Finite Element Analysis of Temperature Field of Electromagnetic Heating in Nitride MOCVD Reaction Chamber

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Abstract. In this paper, the distribution of temperature field in the reaction chamber of metal organic chemical vapor deposition (MOCVD) used for growing GaN material was simulated by finite element method. The induction heating conditions that affect the temperature distribution are analyzed, such as current frequency, current intensity, coil turns, coil spacing and the height of the base. And their influence on the temperature distribution of the substrate and their relationship with the substrate temperature are also given. The optimal design parameters of current intensity, current frequency, coil spacing, coil turns and base height are obtained by simulation.

1. Introduction

GaN material is a wide band gap semiconductor material with excellent properties [1,2]. The organic compounds of Group III and Group II and the hydrides of V and VI are used in MOCVD method as the source of growth and the gas phase epitaxy is carried out on the substrate in a thermal decomposition reaction. And then the III-V, II-VI compound semiconductors and their multiple solid solution thin single layer [3] have been obtained. It is a kind of new gas-phase epitaxial growth technology developed by gas-phase epitaxy. In order to obtain the reaction required temperature, resistance heating or induction heating are often used in MOCVD reaction chamber. Resistance heating is susceptible to pollution, the base design is complex and the life of resistance wire is short, while induction heating heat loss is low, the working environment is clean, and the use of wireless method to introduce the current will not affect the rotation and revolution of the base. And the induction heating power is in line with the requirements of high growth temperature and fast heating rate of GaN materials, so induction heating is a more excellent choice. However among the commonly used induction heating vertical MOCVD, the coil is wound outside the wall of the reaction chamber [4,5], and the temperature distribution of the base and the substrate surface is very uneven due to the presence of the skin effect. At present, there is little research on this aspect at home and abroad [6,7]. In this paper, we mainly analyze the factors influencing the induction heating effect in the single-piece MOCVD reaction chamber with vertical induction heating, and simulate their relationship with the temperature, and give the temperature distribution.
2. MOCVD reaction chamber structure and the structure modal of finite element analysis

A vertical MOCVD reaction chamber structure is shown in Figure 1. (a). It can be seen from the figure that the finite element analysis model of electromagnetic field is mainly composed of graphite base, sapphire substrate, reaction chamber wall, upper and lower flange and coil, and so on, so a two-dimensional axis center symmetric finite element model is adopted. In order to reduce the impact of skin effects, a hierarchical grid is used. The value of the internal mesh thickness factor is 6, and the value of the graphite base skin depth must be 5 or 6. The outer sublayer thickness transition factor is 2, so that when the unit is perpendicular to the line direction, the unit size is increased by about half. The unit type is PLANE13 and the axisymmetric characteristic is specified. Figure 1.(b) is the meshing of the axisymmetric model. After the establishment of the two-dimensional axisymmetric model, the boundary temperature is set to 25°C and coupling method is adopted. The electromagnetic field is analyzed by defining the material region, setting the material phase, meshing and applying boundary conditions and loads in order to obtain the temperature field distribution of the graphite base and the substrate. The thermal conduction and the thermal radiation of graphite and the heat exchange process between the indoor gas and the water in the double quartz tube must be taken into account.

3. Results and discussion

3.1. Influence of current intensity

The curve of current intensity versus substrate temperature is shown in Figure 2.(a). It can be seen that the substrate temperature is proportional to the current intensity. Figure 2.(b) shows the corresponding three kinds of digital features: average value, range, standard deviation. It is not difficult to find that the substrate temperature mean, the difference and the standard deviation are also proportional to the current intensity, indicating that with the increase of current intensity, the substrate temperature distribution is more uneven. The temperature at the left and right edges of the curve increasing abruptly is due to the fact that the substrate is placed in the groove of the upper surface of the base, and the lower side of the substrate edge and the adjacent base groove side are heat-transferred to the substrate edge[8].
3.2. Influence of current frequency

The curve of current frequency versus substrate temperature is shown in Figure 3 (a). It can be seen that the size of the substrate is proportional to the current frequency. Figure 3(b) gives the corresponding three digital features. Through the curve we can easily find the substrate temperature mean, the difference and the standard deviation is proportional to the current frequency, which shows that with the current frequency increases, the heating efficiency is also increased. But the substrate temperature distribution is more uneven due to skin effect. The depth of the induced current is inversely proportional to the frequency of the applied excitation current. The greater the frequency of the external excitation current is, the more obvious the depth of the induced current in the base is, and it is mainly distributed in the double skin depth. So the heat generated is mainly distributed in the vicinity of the side of the base. But the heat generated by the induction inside the base is relatively small, so the temperature near the edge of the substrate is high while that in the center is low. Comparing the above results, the current frequency of 30KHz can guarantee heating requirements.

3.3. Influence of the number of turns

The influence of the number of turns is shown in Figure 4. (a). Three corresponding digital features are shown in Figure 4. (b). The graph shows that the more turns of the coil, the higher the temperature of the substrate. And the uniformity decreases as the number of turns increases. In addition, when the coil turns take 4 to 5 turns and 6 to 7 turns, the substrate temperature changes greatly. Therefore, in determining the number of turns of the coil, it is necessary to compromise the actual temperature
requirements and temperature distribution uniformity. From the simulation results, we can see that 6 turns of the coil are optimized design parameters.

![Graph](image)

**Figure 4.** Curve of the number of turns of the coil and the temperature of the substrate
(a) the original curve  (b) the numerical characteristics

### 3.4. Influence of coil spacing

The dependence of the coil pitch on the substrate temperature is shown in Figure 5.(a). Figure 5.(b) shows the three corresponding digital features. It can be seen from the figure, both the substrate temperature and the distribution uniformity decrease as the coil pitch increases. But the change is small, indicating that the coil spacing on the substrate temperature uniformity is less affected. Consider the actual situation, the coil spacing to take 0.5r are optimized design parameters.

![Graph](image)

**Figure 5.** Dependence of the coil pitch on the substrate temperature
(a) the original curve  (b) the digital characteristics

### 3.5. Influence of Base Height

The effect of base height on substrate temperature is shown in Figure 6. (a). Figure 6.(b) gives the corresponding digital features. It is not difficult to find that as the height of the base increases, the standard deviation of the substrate temperature decreases, that is to say, there is a proportional relationship between the temperature uniformity of the substrate and the height of the base and the temperature standard from 20.92°C down to 9.89°C. But with the height of the base increases, the average temperature of the substrate first rises and then drops. When the base height is 1.50h, the average temperature of the substrate is the largest and the value is 921.90 °C. Comprehensive above all kinds of circumstances, the base height should be taken as 1.50h.
4. Conclusion

In this paper, we found that the substrate temperature is proportional to the excitation current frequency, current intensity and coil turns by simulating the distribution of temperature field in the reaction chamber of MOCVD equipment, but the temperature uniformity is inversely proportional to them. The substrate temperature and the distribution uniformity are inversely proportional to the coil spacing, but the change is not significant. As the height of the base increases, the substrate temperature increases first and then decreases, and the temperature uniformity increases as the height of the base increases. Therefore, the temperature of the substrate and its distribution can be changed by changing the current frequency, coil turns, base height and other parameters to control. From the simulation results, it can be seen that the current frequency of 30KHz, the current intensity of 300A, the coil turns of 6, the coil spacing of 0.175mm and the base height of 38.1mm are the required optimization parameters. At this time it can not only meet the needs of heating, but also allow the substrate temperature evenly distributed. These parameters are very important for the design of the MOCVD device and can provide effective auxiliary means when we debug the MOCVD equipment or set the operating parameters. But under these conditions, the substrate temperature distribution is still uneven and needs to be further optimized.

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