Abstract

In recent years, the wavelength range over which silicon photonics can operate has been extended to the mid-infrared (IR) regions (2 to 20 μm). Since many molecules and substances have their specific absorption peaks in the mid-IR range, this has provided us with a good opportunity to use silicon photonic device as a sensor of trace elements of chemicals in either gaseous, liquid or solid phases. In addition, Mid-IR also has many potential applications in free space data communication, IR imaging of biological tissues, spectroscopy and many.

Conventional Germanium (Ge) on Silicon (Si) structure (GOS) has a small core/clad refractive index contrast which makes a compact design of sensing devices difficult to realize. The silicon on insulator (SOI) structure is a very mature and well established platform. However, SiO_2 is only transparent up to about 3.8 μm. When Ge on SiO_2 structure is used for sensing, absorption by the SiO_2 layer degrades the performance of such devices. Therefore, the main objective of this PhD work is to realize a scalable and CMOS compatible germanium-on-insulator platform with wide transparency range in mid-IR as well as a large core-clad refractive index contrast in order to realize high performance and compact devices at low cost. Silicon Nitride (SiN_x) is known to be transparent up to 9μm and it can provide a significant refractive index contrast with Ge. Therefore, Ge on SiN_x (GON) is proposed as a possible structure for sensing application in the mid-IR range. However, high-quality single crystal Ge cannot be directly deposited on buried SiN_x layer as SiN_x is an amorphous material. In this thesis, a novel method enabled by wafer bonding and layer transfer is used to obtain a high quality Ge on SiN_x structure. The fabrication processes have been discussed and optimized to obtain a Ge layer with low defect level (Threading Dislocation Density$<5\times10^6$ cm^{-2}) and an inherent tensile strain of 0.13%. In order to characterize the passive devices fabricated on GON, an optical testing platform has been built up exclusively for mid-IR applications ranging from 3.65 to 3.9 μm. After the preparation of the new structure wafer and the built-up of testing platform, systematical studies consist of modeling by finite difference time domain (FDTD) method, fabrication and characterization of the strip waveguides and bending waveguides on GON and on GOS wafer, respectively, have been carried out. The simulation results show that the performance gap becomes larger as the radius of the bending waveguide decreases. In addition, the experimental results demonstrate that the propagation loss of the strip waveguide on GON is 3.35dB/cm at the

wavelength of 3.8μm and the bend loss of the bending waveguide is 0.14dB/bend at the radius of 5 μm while the bend loss of the bending waveguide on GOS is 2.54dB/bend at the same radius, which proves the proposal that GON platform can provide us with a more compact design of devices.

Mid-IR sensing applications have been explored using this novel GON platform as optical chemical detection is a fast growing market in many fields of use. The principle of the Mid-IR waveguide sensor is evanescent field sensing which is based on the interaction of the evanescent field of a waveguide mode with the surrounding substances and the resulting perturbation of the intensity of the mode at the output end of the waveguide. In order to improve the sensitivity, two strategies have been applied. One is to increase the length of waveguides thus to increase the interaction area with the surrounding chemicals. Another is to extend the evanescent field to enhance the absorption. Thus different structures of waveguides have been studied like spiral, pedestal, and slot waveguide either to increase the length or to extend the evanescent field. This thesis provides deep insights, with experimental results, into the design and optimization of the Mid-IR waveguide sensors on germanium-on-silicon nitride as well as germanium-on-silicon dioxide platforms.