Heteroepitaxial Growth of 3C-SiC Films on Maskless Patterned Silicon Substrates*

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Abstract: Heteroepitaxial growth of 3C-SiC on patterned Si substrates by low pressure chemical vapor deposition (LPCVD) has been investigated to improve the crystal quality of 3C-SiC films. Si substrates were patterned with parallel lines, 1 to 10μm wide and spaced 1 to 10μm apart, which was carried out by photolithography and reactive ion etching. Growth behavior on the patterned substrates was systematically studied by scanning electron microscopy (SEM). An air-gap structure and a spherical shape were formed on the patterned Si substrates with different dimensions. The air gap formed after coalescence reduced the stress in the 3C-SiC films, solving the wafer warp and making it possible to grow thicker films. XRD patterns indicated that the films grown on the maskless patterned Si substrates were mainly composed of crystal planes with (111) orientation.

Key words: 3C-SiC; LPCVD; patterned substrates
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1 Introduction

3C-SiC is an attractive SiC polytype used in high temperature, high frequency, high power, and even in some harsh environments, owing to its high electron mobility and high electron saturation drift velocity[1,2]. 3C-SiC can be grown on Si substrates, which have high electrical and thermal conductivity, and can also be grown with large diameters at low prices. However, the large lattice mismatch (about 20%) and thermal expansion coefficient mismatch (8%) between SiC and Si often result in crystalline misorientations, surface roughness, wafer bending, and generation of defects such as stacking faults, twins, and cracks, which are the main obstacles to obtaining high quality 3C-SiC films on Si substrates[3]. One effective method of improving the crystal quality of 3C-SiC on Si is the use of patterned Si substrates. Selective epitaxial growth followed by lateral epitaxial overgrowth could minimize the interfacial defects and other planar defects because of the dislocation filtering[4~6]. However, choosing the appropriate mask materials and preventing nucleation on the mask area by optimizing the growth parameters have become the main challenges in this work[7~10]. Recently, patterned substrates without mask layers were used for GaN deposition to reduce the dislocations[11]. Air-gap epitaxy can be also employed for SiC growth on Si substrates, using the etched Si substrates to grow SiC laterally without an interfacial layer.

In this paper, the air-gap epitaxy of 3C-SiC films on maskless patterned Si substrates was studied. The growth behavior for different dimensions was investigated. The growth on the mesa followed by lateral epitaxial overgrowth could improve the crystallinity of the 3C-SiC films. Moreover, the formed air gap after coalescence could release the stress in the films caused by the large lattice and thermal mismatch between SiC and Si, making it possible to grow thicker SiC films on Si substrates.

2 Experiment

3C-SiC films were grown on maskless patterned Si substrates by low pressure chemical vapor deposition (LPCVD). Si (111) substrates were patterned with parallel lines, 1 to 10μm wide and spaced 1 to 10μm apart. The patterning was carried out by photolithography and reactive ion etching. The etching depth was controlled by etching time under certain etching conditions. The patterned Si substrate was in-

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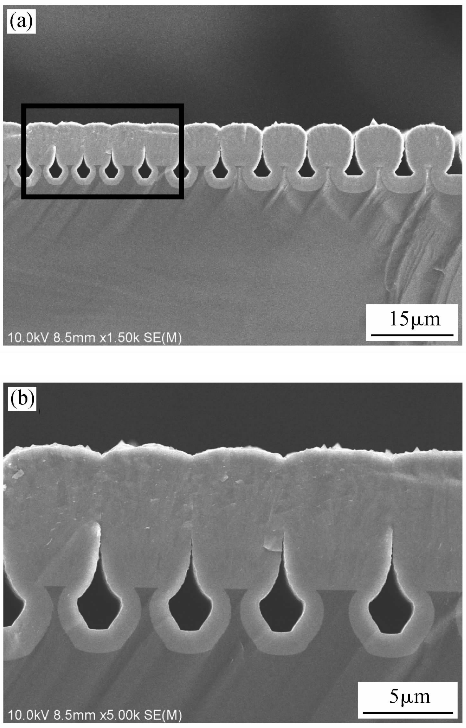

Fig. 1　(a) Cross-sectional SEM micrographs of the 3C-SiC film grown on patterned Si substrate; (b) Magnification of the area marked in (a)

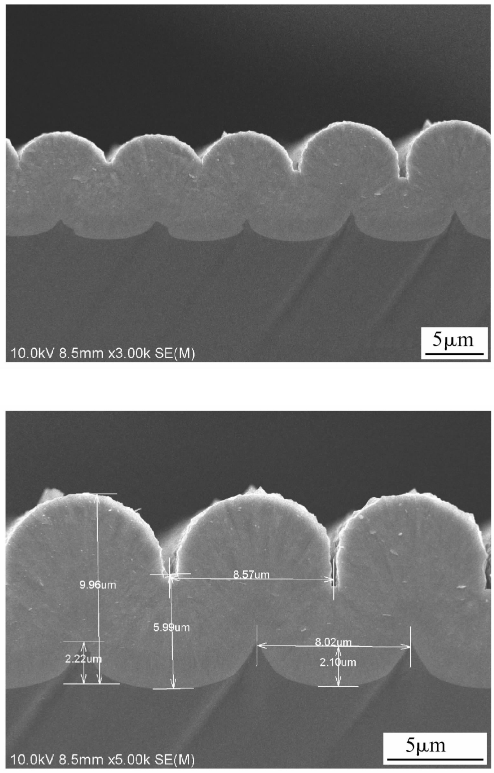

Fig. 2　Cross-sectional SEM micrographs of the 3C-SiC film grown on patterned Si substrate

troduced into the LPCVD chamber after it was dipped in 5% HF solution and was heated by RF induction. The hydrogen etching was performed for 5min at 1100℃. Then the temperature was raised to 1300℃ for SiC growth. SiH_4 and C_2H_4 were used as source gases, with flow rates of 1 and 3sccm, respectively. The flow rate of the H_2 carrier gas was 3slm.

3C-SiC films grown on maskless patterned Si substrates were investigated by field emission scanning electron microscopy (FESEM, Hitachi S-4800). The growth rate and coalesced structure were shown in the cross-sectional SEM images. The crystallinity of the 3C-SiC film was characterized by X-ray diffraction (XRD, PANalytic, X'pert PRO MPD).

3　Results and discussion

The morphology and growth structure of the 3C-SiC films grown on Si substrates patterned with parallel stripes with different dimensions were investigated by SEM. Figure 1 shows the cross sectional SEM micrographs of the 3C-SiC film grown on the patterned area with the valley width and depth of 5 and 5μm, respectively. 3C-SiC grew both on the mesa and in the valley area. The growth rate on the mesa was almost six times of that in the valley area. In the initial stage, the nucleation occurred on both the mesa and the valley area, but the gas molecules easily arrived at the mesa, resulting in the 3C-SiC on the mesa growing faster than that in the window area. With the growth time, 3C-SiC film became thicker and lateral growth on the mesa occurred, which prevented the reaction species from reaching the valley and thus reduced the growth rate in the valley area. Coalescence occurred with the laterally epitaxial overgrowth and the growth in the valley area was stopped because the source gases had difficulty flowing to the bottom of Si valley after coalescence. The air-gap formed in this structure released the stress in the 3C-SiC films caused by the large lattice and thermal mismatch between SiC and Si. This patterned Si substrate for the formation of the air-gap structure reduced the defects in the 3C-SiC films and make it possible to overcome the wafer wrapping when growing thicker films[4,12].

Figure 2 shows the cross-sectional SEM of the 3C-SiC films grown on the patterned Si substrates with mesa width and the depth of 1 and 2μm, respectively. The thickness of the growth on the bottom of the Si valley and on the mesa area was almost the same at 6 and 7.5μm. The preferred nucleation at the area with a narrower mesa and a wider valley became less prominent compared to the wider valley width. The growth rates in these areas were almost the same. A spherical shape was formed on the mesa and the coalescence with the film in the valley occurred with growth time. This growth behavior in the valley area did not successfully diminish the influence pro-

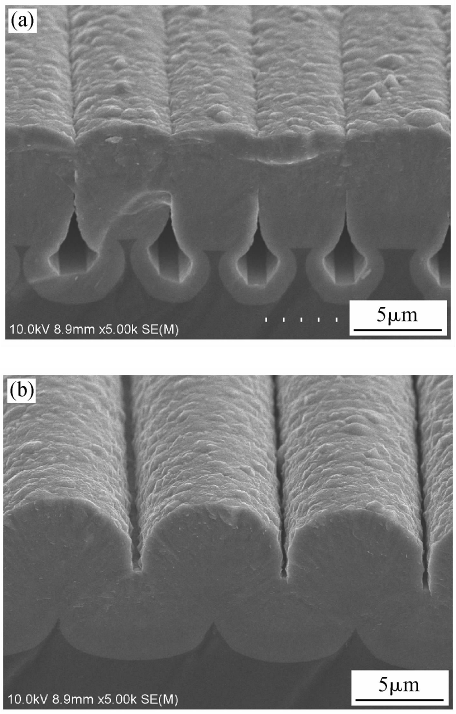

Fig. 3 Tilt SEM micrographs of the 3C-SiC films grown on patterned Si substrate (a) Air-gap structure; (b) Spherical shape

duced by the lattice and thermal mismatch between SiC and Si.

Figure 3 shows the tilt SEM micrographs of the 3C-SiC films grown on patterned Si substrates shown in Fig. 1 and Fig. 2. An air-gap formed structure, shown in Fig. 3 (a), coalesced and the surface was almost flat on this substrate structure. The spherical shape in Fig. 3 (b) indicates the incomplete coalescence growth on the surface. 3C-SiC films grown on these two structures showed a rough surface after the film thickness increased past 6μm, which could be polished to obtain a smooth surface for the regrowth of 3C-SiC films.

Figure 4 shows a typical XRD spectrum of the 3C-SiC grown on patterned Si substrates. The diffraction peaks located at 2θ of 35.5°, 60.3°, 71.9°, and 75.4° correspond to the 3C-SiC (111), (220), (311), and (222) crystal orientations, respectively. The weak peak at 28° was attributed to the Si substrate. The strong SiC (111) peak indicated the SiC (111) orientated growth on the Si (111) substrates.

4 Conclusion

Heteroepitaxial growth of 3C-SiC films on patterned Si (111) substrates without mask layers has been investigated. Si (111) substrates were patterned with parallel stripes with different sizes for the mesa and valley area. The growth behavior on the pat-

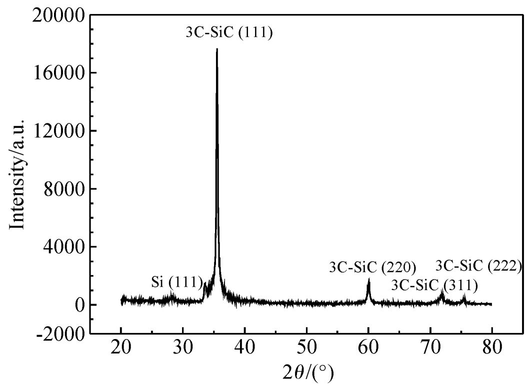

Fig. 4 XRD spectrum of the 3C-SiC film grown on patterned Si substrate

terned substrates was analyzed by cross-sectional SEM. An air-gap structure and a spherical shape formed on the patterned Si substrate with different dimensions. Coalescence growth was obtained for certain aspect ratios of the mesa and valley structure. The air gap formed after coalescence released the stress at the SiC/Si interface to improve the crystallinity of the 3C-SiC films and could also be used to resolve the wafer warp when growing thicker films.

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无掩模硅图形衬底上 3C-SiC 的异质外延生长*

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摘要： 采用低压化学气相沉积方法在无掩模的硅图形衬底上异质外延生长 3C-SiC. 硅图形衬底采用光刻和 ICP 刻蚀得到. 图形由平行长条状沟槽和台面组成，其中沟槽宽度为 1～10μm 不同间隔，沟槽之间距离为 1～10μm 不同间隔. 对于在不同的沟槽和台面尺寸区域 3C-SiC 的生长进行了详细研究. 采用扫描电镜分别观察了不同区域的生长形貌，分析了图形衬底结构上 SiC 的生长行为. 其中合并生长形成的空气隙结构可以释放由 Si 和 SiC 晶格失配引起的应力，从而可以用来解决 SiC 生长中的晶片翘曲问题，进行厚膜生长. XRD 结果表明此无掩模硅图形衬底上得到 3C-SiC (111)取向生长.

关键词： 3C-SiC；LPCVD；图形衬底

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