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JAN VAN DER MERWE: EPITAXY AND THE COMPUTER AGE

This special issue of the Journal of Materials Research contains articles that were accepted in response to an invitation for manuscripts.

Introduction

Guest Editors:

Artur Braun
Empa Switzerland

Mmantsae Diale
University of Pretoria, South Africa

Johan B. Malherbe
University of Pretoria, South Africa

Max Braun
University of Pretoria, South Africa

Materials have always been instrumental for technological progress and social change in the development of mankind and civilization.[1] For example, the industrial age and the industrial revolution were possible because of progress in steel fabrication, which allowed for the development of thermomechanical energy converters and reactor vessels for a chemical industry, in the course of which global population experienced unprecedented exponential growth.[2] The older generations among the readers of this Focus Issue have experienced how a new industrial revolution featuring semiconductor technology and computer processors led mankind to the information age. Specifically, this was based partially on the desire and ability of researchers to be able to add atoms precisely together with solid matter for materials with particular functions. This method was typically applied to single crystal surfaces and was called epitaxy.[3,4]

Much of the behavior of materials is governed by the basic principles of thermodynamics. During his Ph. D. research under Nevill Francis Mott and with Professor Frederic Charles Frank at University of Bristol from 1947 to 1949, Johannes "Jan" Hendrick van der Merwe carried out a theoretical study on intercrystalline boundaries which he published with Frank in a series of four papers. Their work turned out to be guiding principles for precise growth control of homogeneous and heterogeneous surfaces and films on single crystals.[5–9] From the technological perspective of semiconductor heterostructures, so-called layer-by-layer film growth was a favorable growth mode which we now refer to as Frank-van der Merwe Growth.

Prior to the era of layer-by-layer growth, Volmer and Weber[10] and Stransky and Krastanov[11] had studied the precipitation of ions and oriented island growth of precipitates from solutions on surfaces, and had lent their names to the corresponding island growth modes.

The fact that epitaxial growth could be understood at the qualitative and quantitative level was a precondition for the success of semiconductor processing which warranted the corresponding device technology for integrated and miniaturized logic circuits and computer processors. Jan van der Merwe was therefore also a pioneer of the nano-sciences even before the term was coined.

Semiconductors had been identified in the last century as important materials for electronics and solar cells. Absence and controlled presence of imperfections in their crystal structure was found to be critical for their functionalities, particularly as their electric transport processes were affected. The same held for overlayers and thin films thereof when electronic devices were made.[12] Christensen and Teal filed in 1951 a patent which described the process of deposition of a film which continued the structure of the underlying substrate[13] and which was used for forming an epitaxial Germanium p-n junction.[14]

Following the qualitative and quantitative knowledge of the thermodynamic principles governing coherency strain and thin film growth, practical knowledge and experience was developed in many laboratories for tailoring thin films and coherency strain with various aspects of defect management in materials.

The 1950s and 1960s became the years where noteworthy patents and technology progress led to the manufacturing of semiconductor devices with superior performance in size and speed. The 1970s was the decade where microcomputers first became available to consumers and vacuum film deposition technology a standard tool in industry.

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As performance of computer processors improved and the sizes of computers became smaller and smaller, need for improved data storage emerged, particularly in the 1980s. Meanwhile, magnetic surfaces and thin films constituted a major portion of the scientific literature.

It was this era of increased activity in magnetic thin film research, which led to the discovery of the giant magnetoresistance in epitaxial Fe/Cr multilayers in 1989.[15] This effect allows for the design of spin valves for magnetic reading heads, for which Grünberg filed a patent in[16] and Grünberg and Fert received the Nobel Prize in Physics in 2007.

The same crystallographic perfection of thin films applies to semiconductors for multilayer heterostructures for photovoltaic cells[17] and, as is more recently recognized, for photoelectrochemical cells.[18] Therefore, not only the field of computer technology but also energy technology benefitted, ultimately, from van der Merwe's seminal work.

Jan van der Merwe held numerous academic and research positions in South Africa in addition to various appointments overseas. His last appointment as Professor emeritus was with University of Pretoria, Prof Jan H van der Merwe passed away on Sunday, February 28, 2016, on his 94th birthday. At this old age he still frequently attended seminars.

This Focus Issue shows one dozen selected contemporary original research and review papers which feature epitaxy and film defect management, including two-dimensional and one-dimensional structures and quantum dots. As the reader will notice, the development and understanding of epitaxy is not yet final and finished.

We want to finish this Introduction with one important ascertainment. Jan van der Merwe did his groundbreaking research when he was still a PhD student, which reflects back on his mentors' leadership.



ON THE COVER:

This cover features an equation and graph from Jan van der Merwe's seminal 1949 paper representing the thermodynamic conditions of dislocations of ultrathin films on crystal surfaces. In addition, it depicts graphs derived from Lotka Volterra models, a field of interest to van der Merwe (figure from "Interaction between semicoherent interfaces and Volterratype dislocations in dissimilar anisotropic materials") and a sketch of the formation of a uniform homogenous film on substrate by individual atoms from a vacuum chamber.

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