Radiation detectors based on 4H semi-insulating silicon carbide - is it solution for ILC and/or CLIC?

Silicon carbide (SiC) has some unique advantages and is widely used in such applications as:

- **ultraviolet photodiodes;**
- **high voltage diodes for power electronics;**
- **neutron counters in nuclear reactors (photodiodes covered with boron glass)**

These devices are formed in epitaxial layers grown on low resistivity substrates

SiC photodiodes have significantly higher radiation hardness than silicon diodes (detectors). About 5 times higher doses are required to achieve the same degradation in CCE (Charge Collection Efficiency) or in dark current.

Initial dark currents have typically density of 2pA/cm2. Due to energy band gap of 3.2eV, SiC diodes can work at relatively high temperatures.

The main disadvantage of SiC devices are high values of depletion voltages due to low resistivity of epi-layers.

Rapid development of SiC technology (proper compensation of dopants) allowed to produce high resistivity SiC (semi-insulating), now commercially available – even in form of 6-inches in diameter and 300-500 µm thick wafers.

Lifetime of excess carriers in SiC is reported to be between 100ns – 10 µs, depending on material quality.

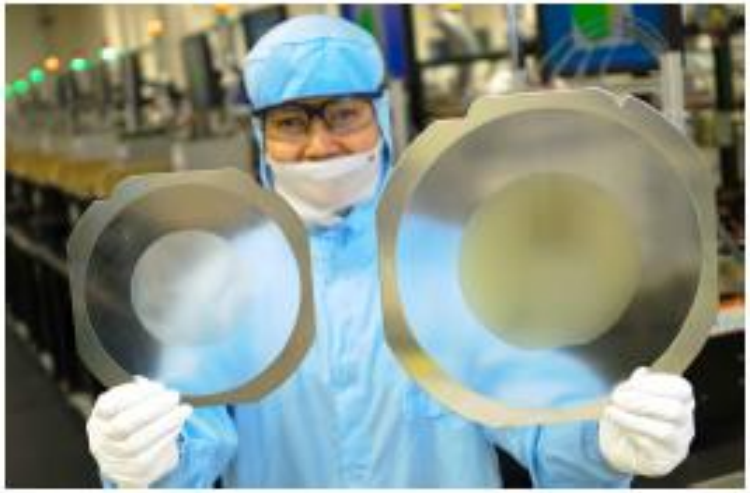
Moreover SiC wafers are processed in existing technology lines for Si, by means of well known technology processes with modified parameters.

Relatively high price of semi-insulating wafers (see next slides) seems to be main obstacle in SiC radiation detectors development.

3-inches wafer from best vendor, CREE (USA), costs 1800 -2000 $, depending on quantity. (see copy of actual Offer in slide 7)

CREE

Cree Silicon Carbide Substrates and Epitaxy



Supported diameters:

- 76.2 mm
- 100.0 mm
- 150.0 mm

Product Specifications

4H Silicon Carbide Substrates
N-type, P-type, and Semi-Insulating

N-type and P-type Silicon Carbide Epitaxy

OFFER AND AGREEMENT FOR SALE OF PRODUCTS

Cree, Inc.

4600 Silicon Drive Durham, NC 27703
(919) 313-5300 Fax: (919) 313-5451

OFFER NUMBER
19027
WHEN ORDERING, PLEASE REFER TO THIS NUMBER

CUSTOMER:

Arkadiusz Moszczynski

INP Krakow

Radzikowskiego 15, Krakow, Poland 31332

phone: (48)12 412 7971 e-mail: arkadiusz.moszczynski@ifj.edu.pl

DATE	REFERENCE	OFFER EXPIRATION DATE	PAYMENT TERMS	EXW POINT
12/10/2015	e-mail RFQ	1/10/2016	NET 30	Durham, NC

LINE ITEM	QTY	PART NUMBER	DESCRIPTION	DELIVERY	UNIT PRICE	EXTENSION
1		W4TRE0R-0200	4H-SiC, high-purity semi-insulating, research grade, 76.2mm dia., on-axis, > 1E5 ohm-cm, both sides polished/silicon face epitaxy ready with CMP finish	4-6 WKS ARO		
	1	Qty. 1-4			$1,927.61	$1,927.61
	10	Qty. 5-10			$1,889.06	$18,890.60
				TOTAL		

Next slides presents fragments of abstracts taken from first (to my knowledge) articles treating on SiC radiation detectors made of semi-insulating material.

Nuclear Physics B (Proceedings Supplements), Volume 78, Issue 1, p. 516-520.; 08/1999;
Particle detectors based on semi-insulating Silicon Carbide;
Rogalla, M.; Runge, K.; Söldner-Rembold, A. (Freiburg University)
Fragment of abstract:

„Particle detectors were made using semi-insulating 4H-SiC as the detection medium. Devices produced with this material have the possibility of being extremely radiation hard. For the purposes of building radiation hard detectors, the parameters of interest are the large band gap and low intrinsic carrier density which implies low leakage currents, the large resistivity that allows ohmic contacts to be used to sense the charge created during ionisation, the large breakdown voltage that gives stable operation…..”

to be continued →

„The investigated photoconductivity detectors are formed by ohmic contacts (Al) on the front- and back-side of a 310 µm thick semi-insulating 4H-SiC substrate from Cree. These structures of contacts are ranging from 1 - 3 mm in diameter and have a guard ring structure to prevent edge leakage currents. From the I-V characteristic a substrate resistivity of 5.1 · 10 10 Ωcm was determined. The detectors respond to β-particles similar as detectors made of diamond. Signal heights of about 2000 e - were achieved for quasi minimum ionising electrons. First radiation hardness tests shows an increase of the substrate resistivity by a factor three after a proton (8 GeV) fluence of 4.16·10 14 cm -2 and a reduction of the signal height of about 23%."

SPIE Proceedings | Volume 7805 (2010)

Radiation detectors based on 4H semi-insulating silicon carbide

Krishna C. Mandal ; Ramesh Krishna ; Peter G. Muzykov ; Zegilor Laney ; Sandip Das ; Tangali S. Sudarshan

Fragments of abstract:

„In this work, radiation detectors were fabricated using 8 mm × 8 mm substrates, ~ 390 µm in thickness, diced from commercial (0001) 4H-SiC semi-insulating wafer (> 109 Ohm-cm)….. Our characterization results show the high quality of the semi-insulating SiC crystals, which are believed to meet the requirements of fabricating high performance radiation detectors. Current-voltage characteristics showed very low leakage current (~ 1.5 pA at -500 V) and the capability of detector's operation up to 200°C.”

Conclusions:

- we should „find” proper founds;

- we should buy some quantity of SiC semi-insulating wafers, possibly from various vendors;

- we should find factory with established technology of SiC photodiodes production and ask them to process our wafers with set of masks designed according to our suggestions.

Summary:

- in my opinion, use of SiC detectors as alternative to Si, GaAs, diamond and sapphire ones should be considered;

- I declare to participate in irradiations (with protons) and measuruments of I(U), C(U) and CCE (with alpha sources) after each step of irradiation of SiC detectors and/or test structures.

Backup slide…

Nuclear Science, IEEE Transactions on (Volume:53 , Issue: 3); June 2006; High-resolution alpha-particle spectrometry using 4H silicon carbide semiconductor detectors;
Wei Wang et al.;

Fragments of abstract:

„SiC detectors with active volume dimensions sufficient to stop alpha particles have been manufactured and tested. A linear energy response and excellent energy resolution have been obtained for various alpha emitters in the 3.18-MeV to 8.38-MeV energy range……
The measured values (of FWHM) are comparable to those achievable with silicon alpha spectrometers.”