Surface & Coatings Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Ion implantation technology for silicon carbide

Anders Hallén *, Margareta Linnarsson

KTH Royal Institute of Technology, School of ICT, P.O. Box Electrum 229, SE 164 40 Kista, Sweden

ARTICLE INFO

Article history:
Received 23 March 2016
Revised 24 May 2016
Accepted in revised form 26 May 2016
Available online xxxx

Keywords:
SiC
Doping
Implantation damage
Diffusion
Activation
Annealing

ABSTRACT

Ion implantation is a key process technique for semiconductor materials, in particular silicon, for local tailoring of the semiconductor properties. The wide bandgap semiconductor silicon carbide (SiC) features outstanding material properties for high power and high temperature electronic devices, but the properties of SiC also make it difficult to manufacture and process the material. The development of implantation technology for SiC has therefore necessitated several changes from mainstream silicon implantation technology. This paper will discuss the difficulties with implantation of SiC for manufacturing of electronic devices and also describe how the problems have been overcome, for instance by implantation at elevated temperatures and using high temperature post-implant annealing.

© 2016 Published by Elsevier B.V.

1. Introduction

The impressive material properties of the wide bandgap semiconductor silicon carbide (SiC) have been recognized for over half a century. Compared to silicon, SiC has 10 times higher dielectric field strength and over three times higher thermal conductivity, while still maintaining mobility values for electron and hole transport similar to silicon. These properties potentially leads to considerably more efficient semiconductor devices and circuits, particularly in power applications, with lower losses, reduced cooling needs and high temperature operation. However, substantial progress in SiC device research has not been possible until the development of epitaxial growth techniques, specifically chemical vapour deposition (CVD) [1,2]. Since the introduction of silicon carbide CVD about 30 years ago, there has been a tremendous improvement in material quality and wafer size, which has enabled device development and manufacturing. Today commercial SiC power devices are available, taking substantial market shares from the prevalent silicon technology and also introducing new areas in extreme voltage and temperature regimes, where other semiconductors cannot compete. Silicon carbide sensors and MEMS devices, as well as integrated circuits for very high temperature applications, in excess of 600 °C, are about to be introduced on the market [3,4].

Most of the development is focused on the 4H-SiC polytype, having the largest bandgap, although 6H and 3C polytypes also offer interesting alternatives for certain applications. The processing technology for SiC is to a large extent inherited from existing Si technology, although modifications and development of new techniques is needed for most of the processing steps since SiC is a much tougher and resistant material than Si. For instance, wet etching, metallization, and dielectric deposition all need to be tuned for SiC usage. This tuning process is ongoing and most noticeably is perhaps the lack of a proper dielectric deposition process for MOS gates, which still demands improvement. Also the process of implantation doping has been considerably modified from normal Si processing. Implantation doping was early recognized as a key technology for introducing dopants, since diffusion of impurities generally requires very high temperatures in SiC. Post implantation annealing temperatures often in excess of 1600 °C is needed to activate the implanted species and to restore the lattice, which lead to surface deterioration due to Si evaporation and step bunching. It was also recognized that, particularly for high fluence p-type doping, it was very difficult to reach full activation, even at these high temperatures, due to a high degree of damage [5–7]. These problems motivated the development of epitaxial doping techniques, where the differently doped layers of a device was grown by epitaxy and then laterally defined by etching. This non-planar epi-technique has been used to manufacture, for instance, pin diodes, where efficient, highly doped p-type emitters can be realized [8–10]. Despite of the usefulness of epitaxial doping, ion implantation doping is still used extensively for SiC device production since it offers excellent control of dopant distributions both laterally by lithography, and in depth by selecting fluence and energy of the ions. Fig. 1 shows typical applications where ion implantation is used in device manufacturing and further examples can be found in the reference list for various devices: high voltage pin diode [11], JFET [12], MOSFET [13,14], and IGBT [15,16].

A further reason for the continued popularity for implantation doping in SiC is that the mainstream Si implantation process has been "tuned" by i) utilizing implantation at elevated temperatures,

* Corresponding author.
E-mail address: ahallen@kth.se (A. Hallén).

http://dx.doi.org/10.1016/j.surfcoat.2016.05.075
0257-8972/© 2016 Published by Elsevier B.V.

ARTICLE IN PRESS

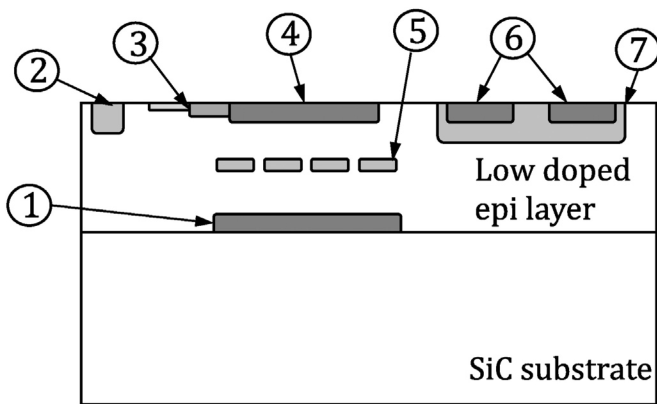

Fig. 1. Various applications for ion implantation in SiC device production: 1) buffer layers, 2) guard rings, 3) junction termination extension JTE, 4) emitters and contacts, 5) buried grids, 6) source and drain, and 7) p- and n-wells for MOSFET.

preventing substantial damage to accumulate, and ii) the use of an efficient capping technique to maintain the surface properties during the high temperature post implant annealing process. The research in this area continues and further improvements in activation, surface properties and damage reduction are constantly reported.

This contribution reviews the present status of implantation doping and indicates some areas where more research effort is needed. First, the main doping elements are introduced, giving diffusion constants for the two most often used dopants today, Al for p-type and N for n-type. Next, the importance of high temperature implants, to keep the implantation damage at controllable levels, is described. The final part of the paper covers post implant high temperature annealing needed to reduce damage and point defects and to activate the implanted species at proper lattice sites.

2. Dopant species

Four elements are extensively used for doping of SiC: boron (B) and aluminium (Al) for p-type, and nitrogen (N) and phosphorous (P) for n-type. Despite the somewhat higher ionization energy for B (E_a-E_V = 0.30 eV), compared to Al (E_a-E_V = 0.20 eV), boron was previously frequently used for implantation doping, since the relatively low mass made it possible to reach deep into the material and also keep the implantation damage at low levels. Here, E_a is the bandgap position for acceptors and E_V is the position of the valence band maximum. However, it was found that B doping also had several drawbacks like formation of precipitates at higher fluence [19], formation of a deep level instead of the shallower acceptor state [20] and uncontrolled diffusion. Diffusion appeared in the lateral direction, as well as in the axial direction, both out of the surface and deeper into the sample via a transient enhanced diffusion (TED) mechanism [21,22]. Therefore, today Al is almost exclusively used for p-type doping in SiC and in Fig. 2 measured diffusivities for Al in SiC [23–28] are compared to Al diffusivity in silicon [29], which is well established. The data for SiC contains values for both 4H and 6H, and also diffusion data from non-implanted samples, implantations at room temperature and at elevated temperatures. In spite of the vastly varying experimental conditions, the figure gives a trend for Al diffusion in SiC. It can be noticed that the diffusivity for Al in SiC is several orders of magnitude smaller than in Si. For boron diffusion, the data are much more scattered and it is not possible to find a general trend.

Of the two n-type dopants, N and P, nitrogen is most often used, both for epitaxial doping and for ion implantation. Fig. 3 summarizes some experimental results from N diffusion in SiC and also here it may be possible to see a trend, although the experimental conditions are very different [30–32] and the trend is not as clear as for aluminium (Fig. 2). Diffusion data for N in Si [33] is included also in this plot for reference,

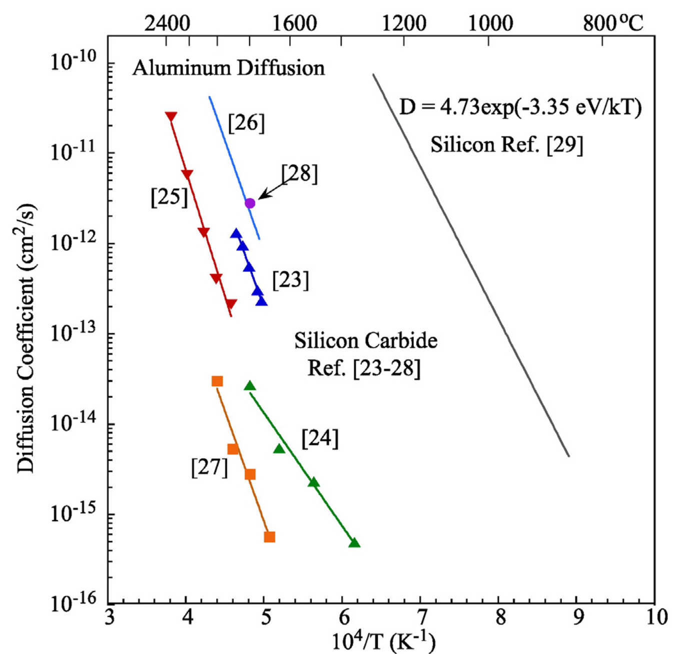

Fig. 2. Aluminium diffusion in SiC compared to Si. The data compiles several different experimental results [23–29].

and again it is clear that diffusion in SiC demands much higher temperatures compared to Si. The ionization energy for nitrogen, E_C-E_d, where E_C is the bottom of the conduction band and E_d is the donor position, is about 0.06 and 0.12 eV, for hexagonal and cubic sites, respectively. This value is substantially smaller than for the acceptors. This leads to complete ionization at room temperature, which is not the case for acceptors. Phosphorous is often used when high concentration of n-type doping is required, for instance in source and drain regions of n-channel MOSFET. The reason for this is that the solid solubility of P appears to be higher than for N at concentrations above 10^{19} cm^{-3}, according to electrical activation measurements [34].

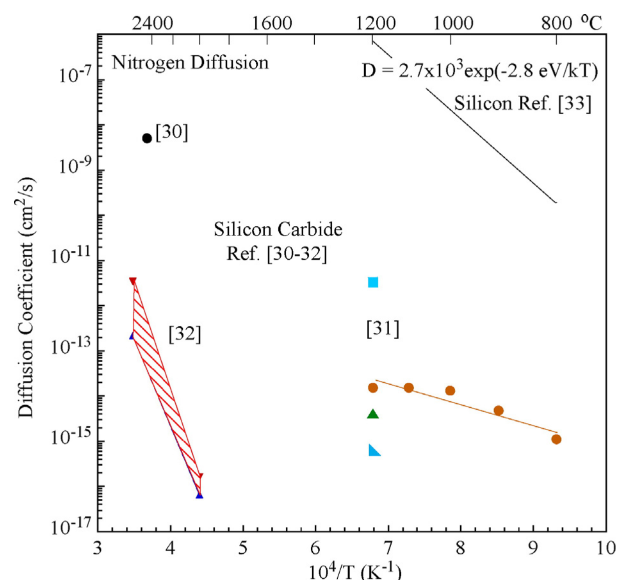

Fig. 3. Diffusion of nitrogen in SiC compared to Si. Data come from several different experiments described in the literature [30–33].

Please cite this article as: A. Hallén, M. Linnarsson, Surf. Coat. Technol. (2016), http://dx.doi.org/10.1016/j.surfcoat.2016.05.075

Download English Version:

https://daneshyari.com/en/article/5465193

Download Persian Version:

https://daneshyari.com/article/5465193

Daneshyari.com