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CAPACITORS INTEGRATED WITH A DIELECTRIC MADE OF IMPLANTED SILICON

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1. Introduction

Capacitors make an indispensable component of integrated circuits. There are two basic technologies of their production [1]. The first one consists in applying the reverse-biased p-n junction. Capacitors of maximum capacity per unit surface of the order of 1.2 nF/mm^2 can be made this way. However, there is one fault in such capacitors. They need a constant feeding voltage to bias the p-n junction. In such a case there is one possibility of increasing the unit capacity and it consists in reducing the distance between space charges that form each side of the junction that is in forming the narrowest possible junction. However, such a solution meets technological difficulties that are related to big values of diffusivity of impurities.

The other technology of producing capacitors in integrated circuits consists in applying special layers of dielectrics. Capacitors made this way can reach the maximum unit capacity of 0.5 nF/mm^2 [1]. This technology requires the introduction of additional operations (spraying and others) and precise control of the thickness of a dielectric layer.

Present times lay down constantly growing requirements on integrated circuits. These requirements induce the necessity of looking for new solutions as far as their production is concerned, both passive elements and active ones. The above discussed methods of producing capacitors do not present greater possibilities of obtaining higher values of their parameters. Therefore instead of trying to find ways of improving existing technologies we attempted to elaborate a new method to make capacitors in integrated circuits.

2. New method of making capacitors in integrated circuits - basics

In the course of testing properties of neutron-irradiated silicon a phenomenon of the increase of its permittivity has been observed. The phenomenon is based on a process of jump recharging between neighbor, electrically neutral defects that lead to the formation of big concentrations of dipoles. High permittivity values of silicon that gets strongly defected due to the neutron bombardment enable to make capacitors of increased unit capacity. However, the neutron bombardment is not widely applied in integrated circuits production technologies and therefore an attempt to replace it with implantation has been made. Ion implantation is one of the widest applied technologies of doping semiconductors and makes it possible to produce IC elements with a great precision as far as geometry (linear parameters, doping depth) and quantity of the doping dose are concerned. The concept of replacing the neutron bombardment by ion implantation at producing silicon layers of increased permittivity is based on the phenomenon of the formation of defects in the course of implantation - defects of the same kind as the ones formed during neutron bombardment but of the significantly greater concentration.

Another advantage of the implantation is a possibility of forming thin layers of defected silicon that can be directly applied to make capacitors in integrated circuits.

3. Investigation into the phenomenon of the increase of silicon layers permittivity

Special capacitors were made to take permittivity measurements of ion implanted silicon. Silicon plates doped with phosphorus (ρ = 10 Ωcm), boron (ρ = 0.03 Ωcm), and antimony (ρ = 0.01Ω cm) were subjected to the implantation with ions of chemically inactive gases (nitrogen, neon, argon). Ion energy was of 100 keV, ion current density - 0.5 μA/cm^2 and ion doses were varied in the range from 2 x 10^{14} cm^{-2} to 2 x 10^{15} cm^{-2}.

A layer of high resistance to be used as a dielectric was obtained in the described way. Capacitor plates were made of doped silicon and a screen of silver paste of little resistivity (fig. 1).

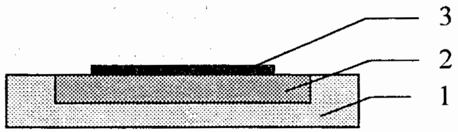

Fig. 1 Diagram of a capacitor made with the application of a silicon layer implanted with ions, 1-silicon plate, 2-layer of increased permittivity, 3-screen of silver paste.

Capacitors made in the given way were subjected to isochronous annealing in the temperature range from 20°C to 600°C , 15 min. for each of the chosen temperatures. Such a duration was indispensable for the reactions between defects and impurities to occur in the implanted layer.

The figures presented below show the dependence of the capacity of chosen capacitors on the annealing temperature (fig.2).

The maximum increase of unit capacity of the tested capacitors was observed at the temperature of about 330 °C. Its value depends on the kind of implanted ions, their dose, and the type of plates. In the case of nitrogen ions the maximum increase of capacity occurs in a capacitor made on a silicon plate doped with antimony (increase by ca 10 times) while for neon ions the maximum capacity can be obtained with a plate doped with boron (increase by ca 13 times). Such a significant capacity increase fully justifies the subject line of the undertaken research.

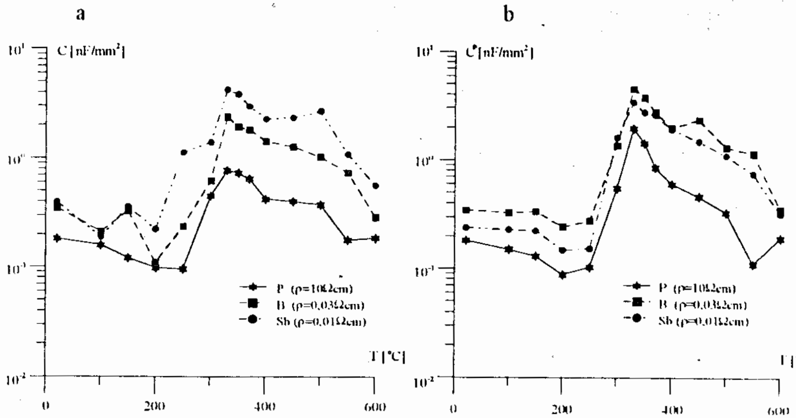

Fig. 2 Unit capacity of capacitors made of silicon doped with P, B and Sb vs. temperature of annealing (measurement frequency: f=1kHz),

a) samples implanted with nitrogen ions (E=100 keV, dose 2x10^{14} cm^{-2}),

b) samples implanted with neon ions (E=100 keV, dose 2x10^{14} cm^{-2}).

4. New type capacitors in integrated circuits

On the basis of the obtained results of measuring permittivity of ion implanted silicon layers a new method of producing capacitors in integrated circuits was elaborated. The basic idea of the method is to implant a doped silicon plate with ions of the same impurity and subject it to annealing (temperature of 1000-1050 °C) for the duration of 10-15 minutes.

A layer of increased permittivity can be obtained this way, a part of it supposed to make one of the capacitor's plates. The obtained plate is subsequently implanted with a neutral impurity (e.g. nitrogen, neon, argon) of energy values selected in such a way that the ion range is smaller than the previously obtained strongly doped layer. Next, the plate is subjected to annealing at a temperature of 300°C - 400°C during 15 minutes and a dielectric layer is obtained this way. A metallization layer that makes the other capacitor's plate is just on the layer. A diagram of such a capacitor and depth-wise concentration distributions of impurity is presented in the fig.3.

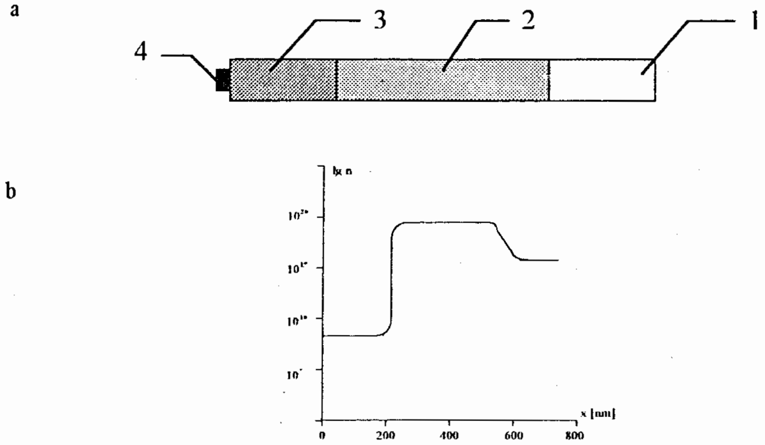

Fig. 3 Diagram (a) and distribution of current carriers concentration (b) in an capacitor made according to the elaborated method; 1 - silicon plate, 2 - layer created in the course of ion implantation, doping, and high-temperature annealing, 3 - layer additionally implanted with ions of neutral gases, 4 - metallization layer

On the basis of the elaborated method a set of capacitors was made on silicon plates doped with boron (ρ = 10 Ωcm) and phosphorus (ρ = 10 Ωcm). The mentioned kind of plates was selected because of its wide application in microelectronics. Nitrogen was applied as neutral impurity.

Fig.4 presents some of the results obtained with the capacitors described above.

The maximum unit capacity was obtained at the annealing temperature of 330°C and it is 2 nF/mm^2, the value being by 70% greater than the capacity of capacitors produced by means of hitherto applied methods. The greatest capacity values were obtained in capacitors implanted with limit (maximum or minimum) doses of nitrogen ions.

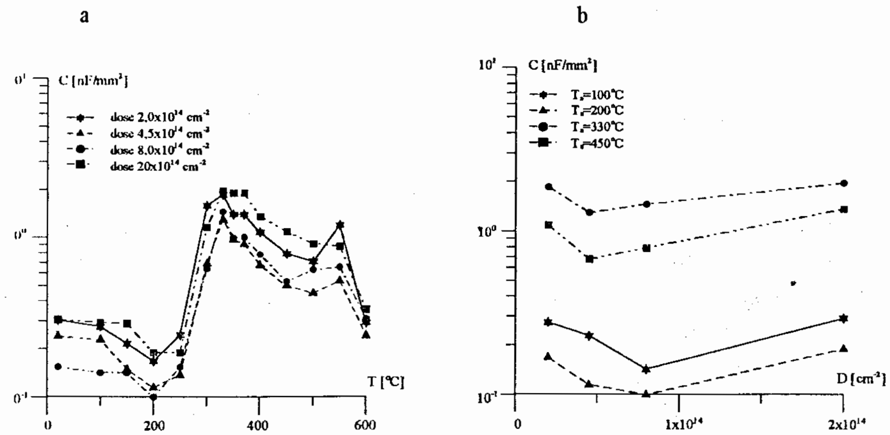

Fig. 4 Unit capacity vs. (a) annealing temperature at varied doses, (b) dose at varied temperature of annealing.

Parameters of the capacitor production process

- (P^+) impurity implantation, E= 100 keV, dose: 1x 10^{15} cm^{-2};
- isothermal annealing, T = 1050°C, t = 15 min.;
- nitrogen implantation, E = 100 keV, dose: (2÷20) x 10^{14} cm^{-2}.

5. Conclusions

The unit capacity of capacitors made with the application of strongly doped silicon plates (fig.1) was by 4 times greater than the capacity of capacitors produced on the basis of reverse-biased p-n junction.

In the capacitors produced according to the patent application [5] (fig.3) the unit capacity by almost 2 times greater than the capacity of traditional capacitors was obtained. A further capacity increase in the mentioned capacitors is possible through adequate selection of doses of electrically active impurities and the types and energy values of neutral impurities.

Acknowledgement

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