博士論文（要約）

Bonding of Single Crystalline SiC using Surface Activation Method for Power Device Applications

（パワーデバイス応用のための表面活性化手法による

単結晶 SiC の接合）

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ABSTRACT

Owing to its superior properties, SiC is a good candidate for power electronics with higher efficiency and for Micro-Electro-Mechanical Systems (MEMS) device capable of working in harsh environments compared with conventional semiconductor such as Si and GaAs. Currently, two of the new trends of SiC device are thin SiC power electronics and all-SiC MEMS, which are expected to be able to realize better device performance and more wide application. However, to achieve a thin SiC device wafer and further form ohmic contact still has some problems. Besides, to fabricate an all-SiC MEMS is also very difficult owing to the absence of a suitable SiC bulk machining technology. Wafer bonding, as one key technology capable of novel structure formation, efficient fabrication, device integration and cost reduction, is expected to be able to solve the problems in current SiC device fabrication. However, most of previous SiC wafer bonding (mainly SiC-SiC, SiC-SiO_2 and SiC-Si) need a very high temperature, even higher than 1000^{o}C, for at least a few hours with an interfacial SiO_2 product layer. A well-developed low temperature SiC wafer bonding method with a high yield is still absent.

Compared with conventional wafer bonding methods, surface activation bonding (SAB) has a larger potential to be a suitable low temperature SiC wafer bonding method, especially capable of avoiding the formation of interfacial SiO_2 layer. After the development of SAB techniques for SiC wafer bonding, how to use them to solve the problems in SiC device fabrication is also very important. Therefore, this research focuses on not only the development of SAB techniques for SiC wafer bonding but also the novel proposals of SiC wafer bonding to solve the problems.

First, systematic study of room temperature SiC wafer bonding (mainly SiC-SiC, SiC-SiO_2 and SiC-Si) by four SAB techniques were conducted in this research. At first, standard SAB was applied to the direct wafer bonding of SiC-SiC, SiC-Si and SiC-SiO_2. The direct wafer bonding of SiC-SiC achieved a bonding energy of ~1.4J/m^2, much weaker than bulk SiC, while SiC-Si bonding could be as strong as bulk Si (2.5J/m^2). Same as direct wafer bonding of Si-SiO_2, wafer bonding of SiC-SiO_2 by standard SAB can only get a bonding energy of 0.2 J/m^2. Bonding mechanism was analyzed by Monte Carlo simulation and various experimental methods. To confirm the bonding mechanism and improve the interface strength of direct wafer bonding of SiC-SiC and SiC-SiO_2, a novel modified SAB with Si-containing Ar-beam was proposed to realize in situ Si compensation during surface activation. The interface strength of direct wafer bonding of SiC-SiC was improved by 30% and the designed in situ Si compensation was confirmed through interface analysis. Wafer

bonding of SiC-SiO_2 by modified SAB with Si-containing Ar-beam was skipped because of the limited improvement of its interface strength. While, modified SAB with Si-containing Ar-beam was confirmed to be also very suitable for direct wafer bonding of SiC-Si. Then, modified SAB with Fe-Si deposited layer by Fe-containing Ar-beam was applied to further improve the interface strength of wafer bonding of SiC-SiC and SiC-SiO_2. Although modified SAB with Fe-Si deposited layer is very effective for strong wafer bonding of SiC-SiC and SiC-SiO_2, the serious diffusion of Fe and Cr at high temperature was confirmed. To avoid the diffusion of Fe and Cr at high temperature, modified SAB with Si deposited layer by Ar-beam was proposed for the wafer bonding of SiC-SiC and SiC-SiO_2. Both of the interface strengths could reach bulk Si strength. To explain the difference between direct wafer bonding of SiC-SiO_2 by standard SAB and wafer bonding of SiC-SiO_2 by modified SAB with Si deposited layer, Monte Carlo simulation and molecular dynamic simulation were carried out to investigate the bonding mechanism because of the experimental difficulties.

Second, novel proposals of SiC wafer bonding for three applications of SiC device fabrication, which are fabrication of thin SiC device wafer, ohmic contact formation on thin SiC device wafer and monolithic integration of all-SiC MEMS, were proposed. Through the process analysis of the proposals, the requirements for the SiC wafer bonding in the novel proposals were figured out. In view of the requirements, the feasibility of the developed SAB techniques for the required SiC wafer bonding was discussed.

At last, it is expected that the combination of the developed SAB techniques for SiC wafer bonding and the novel proposals of SiC wafer bonding will be able to solve the problems in current SiC device fabrication or even meet new requirements with further development.