Analytical Modeling for Fabrication of Biomedical Pressure Sensors by Bulk Micromachining Technology:
Silicon Capacitive Pressure Sensors

A

Florin Gaiseanu
Science of Information and Technology, Romania

INTRODUCTION

In the present informational era, the informational devices have been increasing their impact not only in individual and global mass media communications (Gaiseanu, 2019a, 2022a), but also in the individual and collective decisional processes (Filip, 2022) by big data analysis (Filip, 2020). The production of the informational devices largely has been grown from simple units to sophisticated integrated circuits and microprocessors, involving for about three decades the intensive development of the microelectromechanical systems (MEMS) (Xu et al., 2019), using these systems to complete the advantages of integration of the sensing informational elements with the micro-processing informational complexes (Song et al., 2020), and of the artificial intelligent systems, which are compatible with human health (Filip, 2021). The individual miniature sensing elements serve in a large range of applications in biomedical, aerospace, automation/automobile fields (Xu et al., 2019; Song et al., 2020), and these are also suitable to be further integrated in more complex systems like "Lab-on-a-chip" (Li, 2008; Lin, 2008), and in silicon-silicon-dioxide-chromium for the detection of the proteins and photo lipids, nitrogen-doped silicon to detect specific proteins, and amorphous silicon-image sensor based on thin-film transistors for X-ray medical imaging. These sensing elements can serve in other suitable combined architecture-complex structures such as silicon probe – polyimide monolithic sensor systems for the detection of neural activity, complementary metal-oxide-silicon (CMOS) and combined bipolar junction transistor with CMOS (BiCMOS), with special biomedical applications for the measurement of the heartbeat rate, of the respiration and of the peripheral and cranial nerve activities. These elements are also used in silicon MEMS-type microphone for the determination of the pulse, silicon nanowires for the detection of deoxyribonucleic acid (DNA) molecules, (Xu et al.,2019), in versatile integration in measurement telematics, together with silicon microprocessors in long-time monitoring medical procedures (Khiem, H. (2011); Xu et al., 2008; Şevket, 1998).

In the healthcare and diagnostic domain, the involvement of the sensing devices and intelligent microsystems became of acute importance, because they offer a compatible and complete intervention due to the used compatible materials, micro-miniaturization and integration into in-situ or in operative Lab-stations micro-processing lines (Gaiseanu, 2019b). The silicon capacitive sensors for biomedical applications are informational microelectromechanical systems (MEMS), measuring the blood pressure, with remarkable advantages related to miniaturization, low-cost production – characteristic to the silicon planar technology, diversity and versatile integration in measurement telematics lines together with silicon microprocessors, in long-time monitoring medical procedures.

DOI: 10.4018/978-1-6684-7366-5.ch043

The silicon semiconductor technology in general, specifically the bulk micromachining (BMM) and surface micromachining (SMM) technology in particular (Bliat, 1998), offer advantageous methods to approach the preparation of various capacitive sensors like piezoresistive sensors, optical fiber pressure sensor, and resonant pressure sensors. Classic applications in the medical field refer to measurement of blood, intraocular and intracranial pressure in coronary heart disease, glaucoma and hypertension, and inflammatory diseases of the nervous system (Song et al., 2020), driven by low cost processes, high reproducibility and reliability, and a large range of sensitivity. This is not only due to the special, suitable electrical and mechanical property of silicon as a base-used material, but also because of the possibility of using the technological and design experience acquired within the fabrication of the microelectronic devices and integrated circuits, for the achievement of the microelectromechanical systems (MEMS) (Chircov & Grumezescu, 2022), with even increased spectacular applications in the biomedical field such as drug synthesis and delivery, microsurgery, microtherapy, diagnostics and prevention, artificial organs, genome synthesis and sequencing, and cell manipulation and characterization. While the SMM technology is based on a polysilicon growth process over a silicon dioxide (sacrificial) layer, and its subsequent removal to achieve thin silicon membranes (Bliat, 1998), the BMM technology obtains it by using a tridimensional (3D) etching process of the silicon substrate until a boron doped (stopping) layer (Kovacs et al., 1998; Bliat 1998), the application of both processes being also possible (Lee et al., 1999).

The achievement of the silicon cavity of the capacitive sensors can be obtained by ion-sputtering dry or wet chemical etching processes, common in the silicon technology (Bliat, 1998). The key property used in the wet etching technology consists in the substantial decrease of the chemical etching rate at a high boron concentration in the boron-doped silicon layer (Bohg, 1971), in ethylene diamine-pyrocatechol-water mixture (EDP), and also in solution of KOH, NaOH, LiOH (Bliat, 1998), in tetramethyl ammonium hydroxide (TMAH)-based solutions, or TMAH/IPA (isopropyl alcohol), fully compatible with integrated circuit technologies. In this work a new etching system was used (Merlos et al., 1993), which causes it to be called a self-limiting/self-stopping process. However, this is only a first approximation, because the distribution of the boron concentration in the silicon substrate is not uniform, neither near the silicon surface nor in the bulk. Indeed, after the diffusion process, the boron concentration is a function of the diffusion depth, so the etching process depends on the variation of the boron concentration in the bulk. The main problem concerning the achievement of silicon membranes with a certain well-defined thickness according to the design requirements and the sensitivity range of the pressure, is therefore strictly related to control of the technological process. Such a control requires a practical method to simulate the boron diffusion profile in silicon, according to the technological used parameters, time and temperature and also to the type of the diffusion source (Gaiseanu et al, 1997a,b).

The more their importance increases in applications, the more a precision design and technological control is needed, which should reveal/describe/simulate in advance the technical and technological characteristics of the final product (Gaiseanu et al., 1997d, Gaiseanu & Esteve, 1999). In this chapter it is therefore approached an analytical modeling of the boron diffusion in silicon from boron nitride (BN) and boron tribromide (BBr_3) sources, commonly used for this purpose, and a suitable calculation of the etching rate and etching time for the accurate achievement of silicon membranes of the capacitive pressure sensors for biomedical applications by micromachining technology. As the present trend in the fabrication of the biomedical devices, and in particular of the capacitive pressure sensors, is miniaturization, with all the associated advantages, this approach is of a high impact on a further improvements on this direction, taking into account that independently of the used technology, the processing control plays a decisive role for the size reduction of these devices (Song et al., 2020), with obvious advantages also for the technical performance.