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Monolithic silicon E-ΔE telescope produced by the Quasi-Selective Epitaxy

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Abstract A monolithic, silicon, E-ΔE telescope with a 20 μm thick ΔE detector followed by a 300 μm thick E detector based on the n-p$^+$-n structure was produced using a new developed process named Quasi-Selective Epitaxy (QSE). The resistivity profile of the n-p$^+$-n structure and E-ΔE two-dimensional contour plots obtained after irradiation of the monolithic E-ΔE telescope by α-particles are presented. An energy resolution of about 1 MeV was obtained.

Key words monolithic E-ΔE telescope • quasi-selective epitaxy

Introduction

Epitaxial monolithic E-ΔE detectors [3–5] are produced using n-n$^+$-n structures where the buried layer n$^+$ is created by the impurity diffusion into a high resistivity, thick n-type substrate. The E detector is created using the high resistivity thick n-type substrate. The transmission ΔE detector is made from the epitaxial n-type layer grown on the n$^+$-n substrate. The extraction of the edge of the n$^+$ buried layer is obtained by polishing the surrounding ΔE electrode with a slight slope [4]. The ohmic contact with the buried layer is produced by evaporation of gold on the edge of the buried layer appearing on the polished surface.

The aim of the present work was to develop a method of more simple and easy extraction of the buried layer edge. This problem can be simply solved by application of the selective epitaxial growth which means an epitaxial growth of silicon only into open windows in the SiO_2 layer at reduced pressure using the SiH_2Cl_2–H_2–HCl system [1, 2]. This process is effective and used elsewhere in microelectronics, e.g. for the production of MOSFET transistors [2], however, it is more complicated than the "classical" epitaxy (atmospheric pressure with the SiH_2Cl_2–H_2 system) since the use of low pressure gases of about 50 torr with HCl added is necessary.

To avoid this problems we have elaborated a new technological process named Quasi-Selective Epitaxy (QSE) which consists of two steps:

1. Growth of polycrystalline silicon layers on SiO_2 and epitaxial growth of silicon on silicon into the SiO_2 window openings.
2. Etching of SiO_2 by HF and thereby removal of the polycrystalline silicon layer grown on SiO_2.

As a result of the QSE process we have the silicon mesa epitaxially grown in places of the SiO_2 windows. We have used SiO_2 layers with a thickness of about 4000 Å. For thin epitaxial layers, about 3 μm thick, the density of silicon clusters grown on SiO_2 is low and etching of SiO_2 by HF and removing of polysilicon is easy. When the thickness of

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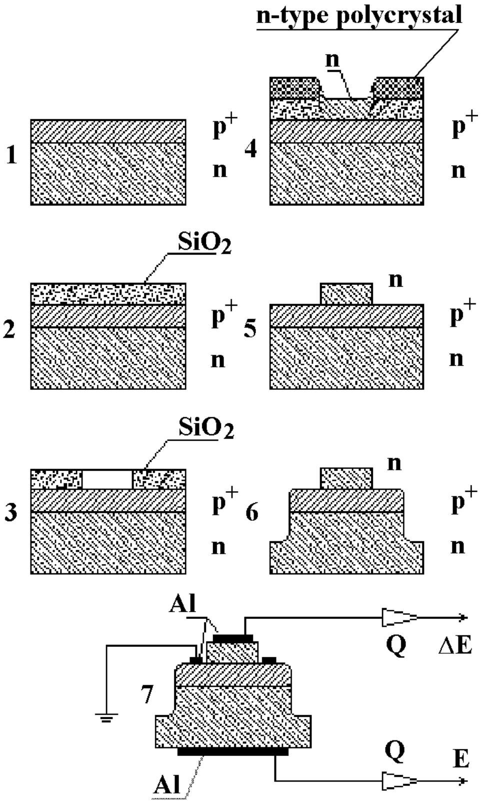

Fig. 1. Technological process of the production of a monolithic E-ΔE telescope is consisting of the following steps: 1 – p^+-n junction creation by epitaxy on the 300 μm thick high resistivity n-type substrate; 2 – deposition of 4000 Å thick thermal oxide; 3 – circular window opening by photolithography; 4 – growth of polycrystalline silicon layers on SiO$_2$ and epitaxial growth of silicon on silicon into the SiO$_2$ window; 5 – n-type mesa fabrication for the ΔE detector by etching of SiO$_2$ with HF acid followed by removal of the polycrystalline silicon layer grown on SiO$_2$; 6 – etching of the detector edges; 7 – evaporation of aluminium contacts to the n-type mesa of the ΔE detector and for the p^+-type buried epitaxial layer. Evaporation of aluminium for the bottom contacts to the E detector. Connection of the detector with the charge preamplifiers denoted by triangles marked with Q.

the epitaxial layer is more than 10 μm on SiO$_2$, a polycrystalline silicon layer is formed. It was experimentally proved that etching of SiO$_2$ leading to removal of the polycrystalline silicon layers is possible up to 50 μm thick epitaxial layers.

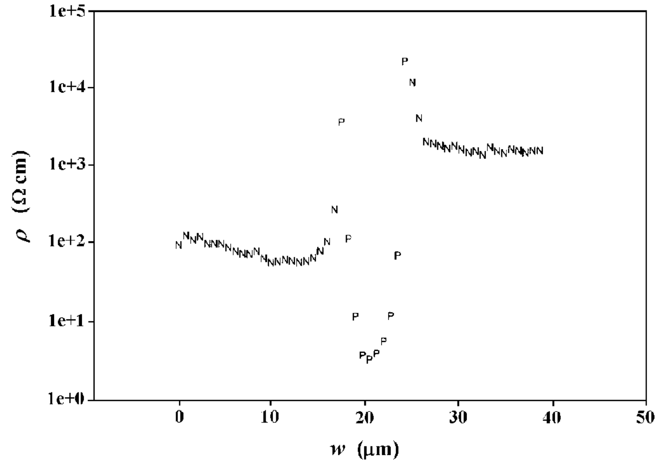

Fig. 2. Silicon resistivity ρ (Ωcm) *vs.* depth w (μm). The spreading resistance of the n-p^+-n structure is shown for the monolithic E-ΔE telescope. Points denoted by letters N or P correspond to n-type or p-type silicon, respectively. The buried p-type silicon layer extends from 17.4 to 24.2 μm, other regions are of n-type silicon. The "high resistivity peaks" correspond to the n-p^+ and p^+-n junctions for ΔE and E detector, respectively.

Construction of an integrated E-ΔE telescope and measurement of α-particles

The process of the telescope design is illustrated by Fig. 1. The float zone, <111> oriented, n-type, 300 μm thick, one side polished silicon wafer of $\rho = 6000$ Ωcm resistivity was covered by a 4 μm thick p^+ epitaxial layer with a resistivity of about $\rho = 0.45$ Ωcm, measured by the four-probe array method. The epitaxial process was performed in a standard production reactor at 1050°C with a growth rate of 1 μm/min. Then the 4000 Å thick oxide on the p^+-n structure was thermally grown by wet oxidation at 1100°C. The window openings with a diameter of about 6 mm were created on the wafer. The 20 μm thick n-type epitaxial layer with a resistivity of about 100 Ωcm was deposited in the open windows accompanied by growth of a polycrystalline silicon layer on the SiO$_2$. The next step was chemical etching of SiO$_2$ with HF acid followed by removal of the polycrystalline silicon layer. Evaporation of Al contacts was performed on the p^+ layer edge and on the back sides of E and ΔE detector without additional formation. The resistivity profile of the n-p^+-n detector structure, measured by a spreading resistance method on a bevel is presented in Fig. 2. Due to boron diffusion at high-temperature processes the distance between n-p and p-n junctions in the final structure was about 7 μm and the resistivity of the

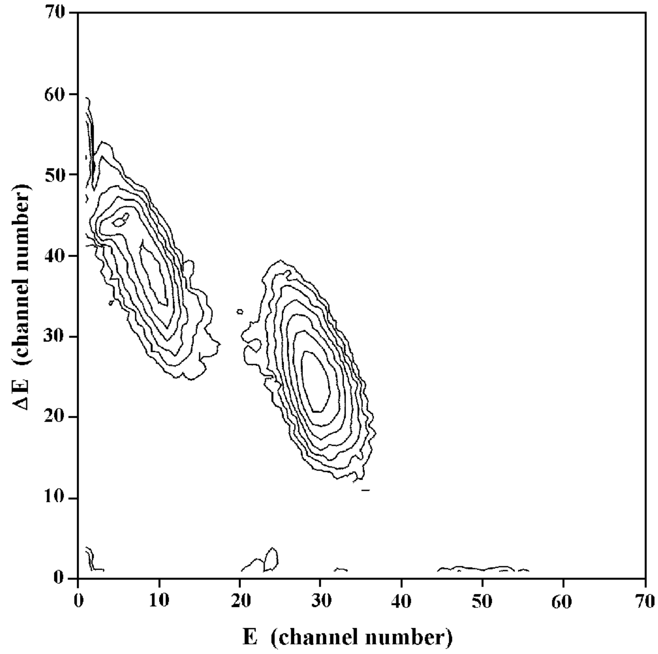

Fig. 3. E-ΔE contour plot of the monolithic E-ΔE telescope obtained after irradiation by α-particles from ^{212}Bi (6.05 and 6.09 MeV, low energy peak) and ^{212}Po (8.78 MeV, high energy peak). The values of contour levels are the following: 8, 16, 32, 64, 128, 256, 512 counts.

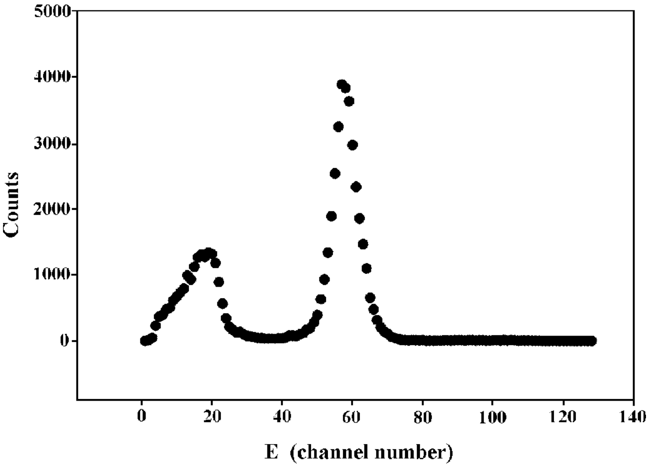

Fig. 4. The projection of the E-ΔE spectrum to the E-axis.

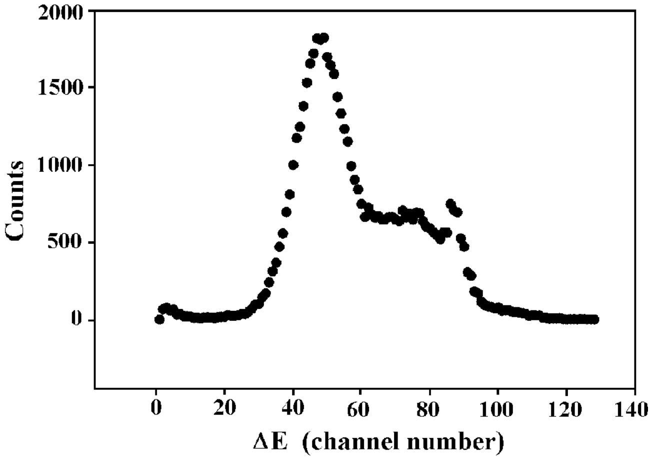

Fig. 5. α-particle energy lost in the ΔE transmission detector.

p^+ layer was higher than measured on the as grown epitaxial layer. As the resistance of a thin p-type layer measured by the spreading resistance method was influenced by two adjacent high resistivity n-type regions, the real resistivity of the p^+ layer was lower than the value (about 3 Ωcm) shown in Fig. 2. To keep this resistivity as low as possible, the starting thickness of the p^+ layer has to be large enough. Taking into account the transition width of a heavily boron doped epitaxial layer deposited on a very high resistivity n-type silicon substrate and further boron diffusion, the thickness 4 μm has been chosen as the optimum.

The monolithic telescope was operated at 50 V bias potential for E and ΔE detectors. In Fig. 3 the E-ΔE contour plot is presented after irradiation of the monolithic detector by α-particle sources: ^{212}Bi (6.05 and 6.09 MeV) and ^{212}Po (8.78 MeV).

The energy resolution (FWHM) estimated from the high energy peak of 8.78 MeV varies from about 0.76 to 0.94 MeV, since the shape of the tree dimensional high energy peak is not symmetrical. The projection of the E-ΔE contour to the E axis is shown in Fig. 4. The energy loss of α-particles in the ΔE detector, given by a projection of the E-ΔE contour plot on to the ΔE axis is presented in Fig. 5. The low energy peak in this spectrum corresponds to the high energy alphas (8.78 MeV) and the high energy part of the energy loss spectrum comes from α-particles of 6.05 and 6.09 MeV.

Discussion and conclusion

The optimum construction of the monolithic silicon E-ΔE telescope needs a very thin p^+-type buried layer with a thickness as low as possible. The finite thickness of this layer decreases the particle energy and the charge generated in this region is not collected by the junctions electric fields. However, when the gradients of carrier concentrations are introduced into the p^+-type buried layer, then built-in-fields are generated [6–8] which can collect part of the charge created in this region. The very low resistance of the p^+-type buried layer guarantees the electric separation of E and ΔE detectors. When this resistance is limited then cross-talks can be observed between E and ΔE detector, i.e. part of the electric pulse from one detector is transferred to the another one mainly via high capacitance since the p^+-type buried layer is very thin. Another source of cross-talks can be generated by improper ohmic contacts between p^+-type buried layer and evaporated aluminium contacts. By this reason formation of the Al contacts will be performed for the new telescopes. To reduce the surface leakage currents and to improve the energy resolution, passivation of the detector junctions will be applied. The energy resolution can be lowered by the nonuniformity of the ΔE detector thickness. This problem will be investigated in the next measurements.

The thickness of the p^+-type buried layer selected by us was restricted by the technological reasons since "classical" high temperature epitaxy has no possibility to create so large gradients of impurities as in the case of a molecular low temperature epitaxy which is not yet available in our laboratories.

We have developed a new technology which gives the possibility to produce monolithic E-ΔE telescopes. The test of telescopes with different thickness of the ΔE detectors is in progress.

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References

1. Classen WAP, Bloem J (1981) The nucleation CVD silicon on SiO_2 Si_3N_4 substrates. Solid State Technol 128;6:1353–1359
2. Ishitani A, Kurogi Y, Tsuya H (1984) Novel device isolation technology with selective epitaxial growth. IEEE Trans Electron Dev 31;9:1283–1288
3. Kim C, Kikuchi K, Husimi K, Ohkawa S, Saito I (1982) Epitaxial integrated E-dE position sensitive silicon detectors. IEEE Trans Nucl Sci 29;1:779–781
4. Kim C, Kim H, Kikuchi K, Husimi K, Ohkawa S, Fuchi Y (1980) Epitaxial integrated E-dE silicon detectors with a buried low-resistive diffused layer. IEEE Trans Nucl Sci 27;1:258–265
5. Kim Y, Kim C, Husimi K, Ohkawa S, Fuchi Y, Osada S (1984) Epitaxial integrated dE_1-dE_2 silicon detectors. Nucl Instrum Meth 226:125–128
6. Kim Y, Kim C, Okhawa S *et al.* (1986) Self-biased silicon detectors with a built-in field for measuring heavy charged particles. IEEE Trans Nucl Sci 33;1:321–325

7. Knabe H, Mizushima Y, Kimura T, Kajiyama K (1976) High-speed silicon avalanche photodiodes with built-in field. J Appl Phys 47;8:3749–3751
8. Kordyasz AJ, Nossarzewska-Orłowska E, Sarnecki J (1996) Large area silicon detectors with built-in field. Nukleonika 41;4:23–28