Frosch & Derick: Fifty Years Later

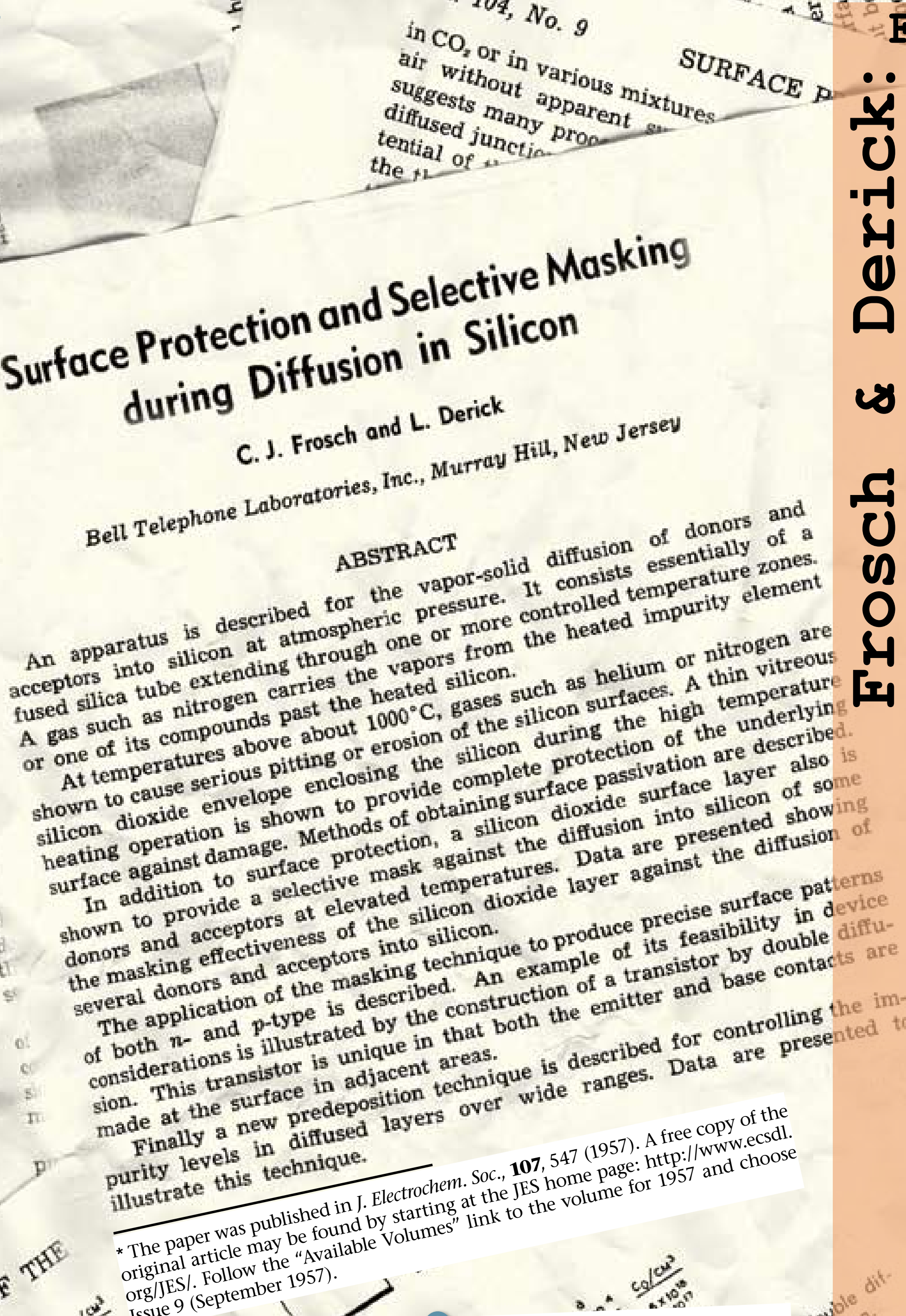
Foreword

by Howard R. Huff and Michael Riordan

In September 1957, Carl Frosch and Link Derick published an epochal paper in the *Journal of The Electrochemical Society* entitled, "Surface Protection and Selective Masking During Diffusion in Silicon." In it they described their 1955 discovery at Bell Labs of ways to form a silicon-dioxide layer on the surface of silicon wafers during the high-temperature diffusion process. In addition, they demonstrated how this glassy protective layer could be etched for use in patterning selected regions of *p*-type and *n*-type impurities in the underlying silicon. Other researchers soon showed that such a dielectric layer could also passivate the silicon beneath it and facilitate the adhesion of aluminum conducting wires while insulating them from the substrate. Taken together, these important technological advances were to have a tremendous impact upon the semiconductor industry. During the late 1950s and early 1960s, researchers at the Fairchild Semiconductor Company applied and extended these techniques to pioneer the planar silicon manufacturing process that finally made the industry vision of monolithic integrated circuits a reality. And in the process, Silicon Valley was born.

To commemorate this pivotal document and its impact on the semiconductor industry, this special issue of *Interface* is devoted to the history and evolution of the silicon-dioxide layer. Indeed, the interface between the oxide layer and the silicon substrate is probably the most important—and most intensively studied—interface in industry, the principal reason why silicon has triumphed over other alternatives and remained the dominant semiconductor material for nearly five decades. Articles by Nick Holonyak and Bruce Deal recount the mid-1950s discovery of the silicon-dioxide layer at Bell Labs and its mid-1960s stabilization at Fairchild. Historians Michael Riordan and Ross Bassett provide wider industry perspectives on the silicon-dioxide layer, including its applications in bipolar integrated circuits, MOS transistors and CMOS circuits. A concluding article by Luigi Colombo and colleagues brings us up to date with recent technology, discussing the issues, challenges and opportunities that confront researchers who today are pushing the MOSFET dielectric layer to an equivalent oxide thickness of less than a nanometer.

We hope you will enjoy the insights and perspectives this special issue has to offer. And we dedicate this issue, in memoriam, to Bruce Deal (1927-2007), who made seminal contributions to silicon oxidation and oxide technology.



Surface Protection and Selective Masking during Diffusion in Silicon

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ABSTRACT

An apparatus is described for the vapor-solid diffusion of donors and acceptors into silicon at atmospheric pressure. It consists essentially of a fused silica tube extending through one or more controlled temperature zones. A gas such as nitrogen carries the vapors from the heated impurity element or one of its compounds past the heated silicon.

At temperatures above about 1000°C, gases such as helium or nitrogen are shown to cause serious pitting or erosion of the silicon surfaces. A thin vitreous silicon dioxide envelope enclosing the silicon during the high temperature heating operation is shown to provide complete protection of the underlying surface against damage. Methods of obtaining surface passivation are described.

In addition to surface protection, a silicon dioxide surface layer also is shown to provide a selective mask against the diffusion into silicon of some donors and acceptors at elevated temperatures. Data are presented showing the masking effectiveness of the silicon dioxide layer against the diffusion of several donors and acceptors into silicon.

The application of the masking technique to produce precise surface patterns of both *n*- and *p*-type is described. An example of its feasibility in device considerations is illustrated by the construction of a transistor by double diffusion. This transistor is unique in that both the emitter and base contacts are made at the surface in adjacent areas.

Finally a new predeposition technique is described for controlling the impurity levels in diffused layers over wide ranges. Data are presented to illustrate this technique.

* The paper was published in *J. Electrochem. Soc.*, **107**, 547 (1957). A free copy of the original article may be found by starting at the JES home page: http://www.ecsdl.org/JES/. Follow the "Available Volumes" link to the volume for 1957 and choose Issue 9 (September 1957).

About the Guest Editors

Howard Huff retired from SEMATECH as Senior Fellow, Emeritus in 2006. His recent responsibilities included issues related to alternative gate stack materials and non-classical CMOS devices. He was co-chair of the Starting Materials section of the *International Technology Roadmap for Semiconductors (ITRS)*. He has organized the ECS Electronics and Photonics Division's Silicon Materials Science and Technology Symposium series. This series has provided a unique historical record of progress in the understanding of silicon materials and related device/IC fabrication and electrical performance issues. He is co-editor of the book *High Dielectric Constant Materials - VLSI MOSFET Applications*, editor of *Into the Nano-Era—Moore's Law Beyond Planar Silicon CMOS* (in press) and is a Fellow of ECS and APS. His current activities include presentations on the Big Band Swing Era (1935-1945), utilizing audios and videos from his extensive collection. He can be reached at hrh2@cox.net.

Michael Riordan earned his PhD in physics from MIT. He is an adjunct professor of physics at the University of California, Santa Cruz, and a Lecturer at Stanford University. He is author of *The Hunting of the Quark* (Simon & Schuster, 1987) and co-author of *Crystal Fire: The Birth of the Information Age* (W.W. Norton, 1997), which won the 1999 Sally Hacker Prize of the Society for the History of Technology. A Fellow of the American Physical Society and a Guggenheim Fellow, he received the prestigious Andrew W. Gemant Award of the American Institute of Physics. He can be reached at mriordan@ucsc.edu.