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Technology roadmap for development of SiC sensors at plasma processes laboratory

Abstract: *Recognizing the need to consolidate the research and development (R&D) activities in microelectronics fields in a strategic manner, the Plasma Processes Laboratory of the Technological Institute of Aeronautics (LPP-ITA) has established a technology roadmap to serve as a guide for activities related to development of sensors based on silicon carbide (SiC) thin films. These sensors have also potential interest to the aerospace field due to their ability to operate in harsh environment such as high temperatures and intense radiation. In the present paper, this roadmap is described and presented in four main sections: i) introduction, ii) what we have already done in the past, iii) what we are doing in this moment, and iv) our targets up to 2015. The critical technological issues were evaluated for different categories: SiC deposition techniques, SiC processing techniques for sensors fabrication and sensors characterization. This roadmap also presents a shared vision of how R&D activities in microelectronics should develop over the next five years in our laboratory.*
Keywords: *Silicon carbide, Sensors, Aerospace applications, Roadmap, Project planning.*

INTRODUCTION

Silicon carbide (SiC) has been widely studied as an electronic material since 1959, when Shockley, the inventor of the bipolar transistor, recognized this material as essential to enable the development of microelectronic devices that can withstand harsh environmental conditions where silicon cannot be used or have limited applications such as high temperatures and intense radiation (Shockley, 1959). The potential of SiC for these applications is due to its inherent properties as excellent thermal stability, high resistance to chemical attack, high hardness, high bandgap, high electric field breakdown and high saturation current of electrons (Rajab, 2005).

Several techniques for obtaining thin films and bulks of SiC have been developed. Some companies that manufacture crystalline silicon wafers also offer SiC bulk wafers up to 3 inches in diameter. However, a SiC wafer has an average price fifteen times more than the Si wafer with the same dimensions (Muller *et al*., 2001). Besides the high cost, another problem of the use of SiC substrates is the difficult micromachining process and high density of defects (Wu *et al*., 2001). In this context, there is a crescent interest in deposition techniques of SiC films on Si or SOI (Silicon-On-Insulator) substrates. These films can be produced in crystalline and amorphous forms.

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Crystalline SiC films are produced by techniques that use temperatures higher than 1000°C such as Chemical Vapor Deposition (CVD), Molecular Beam Epitaxy (MBE) and Electron Cyclotron Resonance (ECR) (Sarro, 2000). The high temperatures involved in these techniques generally become impracticable for the processing of these films in conjunction with conventional microelectronics processes. Hence, the plasma-assisted techniques such as Plasma Enhanced Chemical Vapor Deposition (PECVD) and sputtering, that allow obtaining SiC films at temperatures below 400°C, are very attractive (Prado, 1997). However, SiC films produced at low temperatures are amorphous and their properties are different from those observed in crystalline structures. In general, amorphous films have lower elasticity modulus and higher electrical resistivity.

Since the 1970s, many studies have been performed on doping of amorphous SiC films in order to obtain properties near to crystalline for applications at different types of devices such as photovoltaic cells, optical sensors, diodes and thin film transistors (TFTs) (Spear and LeComber, 1975; Kanicki, 1991; Tawada *et al*., 1982). Nowadays, the processes most used to doping of SiC films are *in situ* doping (during film growth) and ion implantation.

In the 1990s, due to emerging MEMS (Micro Electro Mechanical Systems) technology and the increasing demand for sensors operating at temperatures above 300ºC for different applications, SiC films and substrates started to be used as alternatives to silicon in the fabrication of sensors to operate in severe environments as combustion processes or gas turbine control, oil industry, nuclear power and industry process control (Cocuzza, 2004).

Some sensors and electronic devices based on SiC that are currently commercially available are showed in Fig.1 (Nowak, 2005).

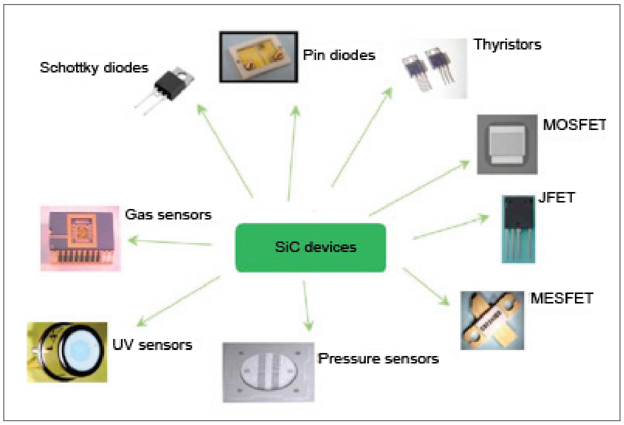

Figure 1: SiC-based devices commercially available.

As there is a great interest in the use of SiC in high temperature devices, especially for applications in aerospace and aeronautics fields, LPP-ITA has established a R&D line oriented to the development of SiC sensors as presented in the next sections.

ANTECEDENTS OF R&D ACTIVITIES IN MICROELECTRONICS

Since 1988, LPP-ITA has carried out research projects on plasma technology applications. One of the main research lines in this field is directed to synthesis and modification of semiconductor thin films through low temperature plasma processes such as radiofrequency (RF) magnetron sputtering, plasma enhanced chemical vapor deposition (PECVD), reactive ion etching (RIE) and inductively coupled plasma (ICP).

The R&D activities in microelectronics were intensified in 2001, when a clean room environment was implemented through a financing of the São Paulo Research Foundation (FAPESP). The development of specific researches related to growth and characterization of SiC thin films were started in 2003 leading to a master thesis about the effect of thermal annealing on physical and electrical properties of SiC films (Rajab, 2005). This project was supported by a grant from CNPq/Microelectronics National Program (PNM). The results obtained during this thesis work showed that the SiC films produced in the laboratory by RF magnetron sputtering technique had appropriate characteristics for applications in electronics and MEMS (Micro Electro Mechanical Systems) devices (Rajab *et al*., 2006).

In this context, in 2005 a PhD thesis on development of piezoresistive sensors based on SiC films was started with support from CNPq/Microelectronics National Program (PNM) (Fraga, 2009). In this thesis, besides the RF magnetron sputtering, the PECVD technique was used to produce the SiC films. This allowed comparing the properties of SiC films produced by both deposition processes. In addition, the influence of nitrogen doping on SiC film characteristics was also investigated (Fraga *et al*., 2008a; Fraga *et al*., 2008b).

The reactive ion etching (RIE) of SiC films using SF_6/O_2 gases mixtures was another process studied, because this step is very important in the fabrication of devices. The etching rate was investigated as a function of film composition and O_2 concentration. The influence of thermal annealing on etching characteristics was also evaluated (Fraga *et al*., 2007a; Fraga *et al*., 2007b).

The evolution of R&D activities related to the development of SiC films at Plasma and Processes Laboratory is summarized in Fig. 2.

In 2008, in order to make possible the development of devices based on SiC films, a collaboration project was established with the Microfabrication Laboratory of the Brazilian Synchrotron Light Laboratory (LNLS). The first devices developed through this project were strain gauges based on SiC films. The structure of these strain gauges consists of a SiC thin-film resistor with Ti/Au electrical contacts (Fraga *et al*., 2010a). Subsequently, a prototype of piezoresistive sensor based on SiC film was designed, fabricated and characterized (Fraga *et al*., 2010b).

The development cycles of the SiC sensors are shown in Fig. 3. As it can be observed, two steps have not been performed in LPP-ITA yet: pattern transfer by photolithography and wire bonding process.

CURRENT STAGE OF R&D ACTIVITIES

The current stage of R&D activities at LPP-ITA aims to implement a technology roadmap for development of SiC sensors (Fig. 4). In this section, the roadmap development process is explained.

The development process is divided into the following stages.

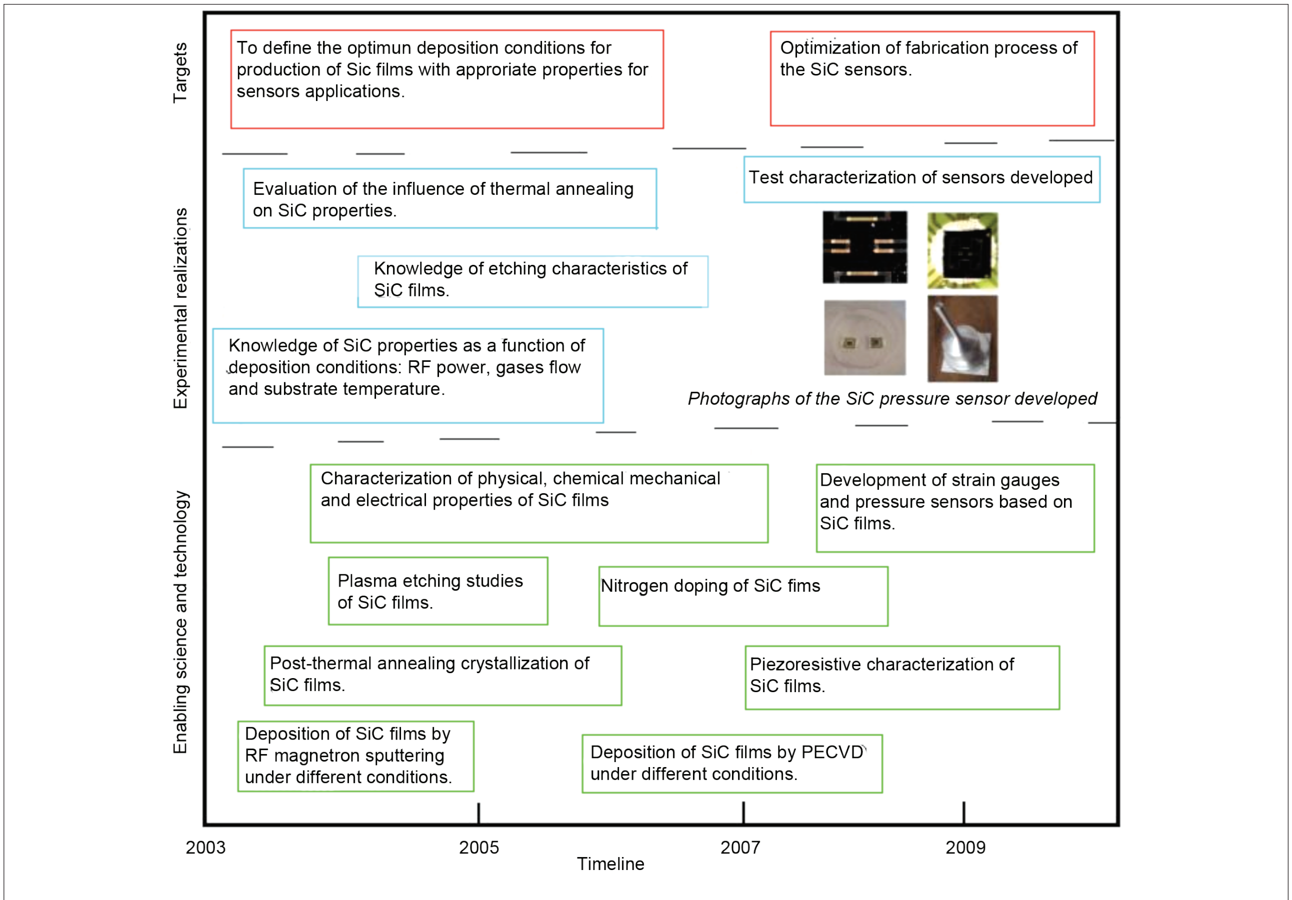

Figure 2: Evolution of R&D activities related to development of SiC films at Plasma Processes Laboratory.

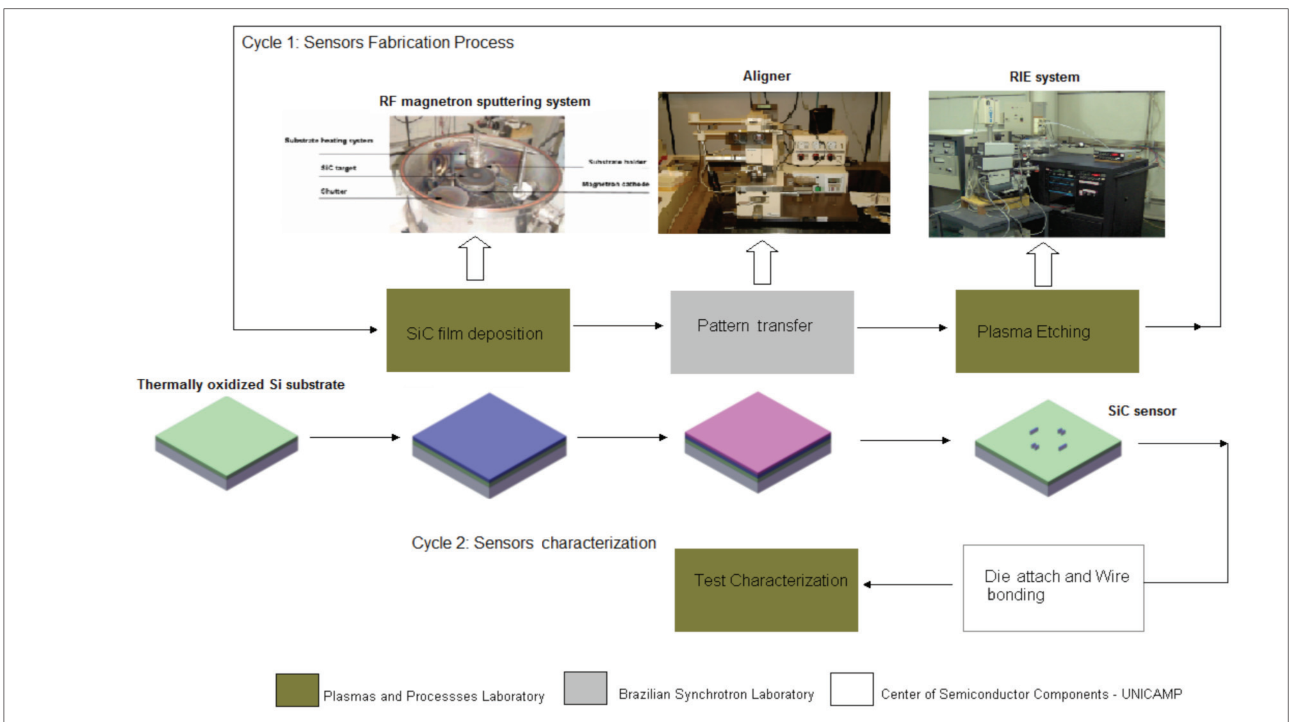

Figure 3: Current development cycles of SiC sensors.

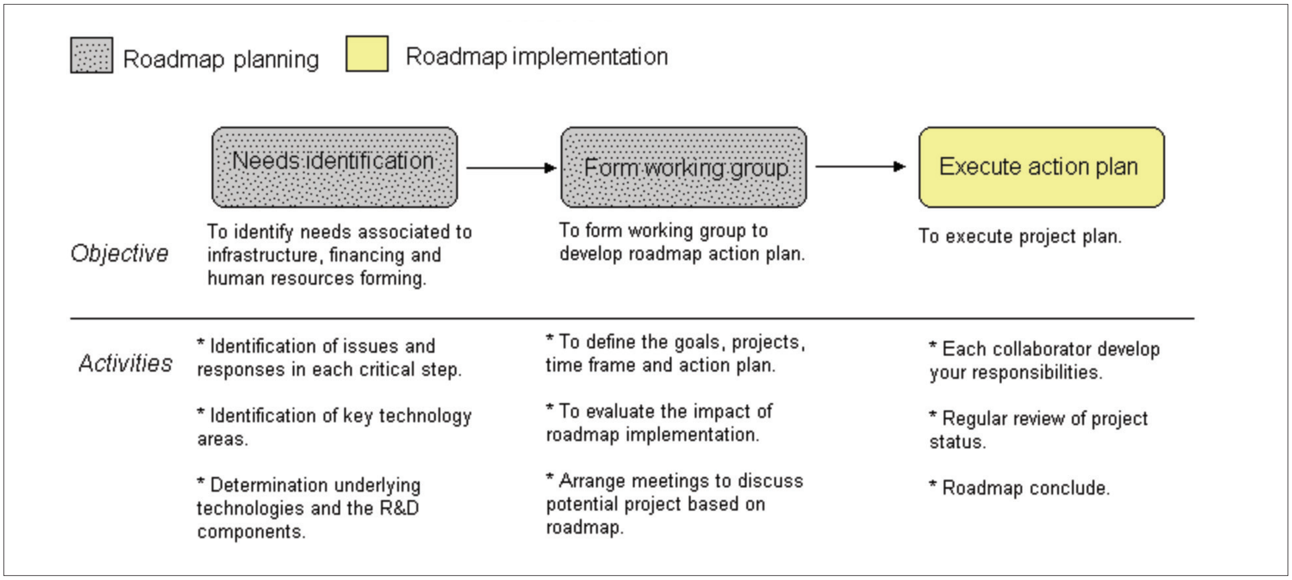

Figure 4: Roadmap development process.

Needs identification

This is the first stage of the process in which occurs the identification of the needs related to the SiC sensors technology development. These needs are grouped in three main categories: infrastructure, financing and human resources.

Nowadays, the Plasma and Processes Laboratory counts on financing of the Brazilian Space Agency (AEB) to assemble a room for characterization of electronics and MEMS devices. Besides, the clean room facilities have been amplified with the recent acquisitions of an oxidation furnace, a KOH etching system and a hot plate through the financial support of the National Council for Scientific and Technological Development (CNPq). Additionally, a dual dc magnetron sputtering system for the growth of SiC films, from targets of silicon and carbon, is being implemented. The idea of this system is to control the stoichiometry and improves the quality/functionality of the films through use of pulsed dc power sources. The main needs associated with infrastructure are the clean room area enlargement and the acquisition of a mask aligner in order to perform all steps of sensors fabrication in the laboratory.

In relation to human resources, since December 2009 the National Post-Doctoral Program (PNPD)/CAPES finances two grants on development of SiC sensors.

Form working group to the development of roadmap

Due to the interdisciplinary nature of SiC sensors technology, researchers from a wide variety of backgrounds are required to form roadmap working groups. The staff of Plasma Processes Laboratory consists of 42 members, and this interdisciplinary background has degrees in physics, material science, microelectronics and engineering. Five PhDs and one PhD student of these staff are working at the moment on researches related to SiC sensors.

This working group discussed the framework roadmap and, subsequently, a methodology was adopted considering the itemization of issues and responses to each critical step and identification of the key technologies. The determination of a realistic timeline and of a cost range for the processes implementation was also required.

In order to define an action plan roadmap, the working group divided the critical technologies into three categories:

a) SiC deposition techniques;

b) SiC processing techniques for sensors fabrication;

c) SiC sensors characterization.

For each category, the working group will define goals, the impact of the technology, the timeframe for development and the execution plan.

Execution action plan

A detailed project plan with indication of roles and responsibilities of each working group member is being finalized. A funding strategy will be developed to overcome critical infrastructure issues.

The progress of roadmap execution action plan will be evaluated by regular review of the project status and deliverables. The expectative is that the implementation of this roadmap raises the level of sharing and integration among staff, facilities and services of the laboratory. This allows that the researchers quickly define the key services and that they focus on the technical challenges.

To help its staff keep pace with the changes in science and technology, the laboratory have formed masters and PhDs in plasma physics, materials science and microelectronics.

PERSPECTIVES UP TO 2015

The development of the SiC sensors is based on progress in the following technologies: 1) improved electrical and mechanical properties of SiC films produced (optimization of SiC deposition process), 2) SiC film processing (optimization of etching process and metallization appropriate for high temperature applications), 3) microfabrication technology to fabricate miniaturized sensors and 4) sensors packaging for harsh environments.

The R&D activities of the Technological Institute of Aeronautics have been focused on aerospace and aeronautical fields. In this manner, the goal of Plasma and Processes Laboratory is to develop SiC sensors with potential for use in a range of these applications. The sensor types of main interest are capable of measuring pressure, strain and acceleration under high temperatures and in the presence of corrosive media or intense radiation.

Figure 5 shows the types of sensors that are being developed and the technological evolution that we intend to follow till 2015. The main technologies involved and some possible applications also are shown. In the next years, our goals will be concentrated in improving the performance of the SiC pressure sensors and strain gauges developed, besides making possible the development of accelerometers and SAW sensors based on the aluminum nitride (AlN) films deposited on SiC.

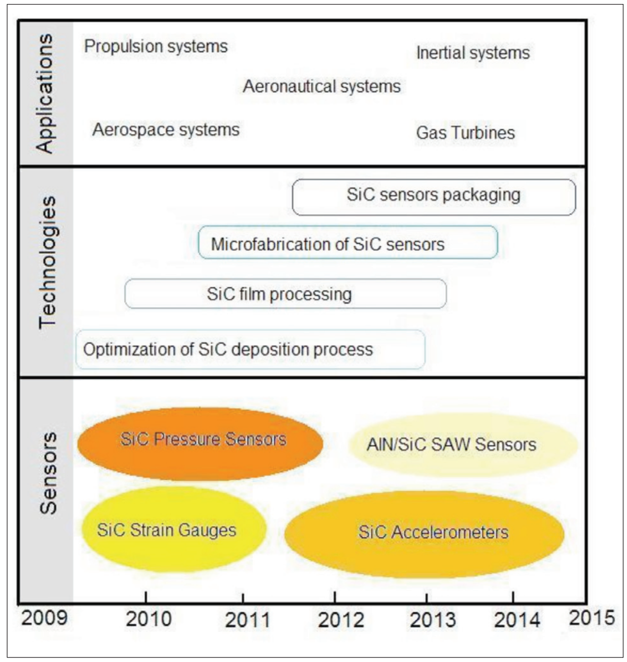

Figure 5: Roadmap for development and application of SiC sensors.

CONCLUSIONS

The vision expressed in this roadmap is to use the know-how of Plasma and Processes Laboratory staff to develop SiC sensors. We believe that the way to do this is developing technologies, which enable science, engineering and manufacturing. Close cooperation between the laboratory and other research centers will always be necessary because this cross-disciplinary development will bring broad benefits through ideas, instruments and techniques that will result from developing and consolidating the required base technology.

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