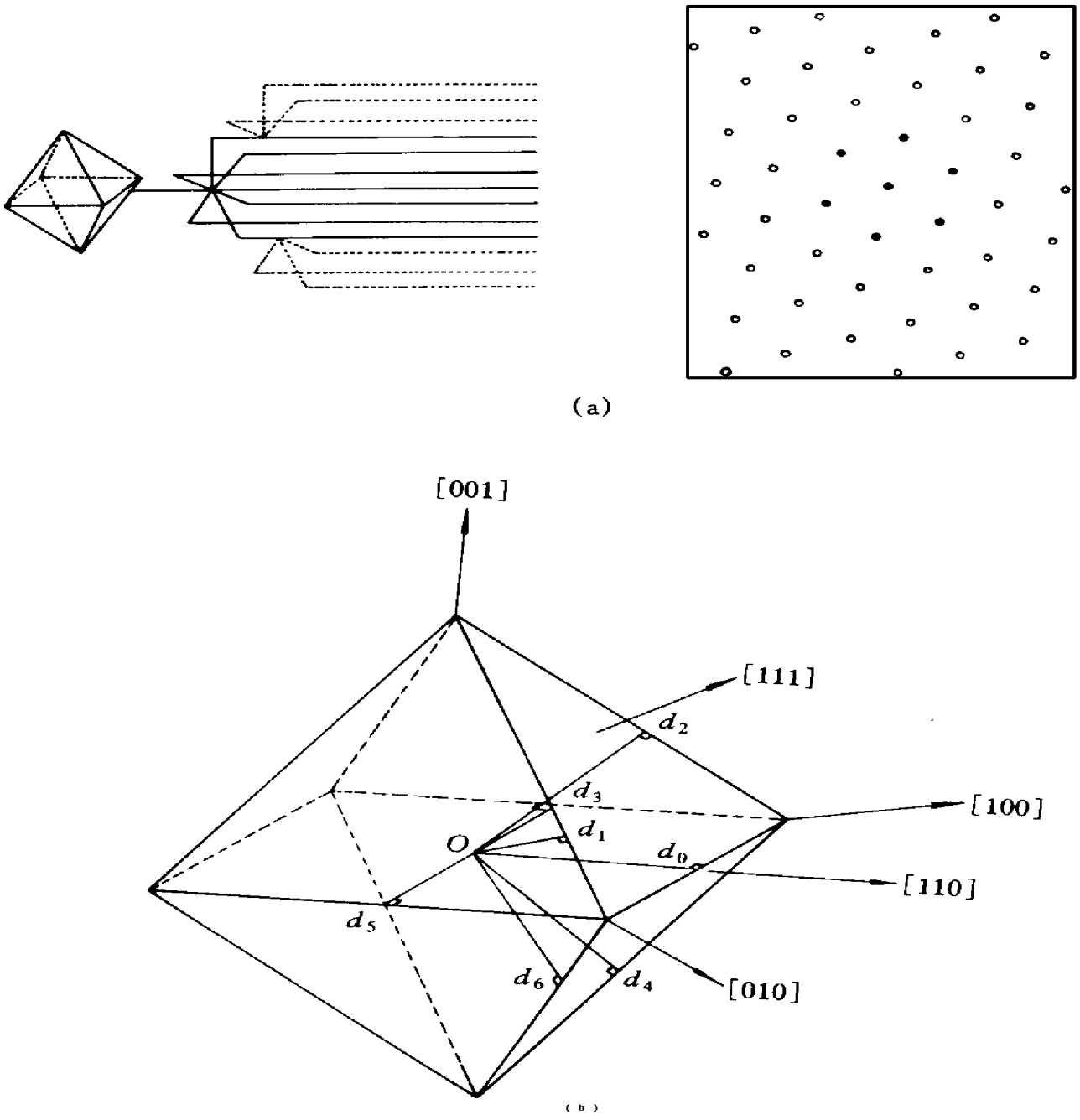


**Fig. 3 Schematic drawing of branching of eutectic phase $Mg_2Ge$**

(a) —Model of mechanism of branching in preferred growth direction;

(b) —Crystallographic directions of branches when directionally growing in [110] direction

crystal and so the structure on the transverse cross section ought to have a pattern of twofold symmetry corresponding to the symmetry of the crystal structure in the [110] direction.

The octahedron in Fig. 3(b) could help us in understanding the branching mechanism in [110]. If the primary branch [110] presents in $d_0$ direction, the [110] orientation of the second branches appear on the basis of this primary branch will have six directions, $d_1 \sim d_6$, which will go on branching by this mechanism. Certainly, only the branches close to $d_0$ direction could grow as a result of directional solidification. If the branching of the eutectic is by the defect mechanism, the arrangement of $Mg_2Ge$ should be chaotic.

## 4 CONCLUSIONS

During the eutectic solidification of α(Al)-$Mg_2Ge$, $Mg_2Ge$ is the favored nucleating phase and the preferred growth direction is [110]. During the eutectic growth in this alloy system, branching of phase $Mg_2Ge$ progresses by the mechanism of branching in the preferred growth direction.

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**(Edited by Peng Chaoqun)**