科技资料

PROCEEDINGS OF THE
TWELFTH STATE-OF-THE-ART PROGRAM
ON COMPOUND SEMICONDUCTORUS
(SOTAPOCS XII)
& THE SYMPOSIUM ON
SUPERLATTICE STRUCTURES & DEVICES

PROCEEDINGS OF THE

TWELFTH STATE-OF-THE-ART PROGRAM ON COMPOUND SEMICONDUCTORS (SOTAPOCS XII)

AND THE SYMPOSIUM ON

SUPERLATTICE STRUCTURES AND DEVICES

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PREFACE

The twelvth State-of-the-Art Program on Compound Semiconductors (SOTAPOCS XII) and the symposium on Superlattice Structures and Devices were held at the spring meeting of The Electrochemical Society, Inc., May 7-11, 1990, in Montreal, Canada. The symposia were sponsored by both the Electronics and the Dielectric Science and Technology Divisions of The Electrochemical Society. Since compound semiconductors are the major topics addressed by the two symposia, papers from both have been combined in this joint proceedings volume.

The program for SOTAPOCS XII consisted of five half day sessions including: Compound Semiconductor Surfaces; Substrate, Epitaxy and Ion-Implantation Technologies; Heterojunction Devices and Circuits; New Process and Device Technologies; and Opto-Electronic Devices and Integrated Circuits. A total of 39 papers were presented including invited papers by C.J. Spindt and W.E. Spicer, V. Swaminathan, M.F. Chang, H. Yajima and A. Scavennec. The authors represent 7 countries, 16 universities and 24 companies. The proceedings volume includes 33 of the papers presented at SOTAPOCS XII plus 2 relevant recent newspapers presented at the Electrochemical Society Meeting. This represents the first time that a collection of full-length papers based on SOTAPOCS presentations have been published in a proceedings volume.

The Symposium on Superlattice Structures and Devices is the first of a series addressing the characterization, growth and device physics unique to superlattice structures. Ten papers were presented by an international group of authors covering a wide range of topics including Si and III-V compounds, MBE and OMVPE growth techniques and x-diffraction and other characterization techniques. Invited papers were presented by J.C. Bean, M.A. Reed, D.P. Bour, P.F. Fewster, M.A.G. Halliwell, A.T. Macrander, J.J. Harris and Z.J. Radzimski.

The editors extend sincere thanks to all the Symposia organizers for their enthusiastic assistance in identifying outstanding invited speakers, reviewing abstracts and contributing to the overall success of the Symposia. In addition the editors gratefully acknowledge the session chairmen, presenters and attendees for their valuable contributions to the Symposia. We would also like to acknowledge the organizing efforts of The Electrochemical Society staff and the financial support of the Electronics and the Dielectric Science and Technology Divisions.

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INTRODUCTION

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Materials and processing technologies of compound semiconductors cover a wide range of techical fields and disciplines. Appropriately, the papers collected in this volume represent state-of-the-art work on 10 semiconductor material systems, 6 different device types and many diverse applications from digital logic to optoelectronics.

One of the major challenges facing compound semiconductor technology is the abscence of a truly passivating native oxide. The papers in the first section address several of the issues which result from this inherent deficiency. Two promising new passivation techniques, sulfides and hydrogen exposure, are described.

The next section deals with crystal growth and ion-implantation. The first two papers present post-growth treatments to improve the quality of LEC GaAs. Topics on ion-implantation include a model for Si activation in GaAs and an investigation of Fe-implantation to isolate InGaAs.

Low-temperature MBE growth is addressed by two papers in the Epitaxy Section. In one case, low-temperature growth is being optimized to grow high quality GaAs while minimizing dopant diffusion. In contrast, the second approach uses low-temperature growth to create a high density of defects below the active layer which effectively isolates devices and minimizes undesirable effects such as sidegating. Three additional papers describe investigations using OMVPE (MOCVD) to improve uniformity, grow GaAs and InP on Si and realize n-type doping of InSb. The final two papers in the Epitaxy Section describe a model for MOMBE growth of InAs and a novel approach to the fabrication of GaAs MESFETs on Si by epitaxial lift-off.

Heterojunction devices are well represented with three papers on HBTs and four papers on HEMT and related structures. HBT topics range from yield limiting mechanisms in relatively mature AlGaAs/GaAs technology to initial investigations of MOMBE growth of C doped base layers and AlInAs/GaInAs HBT IC's. Ohmic contacts to δ doped layers and MOCVD versus MBE were highlighted topics in the HEMT papers.

The section on New Process and Device Technologies includes a broad range of subjects relating to compound semiconductor processing and devices. One paper decribes the use of spin-on glass (SOG) as an inter-metal dielectric for GaAs LSI. Two other papers present the possibility of using laser assisted electrochemical etching to pattern GaAs and SiC. Two more papers address fabrication issues unique to InP.

The Final section of SOTAPOCS XII contains papers on optoelectronic devices and integrated circuits. Two of these are survey papers describing recent OEIC advances in Japan and Europe, respectively.

The papers collected from the symposium on Superlattice Structures and Devices describe materials and devices based on Si or III-V compounds grown by MBE or OMVPE. The Si superlattice work includes hererostructure and quantum wire/dot devices as well as characterization studies and manipulation of dislocations in devices.

Detectors sensitive out to 1.3μm, MODFETs and HBTs have been fabricated in Si/SiGe superlattices, and even the possibility of a direct energy bandgap, has been suggested. Can a Si/SiGe LED be far behind? The III-V compound papers focused on optoelectronic applications including both strained and lattice matched quantum well lasers, and on thin, delta doped layers. In a series of four papers, X-ray analysis of III-V superlattice structures for optoelectronic applications sought to understand the nature of epitaxial growth on both planar and corrugated (grating structure) surfaces.

FACTS ABOUT THE ELECTROCHEMICAL SOCIETY, INC.

The Electrochemical Society, Inc., is a nonprofit, scientific, educational, international organization founded for the advancement of the theory and practice of electrochemistry, electrothermics, electronics, and allied subjects. The Society was founded in Philadelphia in 1902 and incorporated in 1930. There are currently over 5000 scientists and engineers from more than 40 countries who hold individual membership; the Society is also supported by more than 100 corporations through Patron and Sustaining Memberships.

The technical activities of the Society are carried on by Divisions and Groups. Local Sections of the Society have been organized in a number of cities and regions.

Major international meetings of the Society are held in the Spring and Fall of each year. At these meetings, the Divisions and Groups hold general sessions and sponsor symposia on specialized subjects.

The Society has an active publications program which includes the following.

JOURNAL OF THE ELECTROCHEMICAL SOCIETY - The JOURNAL is a monthly publication containing technical papers covering basic research and technology of interest in the areas of concern to the Society. Papers submitted for publication are subjected to careful evaluation and review by authorities in the field before acceptance, and high standards are maintained for the technical content of the JOURNAL.

EXTENDED ABSTRACTS - Extended abstracts of all technical papers presented at the Spring and Fall Meetings of the Society are published in serialized softbound volumes.

PROCEEDINGS VOLUMES - Papers presented in symposia at Society and Topical Meetings are published from time to time as serialized softbound Proceedings Volumes. These provide up-to-date views of specialized topics and frequently offer comprehensive treatment of rapidly developing areas.

MONOGRAPH VOLUMES - The Society has, for a number of years, sponsored the publication of hardbound Monograph Volumes, which provide authoritative accounts of specific topics in electrochemistry, solid state science and related disciplines.

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PART I: SOTAPOCS XII

Compound Semiconductor Surfaces

RECENT ATTEMPTS TO PASSIVATE GALLIUM ARSENIDE USING SULFUR

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The passivation of GaAs by sulfur deposited from liquid $Na_2S \cdot H_2O$ or $(NH_4)_2S$ is examined in terms of the historical difficulties of passivating GaAs. It is concluded that these treatments can reduce surface recombination velocities by orders of magnitude but that they do not remove band bending due to interface states. It is shown that this result can be explained in terms of a model in which As_{Ga} and Ga_{As} antisite defects govern the electrical properties of the interface. Data is reviewed which indicates that the sulfur treated GaAs(100) is terminated with Ga bonded to sulfur. These treatments would be of practical importance if they were stable, however the low surface recombination is lost after about one-half hour exposure to the atmosphere. The problem of providing a protective layer has not yet been fully explored.

I. Introduction, definition of "passivation"

In order to discuss the passivation of GaAs, it is important to clearly define what is meant by "passivation" (1). First, one should make clear that passivation involves placing a coating of another material (usually an insulator or semi-insulator) on the surface of a semiconductor. The purpose of this coating is two-fold: to provide an ideal electronic termination of the semiconductor (electronic passivation), and to provide a layer which will prevent this ideal interface from being chemically damaged (chemical passivation) by the ambients and temperatures the semiconductor will be subjected to during its life. This includes any processing after the layer is placed on the semiconductor.

By definition, an ideal electronic passivation is one in which there are no interface states at the boundary between the semiconductor and the passivating layer (PAL) i.e., no electronic states are induced due to the termination of the semiconductor with the PAL. In practice, this means that the interface state density is reduced so that it has a negligible effect. Another requirement is that there be a sufficiently large potential barrier at the interface to prevent carriers from the semiconductor entering the PAL under operating conditions, i.e., the band gap and offset of the PAL must be sufficiently large. However, a PAL may improve some aspect of the interface without reducing the density of surface states to the point where they can be neglected. This we will term partial electronic passivation. For example, a case may arise where a surface treatment reduces surface recombination significantly, but still leaves a high density of surface states.

To be practical, the chemical passivation must protect the interface against the atmosphere for the lifetime of the device. It is possible that a surface treatment can protect an interface long enough for measurements to be made and the coating and interface specified, but not for long enough to be of practical benefit. Such a case would be an example of limited chemical passivation.

The Si/SiO_2 interface is the closest that man has come to an ideal passivation of a semiconductor. It is for this reason that the silicon integrated circuit industry has been based principally on a MOS (metal-oxide-semiconductor) device technology. However, Si/SiO_2 seems to be a special case rather than something that is to be expected for each semiconductor of interest. Attempts to reproduce Si/SiO_2 like interfaces on other semiconductors have failed, and resulted in great losses of effort and dollars.

Si/SiO_2 is not only the most ideal passivation found to date, but it is also nearly ideal in the way it is formed, which is by oxidizing the Si surface. Because of this, it is called the native oxide. In the late 1960's and 1970's, much effort was spent trying to form native oxides on GaAs. These failed for two related reasons. First, the growth of the native oxide was found to disrupt the GaAs strongly, and based on experimental data, native defects near the GaAs interface were suggested (2). Secondly, arsenic oxide was found to be unstable in the presence of GaAs. For example, reactions such as

$$As_2O_3 + 2GaAs \rightarrow Ga_2O_3 + 4As$$

can occur (2,3). Thus, by 1980 there was a strong consensus that native oxides would not work on compound semiconductors and that a foreign overlayer, rather than a native oxide must be used.

Approaches to GaAs passivation have recently appeared which are exciting but are probably not an analog to the ideal Si/SiO_2 case. The first involves heterojunctions between GaAs and larger band gap semiconductors. Several of these approaches will be briefly discussed here. An early success was $Al_xGa_{1-x}As$ grown epitaxially on GaAs (4). This made the GaAs solar cell practical by sufficiently reducing surface electron-hole recombination. It also forms the internal interface in high electron mobility transistors (HEMTs). However, this approach is not universally applicable. One difficulty is that the band gap difference between the lattice matched $Al_xGa_{1-x}As$ used and the GaAs is not large enough to prevent hot electrons from entering the passivating layer, and secondly, because there are many device structures where it is impractical to deposit epitaxial $Al_xGa_{1-x}As$ on the GaAs surface. Despite these shortcomings, this interface is probably as close to an ideal passivation as has been obtained on GaAs to date. MBE deposited ZnSe on GaAs has been shown (5) to be promising. This can be thought of as an extension of the $Al_xGa_{1-x}As$ case to a wide band gap material which can be lattice matched to GaAs. Despite the encouraging early results, there has been no concerted effort to develop this passivation scheme. One reason is probably the difficulty in growing GaAs and ZnSe in the same chamber. Another recent approach involves placing a Si film on the GaAs and then deposition and/or growing an insulator very carefully (6). A short discussion of this approach illustrates why GaAs is so difficult to passivate. Remembering the difficulties encountered with native oxide passivation of GaAs, it is interesting to examine this approach in terms of avoiding the problems which occured with the native oxide. First, the Si is almost lattice matched to GaAs and it's deposition will cause much less disruption of the GaAs than will the native oxide growth. Second, the Si separates the oxide formation sufficiently from the GaAs to prevent the formation of the troublesome oxides of GaAs. This emphasizes the importance of minimizing defect formation in the GaAs near the interface. We will return to more specific discussions of such defects later in the paper.

With this background, one final approach - the use of sulfur treatments (7) [$Na_2S{\cdot}H_2O$ or $(NH_4)_2S$] will be examined in detail. This sulfur "passivation" reduces the surface recombination very markedly. It was first thought that the treatment resulted in a flat band condition for n-GaAs at the interfaces. However, direct measurements have shown that, in fact, the band bending increases. These results will be discussed in terms of a model based on antisite defects developed for other GaAs surfaces and interfaces.

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