論 文 の 内 容 の 要 旨

論文題目 Process development of selective area MOVPE for Opto-Electronic Integrated Circuits based on InGaAsP
(InGaAsP 系光集積回路用 MOVPE 選択成長プロセスの開発)

氏 名 王 云 鵬

Focusing on the monolithic integration of OEICs, selective area growth (SAG) achieved by metal organic vapor phase epitaxy (MOVPE) is one of the most important monolithic integration methods. With photolithography and etching techniques, dielectric mask can be formed on the substrate. In SAG-MOVPE, because there will be no-consumption of precursors on dielectric mask, concentration gradient of precursor in gas phase would occur between mask and intact region on the substrate. Then the precursor gradient would induce extra gas phase diffusion, which results in growth rate enhancement in selective area (SA). One of the features of SAG is that by deliberately designing the mask pattern and key parameters, growth rate and elemental composition can be controlled in each SA regions. In fact, SAG combined with MOVPE technique has been well applied in fabricating OEICs and it gains tremendous advantages over other alternative ways.

For SAG-MOVPE technique, the challenge is how to precisely construct more complex device structures on the even narrow area. MOVPE is a quite complicated process, it consists of many important steps such as gas phase decomposition of precursor, their diffusion to the surface, adsorption, desorption, diffusion on surface, and surface reactions to form epi-layer. Though various mechanisms have been suggested to explain the MOVPE process, due to complicated transfer of heat and mass and chemical reactions both in the gas phase and on the surface, many details still remain unclear, especially the growing process taking place on the surface of epi-layer. Thus, till now the design of SAG process is only based on empirical optimization procedures. Such trial and error procedure could be effective for rather simple circuits, but not a suitable solution of densely integrated circuits for enormous time and resources expense. Moreover, it fails to predict the growth rate and composition when interference phenomenon occurs between neighbor masks for highly compact OEICs.

Consequently, we try to set up a systematic and reliable method to predict the growth behavior in SAG-MOVPE and to assist the design of integration process. For this target, it becomes quite necessary to acquire surface kinetics by understanding the mechanism of epitaxial process. In my study, SAG is not only used as an integrating method, but an important tool for kinetic analysis

of MOVPE as well. With this analysis process, we are going to build up a kinetic database which includes surface reaction rate constants (k_s) of elemental binary compound such as InP and GaAs to much complicated quaternary compound, InGaAsP. The purpose of this research is to optimize the mask designing and process designing for OEICs integration on basis of some key kinetic parameters in SAG process and to control macro scale growth behavior such as growth rate and composition distribution in device structure.

Due to the complicity of InGaAsP material system, this research started from the binary material, and same kinetic analysis was applied for ternary material. In this research, relation of surface kinetics between simple material and complicate material system has been clarified and mechanism was proposed on base of kinetic data from these investigations and some previous work. With kinetic model and perspective on InGaAsP growth, emission wavelength in SAG was predicted based on elemental composition and thickness distribution control. In the last part of this work, some issues in the design of SAG process has been discussed with my established kinetic database, which cover poly-crystal free growth, mask interference in compact pattern and abrupt growth in edge of mask.

From this research, some important surface kinetics has been revealed and useful suggestions can be concluded for SAG based integration of OEICs in MOVPE. The important features are summarized as below.

1. Investigation exhibits that gas phase diffusion model can well explain surface phenomena in MOVPE, and it can be applied in collecting kinetic information in MOVPE process. With SAG technique, surface kinetic which is hindered in mass transfer limited regime can be successfully extracted by numerical simulation and experimental data fitting. Results show that in MOVPE process, surface reaction rate constant present a dominant role in determine growth behavior in the selective area and the relative investigation of this parameter would be valuable to process design of fabrication for OEICs.
2. Kinetic analysis had been successfully made for InGaAsP material system, kinetic database of surface reaction rate constant (k_s) has been built up for better understanding on MOVPE and for achieving accurate process design of SAG. My investigations indicate that ks have temperature and concentration dependency. Generally, k_s would increase with increasing temperature. Under practical growth conditions, it indicates indium species in MOVPE has rather moderate temperature dependence and is not as sensitive as ks of GaAs whose activation energy is about 84.1 kJ between 475 °C to 610 °C. Additionally, gallium and indium species shows quite different surface kinetics. Compared with InAs and InP, the data indicate values of k_s for both InP and InAs are significantly larger than that of ks for GaAs. Their value of k_s is two or three times of the value of gallium species in MOVPE. As for indium related binary compounds, k_s

value of InP growth is always larger than that of InAs. All these kinetic information suggest that group-V elements have significant influence on the value of ks for III-V binary compound. These results show group- III species have quite different reactivity on phosphorus and arsenic site which could be a fundament for kinetic analysis of ternary and quaternary compounds, such as InAsP and InGaAsP.

3. In this study, non-linear phenomena which depend on mask width and partial pressure of precursors were observed in kinetic analysis for both indium and gallium related materials. And all evidences proved that it is essential to consider concentration dependency due to over saturated adsorption of species on surface. Then non-linear simulation based on Langmuir-Hinshelwood model was introduced into kinetic analysis procedure to explain mask dependency and partial pressure dependency of precursor on surface reaction rate constant. Results showed non-linear kinetic analysis had been well applied in understanding these non-linear phenomena. It revealed that adsorption-desorption process should not be neglected in MOVPE at low temperature or high concentration. Combining nonlinear analysis data and practical operating condition in MOVPE, it suggests that under low precursor concentration, SAG could avoid non-linear phenomena and linear kinetic data would be appropriate to precise process design. Such kinetic information could be very precious and useful to gain perspective of surface process or design device fabrication with MOVPE technique.
4. On base of binary kinetic database of k_s, investigation revealed overall k_s obtained in experiments for ternary compounds can be linearly calculated from binary k_s and elemental ratio of group-V species. It clarified the relation of surface kinetics between binary material and ternary material system, and suggested that incorporation of indium and gallium species in MOVPE should be independent to each other.
5. With kinetic model and established database for InGaAsP material system, emission wavelength in SAG had been simulated for a multi-width mask pattern based on elemental composition and thickness distribution control in SAG. This demonstration was designed to test reliability of both kinetic model and our database, and the simulated results showed very good consistency with experimental data. Therefore, it clearly indicated the reliability of my model and database. The most significant meaning of this demonstration is that it confirms the feasibility of process design via numerical simulation on base of kinetic model, and it could be expanded to compact OEICs design with the help of computer.
6. In the last part of this work, some issues in the design of SAG process has been discussed with my established kinetic database, which cover free-polycrystal growth, mask interference in compact pattern and abrupt growth in edge of mask. These applications exhibit great advantage to use my process design methods in SAG, it can save time and resources. Instead of repeating growth and analysis in trial and error way, all these work can be done on computer with

sufficient kinetic data for MOVPE. The discussion on issues, such as poly-crystal free growth, mask interference in compact pattern and abrupt growth in edge of mask, indicate that poly-crystal free growth and abrupt growth in edge of mask can be easily achieved and mask interference even be used to reduce the mask coverage with help of such method. A reliable kinetic database shows most significance in these applications, it reveals that the different surface kinetics between indium and gallium should be concerned in all the mask design.