Quantum structures of Si/Ge system are successfully fabricated by utilizing advantages of gas source molecular beam epitaxy (GSMBE). Growth kinetics of gas molecules is significantly dependent on the surface, providing unique structures on patterned substrate. Crystal quality and pattern formation of quantum structures strongly depends on the growth condition of GSMBE and then a new technique is developed to meet difficult requirements to realize SiGe/Si quantum wires (QWRs) with high quality and well-defined structures. QWRs grown here give rise to characteristic optical properties of the wire structure. Exciton diffusion dynamics is also studied in the composite structure grown on patterned substrates and important quantities of SiGe/Si quantum structures are deduced.

1. Introduction

Formation of high quality quantum structures including quantum wires and dots in the system of Si/Ge has recently been attracting much attention. These quantum structures can be realized mainly by utilizing characteristic properties of gas source molecular beam epitaxy (GSMBE) where hydrogenated gases such as Si$_2$H$_6$ and GeH$_4$ are employed as molecular sources. The most important feature of GSMBE here is selective growth of semiconductor layers, that is, Si and Ge epitaxial growth takes place only on Si surfaces when epitaxy is carried out on patterned Si substrates with such films as SiO$_2$ [1,2]. This selectivity comes from the difference in sticking probability of Si$_2$H$_6$ molecules between Si and SiO$_2$. Although the molecule dissociatively adsorbs on Si surfaces with dangling bonds, it hardly occurs on SiO$_2$ surfaces.

The sticking probability of molecules also depends on the crystal-
lographic orientation of Si substrates and the growth rate of Si and Ge layers on (100) surfaces is higher than that on (111) surfaces [3]. This provides the possibility to form interesting structures of wires and dots on patterned substrates.

In this paper, properties of GSMBE are discussed in conjunction with the formation of quantum structures and the optical properties of quantum wires and related structures are examined.

2. Growth Mechanisms of Si Gas Source MBE

GSMBE is usually performed in a conventional Si MBE machine equipped with a gas handling system [4] or gas source dedicated MBE machine [5]. Although various kinds of source gases can be used, Si$_2$H$_6$ and GeH$_4$ are mainly used in these days. The main part of MBE growth mechanism is dissociative adsorption of the gas molecules and the following desorption of dissociated products which leave Si atoms on Si substrates. Since the thermal decomposition of the molecules does not occur in gas phase under the molecular flow condition of MBE, the reaction of molecules with substrate surfaces is essential. At high temperatures where MBE growth takes place, therefore, it is well speculated that impinging Si$_2$H$_6$ molecules immediately dissociate into SiH$_x$ fragments and hydrogen desorbs from surface-sitting SiH$_x$ segments as a final process, leaving Si atoms on the growing surface. In other words, the hydrogen desorption is the process governing Si-GSMBE growth. Although Si surface dangling bonds are chemically active and act as active sites for Si$_2$H$_6$ adsorption, hydrogen covered surfaces resulting from decomposition of Si$_2$H$_6$ are very much inactive and further adsorption of Si$_2$H$_6$ is seriously blocked. To proceed adsorption of Si$_2$H$_6$ and initiate crystal growth, hydrogen should desorb from SiH$_x$ adsorbates and leave Si dangling bonds on the surface. It is, therefore, concluded that the MBE growth temperature should be above the hydrogen desorption temperature and above 700 K.

From the above discussion, we can anticipate two distinctive growth modes resulting from competition between the dissociative adsorption of Si$_2$H$_6$ and the hydrogen desorption from relevant segments. If the hydrogen desorption rate is high enough compared with the Si$_2$H$_6$ adsorption rate, the growth is determined by the Si$_2$H$_6$ supply and the growth rate becomes to be proportional to the Si$_2$H$_6$ supply. If the growth temperature is relatively low and the hydrogen desorption rate is not high enough, on the other hand, the growth is limited by the hydrogen desorption.

In Fig. 1, a typical example of temperature dependence of Si-GSMBE growth rate with Si$_2$H$_6$ is shown. It is clearly seen that at tempera-