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Fabrication of SiGe/Si Multi-Quantum Wells Resonant-Cavity-Enhanced Detector*

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Abstract: A SiGe/Si multi-quantum wells resonant-cavity-enhanced(RCE) detector with high reflectivity bottom mirror is fabricated by a new method. The bottom mirror is deposited in the hole, which is etched from the backside of the sample by ethylenediamine-pyrocatechol-water(EPW) solution with the buried SiO_2 layer in SOI substrate as the etching-stop layer. Reflectivity spectrum indicates that the mirror deposited in the hole has a reflectivity as high as 99% in the range of 1.2~ 1.5μm. The peak responsivity of the RCE detector at 1.344μm is 1.2mA/W and the full width at half maximum is 12nm. Compared with the conventional p-i-n photodetector, the responsivity of RCE detector is enhanced 8 times.

Key words: RCE; detector; SOI; SiGe
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1 Introduction

The advantage of their compatibility with the very large scale of integrated technology makes Si-based photodetectors a very important subject of investigation for applications in long distance optical fiber communications, local area networks, as well as optical interconnects in high-speed computers. Although[1,2] III-V semiconductors provide high detection efficiency in the range of interest (1.3~ 1.55μm), incorporating them in the well-established Si technology is difficult and expensive. It is therefore desirable to grow materials directly on Si substrate. Because of their narrower band gap compared to Si, SiGe alloy, SiGe/Si multi-quantum wells and Ge quantum dots have been used as active layers in p-i-n photodetectors and their operation at 1.3~ 1.55μm has been successfully demonstrated for both normal incidence[3~10] and waveguide configurations[11,13].

Due to the small absorption coefficient for its indirect band gap, the SiGe/Si photodetectors fabricated as a waveguide structure can get high responsivity, which, however, reduces the high frequency characteristics at the same time. Resonant-cavity-enhanced[14](RCE) photodetectors can effectively improve the quantum efficiency by increasing the equivalent absorption length and can circumvent the trade-off between responsivity and band-

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width by reducing the thickness of active layer. Moreover, RCE detector can be applied in the wavelength-division multiplexing (WDM) system. However, the preparation of the bottom distributed bragg reflector (DBR) in this structure is very difficult because it is impossible to grow a SiGe/Si MQWs absorption region on an amorphous SiO_2/Si reflector. Although bonding technique can be competent for it, it requires sophisticated and costly procedures. To our knowledge, there are few reports about the fabrication of SiGe/Si multi-quantum wells resonant-cavity-enhanced detector with high reflectivity bottom mirror.

In this letter, we report a new way to prepare the SiGe/Si multi-quantum wells resonant-cavity-enhanced detector with high reflectivity bottom mirror. The responsibility of RCE detector by this method has an 8 times enhancement compared with the conventional ones.

2 Experiment and discussion

All samples of $Si_{0.59}Ge_{0.41}$/Si MQWs were grown by ultra high vacuum chemical vapor deposition (UHV-CVD) on (100) oriented n-type SOI substrates with pure disilane and germane (Si_2H_6 and GeH_4). The SOI substrates were cleaned in an ex situ chemical etching process and loaded into an UHV growth chamber with background pressure of 1.2×10^{-7}Pa, and then heated up to 930℃ to deoxidize. The multilayer structures underwent the following growth procedure: growth of 250nm Si buffer layer at 850℃, followed by ten bilayers consisting of 6nm $Si_{0.59}Ge_{0.41}$ and 33nm thick Si, 150nm intrinsic Si spacer and a 150nm p-doped silicon capping layer at 650℃. The high quality of SiGe/Si MQWs structures was proved by X-ray double-crystal diffraction and low temperature photoluminescence (PL).

The RCE p-i-n photodetector was fabricated by standard photolithography and chemical etching technology. Figure 1 shows the structure of the photodetector. Mesas (200μm × 200μm) were etched down to the n-type top silicon layer of SOI substrate. After the electrode was made, the back side of the silicon slice was thinned to 120μm. Then it was etched in ethylenediamine-pyrocatechol-water (EPW) solution at 95℃ with 1μm PECVD-deposited SiO_2 as mask layers on both sides of the slices to form the back hole. The SiO_2/Si Bragg reflector was deposited on the surface of the samples (top mirror) and in the back hole (bottom mirror) with a quarter-wavelength pair of amorphous Si (93nm) and SiO_2 (220nm) by plasma-enhanced chemical vapor deposition. The $Si_{0.59}Ge_{0.41}$/Si MQWs as an absorption region was sandwiched between the two mirrors to form a RCE photodetector.

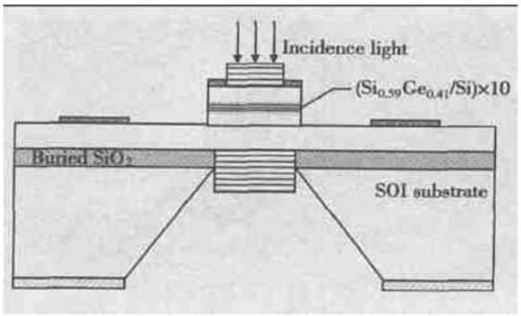

Fig. 1 Sketch of the $Si_{0.59}Ge_{0.41}$/Si MQWs RCE detector

The buried SiO_2 in SOI substrate can act as etching-stop layer during the etching of the back hole and the smooth surface of the bottom of back hole was proved by the SEM results as shown in Fig. 2(a). In order to detect the possibility to prepare of the bottom DBR in the hole, we deposited 3 pairs of SiO_2/Si DBR in it (shown in Fig. 2(b)). Figure 3 gives the reflectivity (R) spectrum of the bottom DBR grown in the hole. The high reflectivity of the mirror in the range of 1.2~ 1.5μm ($R>99\%$) suggests the successful preparation of the bottom DBR in the hole.

When the relation of $R_1 = R_2\exp(-2\alpha d)$ is satisfied, the RCE detector will have the maximum responsibility[12]. Here R_1 and R_2 are the top and bottom mirror reflectivities, respectively, α is the absorption coefficient, and d is the equivalent length of the absorption layer. So 2.5 pairs of

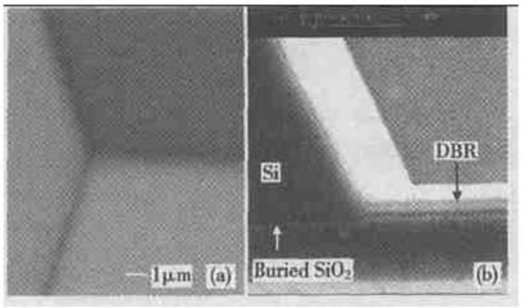

Fig. 2 SEM topographs of the back hole (a) Bottom of the hole; (b) Section of the back hole after deposting the DBR

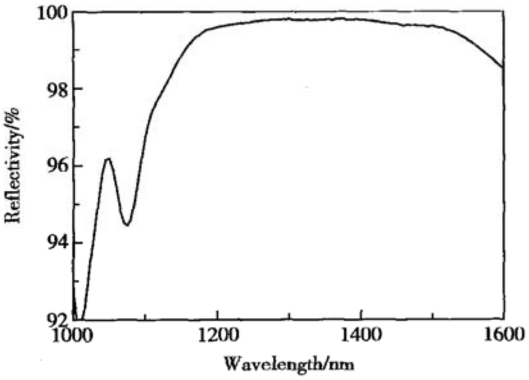

Fig. 3 Reflectivity spectrum of the bottom DBR grown in the hole

SiO_2/Si top DBR(R_1= 90% around 1.3μm) are deposited, which allow us to make a high-responsibility device.

The current-voltage characteristics of the RCE photodetector was measured by HP 4140B amperemeter (as shown in Fig. 4). The threshold and breakdown voltage of the device are about 0.25V and 15V, respectively. The dark current density at 5V reverse bias is measured as 1.92×10^{-7} μA/μm^2, which is one order of magnitude lower than the value reported before[6,12,13].

The responsivity of the RCE photodetector under reverse bias of 5V is shown in Fig. 5 (the solid line). A monochrometer with 1nm resolution was used to adjust the wavelength of detective signal from a chopped tungsten light source. The light was coupled into a single-mode optical fiber and then aligned to the optical window of the photodetector normally. From the inlet in Fig. 5 we can find that the peak responsivity at 1.344μm and 1.275μm are 1.2mA/W and 2.6mA/W while the FWHM are 12nm and 10nm, respectively. Compared with the conventional p-i-n photodetector (without top and bottom DBR, the dotted line shown in Fig. 5), the responsivity of RCE detector has an 8 times improvement.

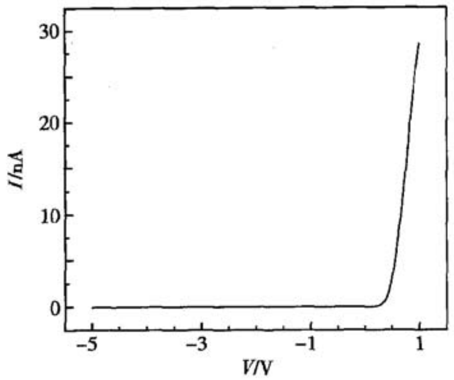

Fig. 4 Current-voltage characteristics of the RCE photodetector

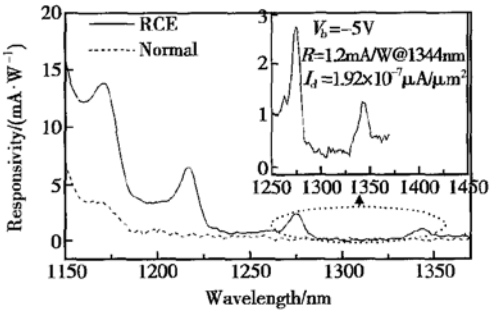

Fig. 5 Responsivity of the RCE photodetector under reverse bias of 5V

3 Conclusion

The SiGe/Si multi-quantum wells resonant-cavity-enhanced detector with high reflectivity bottom mirror was fabricated. The bottom mirror was deposited in the back hole, which was etched by EPW solution with the buried SiO_2 in SOI substrate as the etching-stop layer. Reflectivity spectrum indicates that the mirror deposited in the hole is perfect for its smooth bonding interface. The threshold and breakdown voltage of the device are about 0.25V and 15V, respectively. The dark current density at 5V reverse bias is measured as 1.92 $\times 10^{-7}\mu\mathrm{A}/\mu\mathrm{m}^2$. The peak responsivity of the detector at 1.344μm and 1.275μm are 1.2mA/W and 2.6mA/W while the FWHM are 12nm and 10nm, respectively. Compared with the conventional p-i-n photodetector, the responsivity of RCE detector has an 8 times improvement.

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SiGe 共振腔增强型探测器的制备*

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摘要: 利用 SOI 材料的埋层二氧化硅的自停止特性, 成功制作了具有高反射底镜的共振腔增强型 SiGe 探测器. 底镜沉积于 EPW 腐蚀液腐蚀形成的背孔内, 在 1.2~1.5μm 范围内, 反射率高达 99%. 探测器的共振峰在 1.344μm, 光响应为 1.2mA/W. 与普通结构的探测器相比, 文中所报道的探测器光响应有 8 倍的增强.

关键词: RCE; 探测器; SOI; SiGe

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