

Silicon Crystal Growth and Wafer Technologies

This paper reviews the historical development of semiconductor silicon wafer technology including recent advances in wafering and bulk crystal growth, and discusses technologies that will take us beyond current CMOS capabilities.

By GRAHAM FISHER, Member IEEE, MICHAEL R. SEACRIST, Member IEEE, AND ROBERT W. STANDLEY

ABSTRACT | Silicon substrates form the foundation of modern microelectronics. Whereas the first 50 years of silicon wafer technology were primarily driven by the microelectronics industry, applications in photovoltaics (PV) also promise to drive new advances in silicon wafer technology over the next ten years. In the first part, we review the historical development of semiconductor silicon wafer technology and highlight recent technical advances in bulk crystal growth and wafering technologies, including the development of silicon-on-insulator (SOI) technologies and ultrathin wafers. We then discuss technologies that could take us beyond the current capabilities of complementary metal-oxide-semiconductor (CMOS) devices. In the second part, we review silicon manufacturing for PV applications and some unique wafering technology challenges in that field. Finally, we summarize industry roadmaps and product needs highlighting key technical areas which promise to shape the future of silicon wafer technologies in the coming decades.

KEYWORDS | Photovoltaics (PV); semiconductor materials; silicon; substrates

I. INTRODUCTION

Silicon accounts for well over 90% of all semiconductor and solar cell wafer production. During the early days of semiconductor electronics, discrete transistors were typically made from germanium. The lower melting point of germanium meant that crystals were easier to grow. However, this did not last long and the lighter, cheaper, stronger, more abundant element silicon was soon a

Table 1 Maximum Operating Temperature for Various Semiconductors. Commercial Device Specifications Are Significantly Below These Ratings

Material	Bandgap @ T_{room} (eV)	Approx T_{device} (°C)
Ge	0.67	100
Si	1.1	250
GaAs	1.42	400
GaP	2.26	800
β -SiC	2.2	800
α -SiC	3.1	~1000
GaN	3.4	~1000

contender for transistor production. By the late 1960s, at the start of the integrated circuits industry, silicon was favored for two main reasons. First, silicon has a larger bandgap giving it the ability to operate at higher temperatures (see Table 1), and second, because of the remarkable synergy with its oxide, silicon dioxide (SiO_2 , quartz glass). By simply heating silicon in an oxygen containing atmosphere, a high dielectric strength, electrically insulating SiO_2 layer is inexpensively formed. This SiO_2 layer is chemically and mechanically very stable, effectively passivates the surface states of the underlying silicon, forms an effective diffusion barrier for the commonly used dopant species, and can be easily preferentially etched from the silicon, and vice versa, with high selectivity. By contrast, GeO_2 is a chemically unstable, poor electrical insulator that is 33 times more soluble in water than SiO_2 , making it less suited to the photolithographic and wet chemical processes used to fabricate integrated circuits.

Silicon semiconductor material has been studied for over 50 years and the silicon wafer industry today now has

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