Effect of heat shield on the heating efficiency in MOCVD chamber by resistive heating

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Abstract. In the conventional resistive heating systems, the heating efficiency of the resistance heating system is too low. In this work, by adding heat shield in the traditional heating structure. The effects of factors such as the number of layers, spacing and thickness of the heat shields on the heating efficiency of the heating system with a diameter of 12 inches are investigated. The results show that the heat shields significantly improve the heating efficiency compared to the heating systems without heat shields. When the number of layers of the heat shields is 3, the efficiency of the heating system is increased by about 26%.

1. Introduction

With the technological maturity of semiconductor devices and their wide application in various aspects, people pay more and more attention to the quality of semiconductor crystal materials [1-5]. Metal organic chemical gas phase epitaxy (MOCVD) is one of the important technologies for the preparation of nitride semiconductor materials [6-8]. In MOCVD devices, the reaction chamber is required to provide suitable temperature for the film growth and the temperature variation range is small throughout the growth process. Therefore, the design of the reaction chamber, especially the design of the heating system, will directly affect the quality of the crystal film [9]. The domestic and foreign researchers expect to design a superior reaction chamber to meet the growth requirements of crystal films.

References[10-12] shows that the position of the electromagnetic coil and the related electrical parameters is change in the simulation experiment. The article analyses the rule of radial temperature change on the surface of graphite disc, optimizes the structure of reaction chamber and improves the heating efficiency. In reference [13], the MOCVD reaction chamber model was heated by resistance wire, and it was found that the average temperature of graphite base changed linearly with the vertical distance from heater to base, and the heating structure was optimized. Literature [14] proposed two design schemes, array control heater and non-uniform resistance module, which were used to regulate the temperature distribution in the reactor, and both achieved fine adjustment of the temperature distribution in the reactor.
In conventional resistive heating systems, the heating efficiency of the resistance heating system is low. In this paper, heat shields under the susceptor are placed. And the influence of factors such as the number of layers, spacing and thickness of the heat shields on the heating efficiency of the heating system with a substrate whose diameter is 12 inches are investigated. The purpose is to improve the heating efficiency of the heating system and to provide theoretical and technical references for the development of large-sized MOCVD reactor.

2. Model of MOCVD reactor

MOCVD epitaxial growth mechanism is complex, and the heating efficiency is influenced by many parameters, such as the heating parameters, the structure and the gas flow. The finite element method is usually used to establish the mathematical model, and the heat conduction model is coupled with the fluid model. In this work, the fluid and heat conduction equations are referred to manuals of the COMSOL multiphysics.

Heat conduction equation:

$$\rho C_p \frac{dT}{dt} + \nabla \cdot (-k \nabla T) = Q - \rho \nabla \cdot \bar{u}$$

Fluid equation:

$$\frac{\partial \bar{u}}{\partial t} - \nabla \left[ \eta (\bar{v} + \bar{v}^T) \right] + \rho \bar{v} \nabla \bar{v} + \nabla p = 0$$

Where $\rho$ is density, $C_p$ is specific heat, $T$ is temperature, $k$ is material thermal conductivity, $Q$ is resistance heating, $\bar{u}$ is gas velocity, $\eta$ is gas viscosity coefficient, and $p$ is pressure. In order to improve the calculation speed in the simulation experiment, the following assumptions are made for the model without affecting the main simulation results [15].

1. regardless of the rotation of the susceptor;
2. chemical reactions between gases are ignored;
3. assume that the gas is in an ideal state;
4. the wall temperature is constant;
5. the thermal expansion of the materials of the various materials is not considered.

The MOCVD reactor to be modeled is shown in Figure 1. The reaction chamber is axisymmetric, which including the chamber walls, the inlet and outlet, heating resistances, the substrate and the heat shields. The material of the susceptor is silicon graphite, and the material of the heating resistances and the heat shields are tungsten and molybdenum, respectively. The susceptor height is 25.4mm, the radius of the substrate is 152.6mm. The power densities of the heating resistors from left to right are 7.5E+007, 7.5E+007, 7.5E+007, 8E+007, 9E+007, 1E+008, 1E+008, 1.2E+008, respectively. The length of the heat shields are all the same value-- 148.7 mm and the thickness of each shield is 2 mm. The spacing between the shields is 2 mm.
The gases in the reactor include, H2 (carrier gas) NH3 (N source) and TMGa (Ga source), which
are mixed into the reaction chamber from the inlet. The flow rates of H2, NH3 and TMGa are 40slm,
10slm and 10sccm, respectively, which remain unchanged in the simulation. In addition, the boundary
condition of the wall temperature is set to be 27℃.

3. Results and analysis

3.1. Effect of the thickness of the shield on heating efficiency
In order to reduce the heat loss caused by the thermal radiation, a layer of heat shield is added under
the resistances in the heating system. Under the condition that the length of the shield is kept constant,
and the thickness of the heat shield is gradually increased, the effect of heat shield on the heating
efficiency is analyzed.

Figure.2 Temperature distributions of two susceptor: new susceptor (a) and conventional susceptor (b)

Figure.2 shows the temperature distribution contours of the susceptor with one heat shield (a) and
the traditional susceptor (b). It can be seen from the figure that the temperature distribution in the
susceptor is basically the same, and the high temperature region is mainly focusing on the lower part
of the base, the temperature at the edge of the base is relatively low. Due to the radiation effect of the
heat shield, the temperature of the base substrate including the edge portion is greatly increased as a
whole. Which means that the increase of the heat shield can improve the heating efficiency of the
heating system and improve the uniformity of the temperature field in the reaction chamber.

Figure.3 Temperature distributions of substrate in the heating structure with different thicknesses of
heat shield and without shield

Figure.3 shows the temperature distributions of substrate in the heating structure with different
thicknesses of the heat shield and without the heat shield. It is found that the average temperature of
the substrate in the structure without the shield is 960℃, while the average temperatures of the
substrate are 1134℃, 1095℃, 1093℃ and 1091℃, under the conditions of the thicknesses of the shield
are 2 mm, 4mm, 6mm and 8mm, respectively, which shows that the heating efficiency of the structure
with the shield is higher than that without the shield. In addition, as the thickness of the heat shield
increases, the heating efficiency is slightly reduced. The combination is the actual situation, the thickness of the heat shield to take 2mm is more appropriate.

### 3.2 Effect of the number of heat shield layers on heating efficiency

On the basis of the above calculation, the thickness of the heat shield is kept at 2 mm and the spacing is 2 mm. The number of layers of the heat shields is gradually increased, and the influence of the number of shield layers on the substrate temperature is investigated.

![Temperature distributions of substrate in heating structure with different layered shields](image)

Figure 4 Temperature distributions of substrate in heating structure with different layered shields

Figure 4 shows the temperature distributions of the substrate under the conditions of the heating structure with different layered shields. It can be seen that the substrate temperature is directly proportional to the number of shield layers. Meanwhile, with increasing of the number of shield layers, the substrate temperature decreases. When the number of heat shield layers is changed from 1 to 4, the average temperatures of the substrate are 1134℃, 1175℃, 1196℃ and 1208℃, respectively, which means that the heating efficiency is increased by 18%, 22%, 25% and 26%, respectively. Taking the changes of the substrate temperatures with the shield layers and the growth temperature into account, three-layered shields can meet the actual need of film growth.

### 3.3 Effect of heat shield spacing on heating efficiency

The thickness of the each shield is kept at 2 mm, and the number of the shield layers is 3. The influence of the spacing of the shields on the temperature is studied.

![Temperature distributions of substrate in heating structure with different spacings of heat shields](image)

Figure 5 Temperature distributions of substrate in heating structure with different spacings of heat shields

Figure 5 shows the temperature distributions of substrate in the heating structure with different spacings of heat shields. It is found that the changes of the substrate temperature are not obvious with the increase of the heat shield spacings, which indicates that the heat shield spacings have less influence on the substrate temperature and heating efficiency.
4. Conclusions
In the MOCVD chamber, the resistance heating system without the heat shields has low heating efficiency, because that part of the heat generated by the heating resistance is taken away by the gas flow and the radiation in the reactor. In order to improve the heating efficiency of the heating system, the heat shields are placed under the resistances in the MOCVD reactor to improve the heating efficiency. By studying the influence of the thicknesses, the number of shield layers and the spacings of each shield layer on the substrate temperature, it is found that the shields significantly improves the heating efficiency compared with the system without shields. And the number of layers is directly proportional to the heating efficiency, but the thicknesses and spacings of the shields have little effect on the heating efficiency. The calculation results show that the heat shield can meet the heating requirement when the layer number is 3.

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