第 22 卷第 3 期　　半 导 体 学 报　　Vol. 22, No. 3
2001 年 3 月　　CHINESE JOURNAL OF SEMICONDUCTORS　　Mar., 2001

Low-Cost, High-Reflectivity Silicon-on-Reflector for Optoelectronic Device Application*

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Abstract: A silicon-on-reflector (SOR) substrate containing a thin crystal silicon layer and a buried Si/SiO_2 Bragg reflector is reported. The substrate, which is applied to optoelectronic devices, is fabricated by using Si-based sol-gel sticking and smart-cut techniques. The reflectivity of the SOR substrate is close to unity at 1.3μm's wavelength under the normal incidence.

Key words: silicon-on-reflector; SiO_2/Si Bragg-reflector; smart-cut technique; optoelectronic device; photodetector
PACC: 4200; 0762; 7755; 8160C
CLC number: TN203　　**Document code**: A　　**Article ID**: 0253-4177(2001)03-0261-04

1 Introduction

Si-based optoelectronics has become more and more attractive due to its potential application to the fiber communication, its compatible with the silicon integrated circuits and the low cost. Si-based photodetectors, modulators, wavelength-division-multiplexing (WDM) devices and Si-based materials for photoluminescence have been studied for several decades[1]. One of the key techniques is to fabricate the Si substrate with Bragg reflectors, which act as resonant-cavity-enhanced photodetectors, and other devices with micro-cavity[2—4]. The epitaxial reflectivity of SiGe/Si Bragg reflector has proved to be very low because of the limitation of both the SiGe critical thickness and the small refractive difference between the SiGe alloy and Si[5,6]. Ishikawa *et al.*[7] have reported the fabrication of 4 and 5 pairs of Si/SiO_2 reflectors by using the Si epitaxy and multiple separation-by-implanted-oxygen techniques. However, there exists limitation on the choice of the thickness of SiO_2 and Si, and the quality of the top Si layer is not guaranteed by the multiple epitaxy and implantation, and besides, the cost of multiple epitaxy and implantation is expensive and the process is time-consuming. Recently, the direct bonding and smart-cut process of Si has been introduced to fabricate the silicon-on-insulator (SOI) substrates[8,9], which requires the roughness of the Si surface to be less than 1nm. If the roughness of the surface of Si/SiO_2 reflector evaporated due to the electron-beam evaporation is larger than 1nm, bonding to silicon direct-

* Project Supported by "973" Plan Under Grant No. 2000036603 and by National Natural Science Foundation of China Under Grant Nos. 69789802 and 69896260.

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Received 22 September 2000, revised manuscript received 30 October 2000

ly will become impossible.

In this letter, a novel method for fabricating a low-cost, high-reflectivity silicon-on-reflector (SOR) substrate has been reported. To fabricate SOR substrate, silicon-based sol-gel and smart-cut techniques are applied and described as below. Si wafer A is implanted by hydrogen and the Si/SiO_2 Bragg structure is evaporated on Si wafer B. Then, wafers A and B are glued together face to face by silica gels. Under certain conditions, the glued wafers are heated to bond together and form a new substrate with a thin monocrystalline surface layer on the Si/SiO_2 Bragg reflector. This substrate is called SOR, compared with silicon-on-insulator(SOI). The thickness of the Si crystal layer is about 1.2μm (determined by the energy of implanted hydrogen) and the reflectivity of the SOR substrate at 1.3μm is close to unity. Owing to its advantages, such as low cost, high reflectivity and easy-to-control at different operating wavelength, the SOR substrate is attractive and applied in the Si-based resonant-cavity-enhanced photodetectors and other micro-cavity devices.

2 Experiment and Results

Hydrogen ions are implanted into wafer A with an implantation energy of 140keV and a dose of $6\times10^{16}cm^{-2}$. Five pairs of SiO_2(15nm) and Si (130nm) layers are evaporated on wafer B by electron-beam evaporation with in-situ controlling. Both wafer A and B are coated with silica gels prepared by catalyzed method described in Ref. [10]. Then, wafer A is glued onto wafer B at room temperature. Wafer B is used as a handle wafer during the process. After that, two-step heat treatments are carried out for the glued wafers. In the first step, wafer A splits into two parts at 450℃, which lasts 30min and gives rise to a thin silicon layer's transferring to wafer B. Once the splitting occurs, high-temperature annealing begins and proceeds at 1100℃ for 1h to strengthen the bonding, and the silica gels turn into SiO_2 as well.

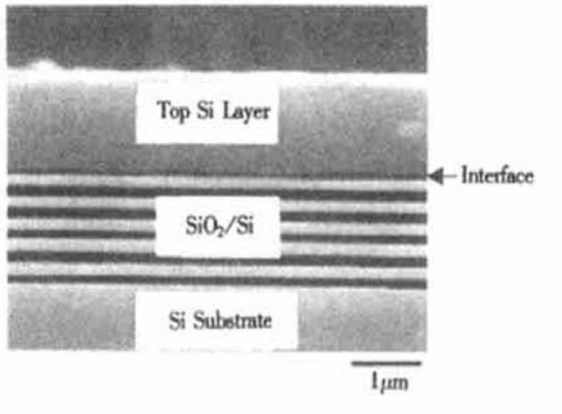

FIG. 1 Cross-Sectional SEM Image of SOR Substrate (with 5 Pairs of SiO_2/Si Bragg Reflector)

The cross-sectional scanning electron micrograph (SEM) image of the SOR substrate with 5 pairs of the Si/SiO_2 Bragg reflector structures is shown in Fig. 1. The thickness of the top silicon layer is about 1.2μm, directly related to the hydrogen ion implanted energy. The glued and evaporated interface of SiO_2 and Si is smooth, sharp and flat. The average thickness of Si/SiO_2 in the Bragg reflector is about 130nm/150nm, which is designed for a high reflectivity at the wavelength of 1.3μm and evaporated by electron-beam evaporation with in-situ monitoring. The thickness of Si/SiO_2 can be easily changed at different operating wavelength.

Figure 2 shows an atomic force micrograph of the smart-cut surface of the top monocrystalline Si. The surface roughness (characterized by root mean square (RMS)) is 15.2nm, which makes it necessary for epitaxy of SiGe/Si multiple-quantum wells to polish the split surface for the resonant-cavity-enhanced photodetectors. The values of RMS are consistent with the data reported for the smart-cut surface that is obtained by Si direct bonding at high temperature[11].

The reflectivity of the SOR substrate under near-normal incidence is measured and simulated by transfer matrix method[12] (shown in Fig. 3). The simulated reflectance spectra are similar to the measured ones, but there are still some discrepancies between them. We consider that the discrepancies may be due to the non-uniform of interfaces

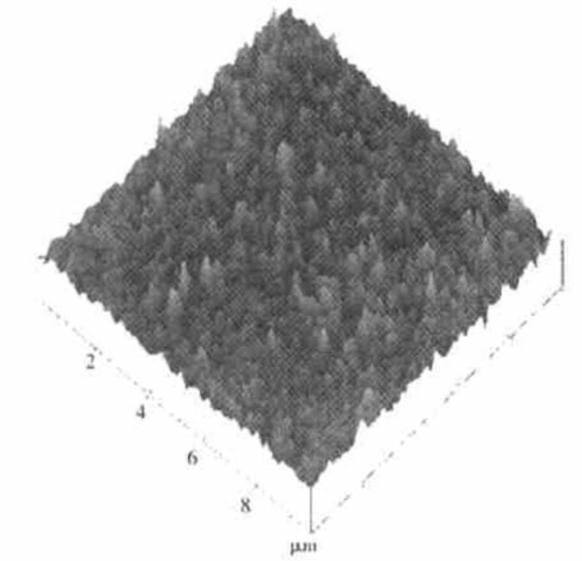

FIG. 2 Atomic Force Micrograph of the Smart-Cut Surface of Top Monocrystalline Si

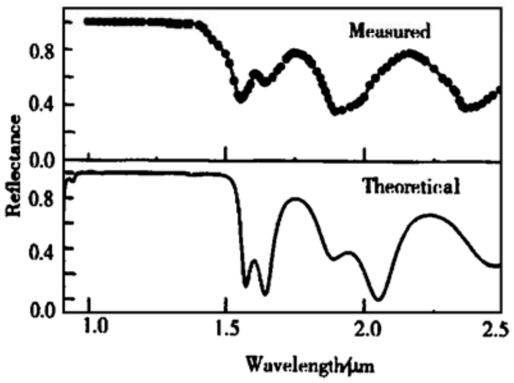

FIG. 3 Measured and Simulated Reflectance of SOR Substrate

of SiO_2 and Si layers. The maximum reflectivity at wavelength of 1.3μm is near unity, as has attracted a lot of attention on currently. The high reflectivity of the Bragg reflector as a bottom mirror, is of great benefit to the resonant-cavity-enhanced photodetectors.

3 Conclusion

In conclusion, the silicon-on-reflector substrate with high reflectivity Bragg structure and thin monocrystalline Si layer is designed and fabricated by using sol-gel and smart-cut techniques. The interface between SiO_2 and Si in the Bragg reflector is sharp, smooth and flat. The maximum reflectivity at the designed wavelength of 1.3μm is close to unity. This substrate is applied to Si-based optoelectronic devices, especially to the resonant-cavity-enhanced photodetectors and the devices with micro-cavity.

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用于光电子器件的低成本、高反射率 SOR 衬底*

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摘要: 报道了一种包含一薄层单晶硅和隐埋 Si/SiO_2 布拉格反射器的 SOR 衬底. 这种可用于光电子器件的衬底是由硅基乳胶粘接和智能剥离技术研制而成的. 在垂直光照条件下, 这种 SOR 衬底在 1.3μm 处的反射率接近 100%。

关键词: SOR; SiO_2/Si 布拉格反射器; 智能剥离技术; 光电子器件; 光探测器

PACC: 4200; 0762; 7755; 8160C

中图分类号: TN203　　**文献标识码**: A　　**文章编号**: 0253-4177(2001)03-0261-04

* "973"计划(批准号: 2000036603)和国家自然科学基金(批准号: 69789802, 69896260)资助项目.

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2000-09-22 收到, 2000-10-30 定稿