Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 572 (2007) 1056–1064
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Noise and trigger efficiency characterization of cooled silicon pad detectors

A.C. Marques[a,c,*], U. Wahl[a,b], J.G. Correia[a,b,c], M.R. Silva[a], A. Rudge[c], P. Weilhammer[c], J.C. Soares[a], the ISOLDE collaboration[c]

[a] *Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
[b] *Instituto Tecnológico e Nuclear, Sacavém, Portugal*
[c] *CERN European Organization for Nuclear Research, CH-1211 Genève 23, Switzerland*

Received 24 February 2006; received in revised form 6 November 2006; accepted 19 December 2006
Available online 19 January 2007

Abstract

Technical progress on silicon pad electron detectors, currently used in emission channelling experiments to study lattice location of radioactive dopants and impurities in single crystals, is reported. Noise and trigger efficiency improvements are achieved by using 500 μm and 1 mm thick detectors coupled to a cooled readout system. The static properties, noise, gamma ray and electron trigger efficiency and energy resolution for different temperatures under air and vacuum were measured. The advantages of the future implementation of 1 mm silicon pad detectors with cooled self-triggering readout chips are discussed.

PACS: 07.77.Ka; 29.30.Dn; 29.40.Gx; 29.40.Wk

Keywords: Position-sensitive detectors; Cooling silicon pad detectors; Electron detection; Noise and trigger efficiency characterization

1. Introduction

The production of devices with fast readout and reduced noise levels has been the main aim of an intense research and development programme on highly segmented silicon pad detectors. The detection of low-energy X-rays and electrons below 10 keV is currently available using prototype devices triggering at high-speed, up to the MHz range [1]. This technical progress was achieved with such devices which provide a wide field of applications in high-energy physics, solid state research and new imaging Positron Emission Tomography technologies.

Pad detectors are being used at the ISOLDE/CERN facility since 1996 [2–4]. Conversion electrons, β^- and β^+ particles are detected in emission channelling (EC) experiments with the aim of studying the lattice sites of radioactive impurities implanted at low doses in single crystals. The EC method is based on the fact that charged particles from nuclear decay (α, β, β^+, conversion electrons) experience channelling or blocking effects along major crystallographic axes and planes. The resulting anisotropic emission yield from the crystal surface characterizes the lattice site occupied by the probe atoms during decay. In most EC experiments, the typical energy range for conversion electrons and β particles is from a few tens of keV to a few MeV. Table 1 lists some examples of isotopes that are short-lived β emitters or low-energy conversion electron emitters and are of interest for future EC experiments [5]. At present, however, EC experiments with these isotopes are not yet possible, for the following reasons.

In currently used detectors, limitations are due to the method of using the signals from the full backplane of the pad detector for triggering the readout of a set of four VA1

*Corresponding author. CERN European Organization for Nuclear Research, CH-1211 Genève 23, Switzerland. Tel.: +41 227679709; fax: +41 227678990.
E-mail address: ana.marques@cern.ch (A.C. Marques).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2006.12.028

Table 1
Some radioactive isotopes for possible future use with the EC technique

	Radioisotope	Parent	Half-life	Decay ratio (%)	E (keV)
Low energy conversion electron emitters	^{73}Ge	^{73}As	80.3 d	181	10–53
	^{119}Sn	^{119}Sb	38.2 h	95.8	19–28
	^{119}Sn	^{119m}Sn	293.1 d	192	19–66
	^{125}Te	^{125}I	60.1 d	33.3	22–35
	^{58}Co	^{58m}Co	9.15 h	92.6	17.2–24.1
	Radioisotope	Parent	Half-life	E (keV)	E_{max} (keV)
Short-lived β^- emitters	^{27}Mg	^{27}Na	9.5 min	703	1767
	^{61}Co	^{61}Fe	1.7 h	460	1254
	^{65}Ni	^{65}Co	2.5 h	629	2137
	^{69}Zn	^{69}Cu	56 min	322	906
	^{75}Ge	^{75}Ga	1.4 h	421	1177

chips [6]. Due to the high backplane capacitance and the relatively high leakage current of the guard ring, the equivalent noise charge (ENC) of the backplane trigger electronics is above 1000 e^-, thus limiting the threshold for electron detection to ~35 keV. The readout cycle is limited to count rates of 250 Hz, thus hindering the use of isotopes with half-lives shorter than few hours. As will be shown, the detector capacitance is the main noise source in this detection system since the leakage current of single pads is very low (<100 pA) [7–9]. The main contributions to the load capacitance, which a specific electronic channel is exposed to, are the capacitance of the p^+n junction of a specific pad to the backplane and of the capacitance of the routing lines to the virtual ground of all amplifier channels of the pads over which a specific routing line passes. All other stray capacitances in the detector system are negligible. To obtain optimum performance it is necessary to cool the in-vacuum readout chips, which otherwise heat up the detector and thus increase its leakage current.

The purpose of the work presented here was twofold: (1) to develop a reliable and stable way in order to cool a pad detector and its readout chips in vacuum (this development was made necessary since in the near future a new generation of detection systems will be equipped with self-triggering readout chips whose increased thermal load makes active cooling imperative); (2) to characterise the noise behaviour of currently used detector systems with backplane triggering upon actively cooling the device and find their optimum operating conditions. The detector used in these studies was selected from a group of 500 μm and 1 mm thick position-sensitive electron pad detectors for EC applications. All detectors were extensively tested on the wafer and after cutting at a probe station. The detectors have no defects. The selected detector had the lowest leakage current (10 pA/pad at 20 °C) and it was mounted on a printed circuit board (PCB) with four VA1 chips, triggered by the backplane signal, and coupled to a Peltier and water-cooled refrigeration system.

2. Layout of the in-vacuum EC detector mounting and cooling system

The implementation of the cooling system required the development of a new chamber for the detector and of the tube connecting it to the sample chamber.

Fig. 1(a) shows the new mechanical design of the detector chamber and (b) the photo of the whole setup. The detector chamber has two removable square side flanges, a back flange and a large circular opening with a diameter of 100 mm facing the radioactive sample. The back flange has a 50-pin vacuum feed through for the electrical connections. The side flange supports a lateral plate holding the PCB board of the detector, allowing the passage of the water-cooling pipes. This flange enables the detector to be mounted so that either the pad or the backplane side can face the sample. The inner walls of the connection tube have a special *seesaw* profile that reduces electron scattering from the walls onto the detector.

Fig. 2 shows the system developed to cool the four VA1 readout chips with four Peltier elements mounted opposite to the chips and refrigerated by circulating water. Fig. 2(a) shows the cross section view of the cooling system and Fig. 2(b) and (c) show its square-shaped copper ring braised to the water pipe. This ring is pressed against the hot side of the Peltier elements, while the cold sides are in contact with the small ceramic plates that hold the detector (visible in Fig. 2c). A thin layer of vacuum grease is used to improve thermal conductivity. The VA1 chips are thus cooled via the ceramic holders and the thin PCB layer on which they are mounted. A platinum resistance temperature sensor (Pt 100) has been glued on top of one VA1 chip (in between bonds) to provide reference temperature measurements. The measurement of the detector performance as a function of this parameter clearly shows its temperature to follow the VA1 chip temperature. A simple current supply was developed to stabilize the temperature at a pre-set value using feedback from the sensor.