RADIOTRACER MEASUREMENTS OF SPUTTERED CONTAMINATION INCURRED DURING ION IMPLANTATION PROCESSING

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Summary

Radioactive tracer measurements have been performed in order to establish limits for the degree of sputtered contamination to be expected during implantation processing in stainless steel target chambers. The information collected provides a useful set of working curves for the particular wafer-holding arrangement employed, and is presented in a form that should be convenient for use in the design of other stainless steel target-holder geometries.

Introduction

Ion implantation is proving to be commercially feasible for the introduction of controlled amounts of dopant impurities into silicon devices and integrated circuits. In most production implantation systems, oxide-masked silicon wafers are mounted in stainless steel or aluminum target holders and exposed to beams of accelerated and mass-separated boron, phosphorus, or arsenic ions in the keV to MeV energy range. Ion beam currents may range from a few nanoamperes to 1mA, with radial doping uniformity achieved either by electrostatically sweeping the beam across a fixed target holder or by mechanically translating the wafer holder through a stationary ion beam. Because the target holder is generally exposed to the primary ion beam, the possibility that undesired impurities will be introduced into target wafers by sputtering of the holder material is a matter of some concern and is the subject of the present study.

Experimental

All implantations were performed with a 500keV Van de Graaff system producing mass-analyzed and electrostatically swept beams of $^{11}B^+$, $^{31}P^+$, or $^{75}As^+$ at current densities on the order of 10^{-6} A/cm^2, while maintaining a vacuum of approximately 5×10^{-6} torr in the target chamber. The "standard target-holder geometry," to which the sputtering results are referenced, is shown in Fig. 1. In this arrangement, a 2.25-in. (5.72cm) diameter silicon wafer covered on the front surface with a thin layer of thermally grown SiO_2 is held in a recessed stainless steel backing plate by means of an annular clip of #302 stainless steel, 5.51cm ID and 0.041cm thick. The clip presses the wafer firmly against the plate, thus ensuring that the wafer backside is thermally and electrically contacted. Because the ion beam is swept over an area slightly larger than the wafer area, this clip defines the implanted area on the wafer, and the 17.3-cm internal perimeter of the clip is directly exposed to the ion beam.

A radiotracer technique was employed to measure the amount of material transferred from the clip to the wafer during implantation processing. For this purpose, strips of clip material or of #302 stainless steel wire mesh, made radioactive by exposure to thermal neutron fluences of 0.25 - 1.0×10^{19} neutrons/cm^2, were positioned in front of thermal oxide-coated silicon wafers to serve as sputtering sources during implantation. Material transfer was calculated from radioactivity measurements of the implanted wafers, together with radioassay of known aliquots of clip or mesh material from the same radioactivation vintage. A 90cm^3 Ge(Li) detector and multichannel analyzer were employed to count the 0.32MeV gamma rays emitted by ^{51}Cr ($t_{1/2} = 27.8$ days). Since the major constituents of #302 stainless steel (71% Fe, 18% Cr, 9% Ni, 2% Mn) are very close to each other in mass number, preferential sputtering of any one species was assumed to be negligible. (This was roughly confirmed by peak gamma counting of other sputtered radioactivation products, ^{59}Fe, ^{60}Co, and ^{58}Co.) For wafers in direct contact with the sputtering source and near-normal incidence of the ion beam, the amount of sputtered contamination transferred was observed to vary in direct proportion to the perimeter of clip or mesh material exposed to the beam. Consequently, simple corrections have been applied to the measurements, and results are reported as the total number of "atoms of stainless steel" expected to be transferred for the "standard target-holder geometry" of Fig. 1.

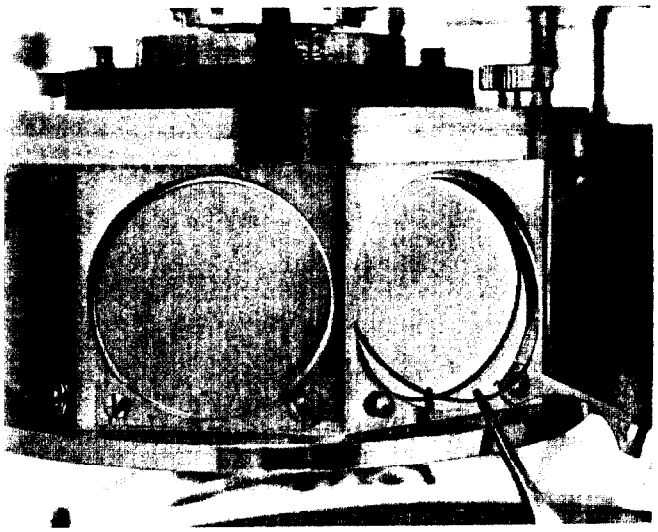

Fig. 1. View of the "standard target-holder geometry to which the results presented in Figs. 3 and 4 are referenced.

Results and Discussion

Figure 2 is a reverse autoradiogram of a wafer previously in contact with a rectangular strip of activated clip material during a 5×10^{16} cm^{-2} implant of 150 keV $^{75}As^{+}$ ions. The predominance of sputtering from the lower edge of the clip arises from the dependence of forward sputtering upon the incidence angle of the ion beam. Owing to the 7° misorientation of the wafer with respect to the ion beam (for the purpose of minimizing lattice channeling of the implanted ions), the lower edge of the clip was more exposed to the beam than were the right-hand or upper edges.

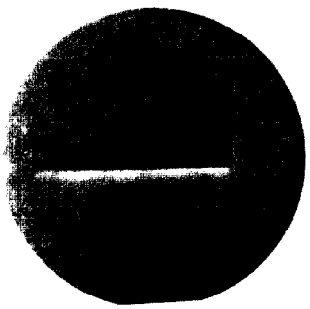

Fig. 2. Reverse autoradiogram showing radial distribution of contamination sputtered from a rectangular piece of clip material.

The observed dependence of sputtered contamination upon implant fluence or dose is shown for 60 keV arsenic implants in Fig. 3, and a first-order relationship is evident. From the standpoint of silicon device processing, it may be noted that 10^{15} atoms of the first transition group metals represents an amount sufficient to exceed the solid solubility of these elements in the wafer at temperatures commonly employed for post-implant annealing cycles. The performance of an electrical junction in silicon may be seriously degraded by such precipitation effects. Furthermore, even at concentration levels far below that required for precipitation, these elements may produce deleterious effects upon the bulk electrical properties of silicon (e.g., carrier concentration, resistivity, and carrier lifetime).

The observed amounts of sputtered contamination incurred as a function of incident boron, phosphorus, and arsenic ion energy are presented in Fig. 4, for ion fluences of 1×10^{16} cm^{-2}. It appears that sputtering yield variations with energy are of only secondary importance throughout the energy range commonly employed for implantation processing. However, a strong dependence upon the incident ion mass is

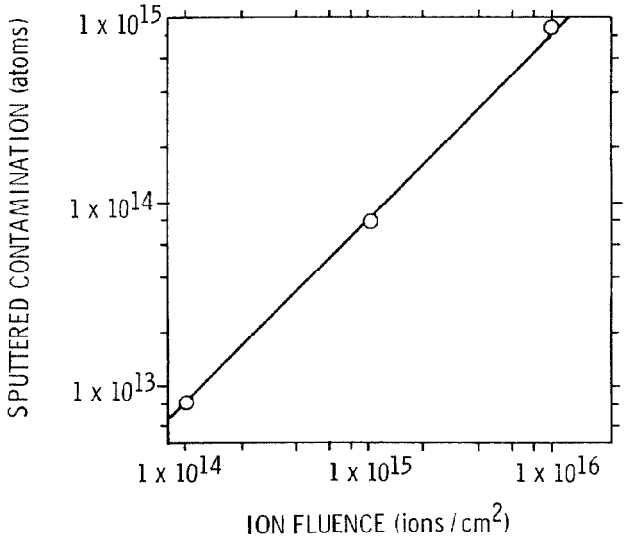

Fig. 3. Amount of stainless steel transferred from retaining clip to wafer as a function of 60 keV As^{+} implanted ion fluence, for "standard target-holder geometry."

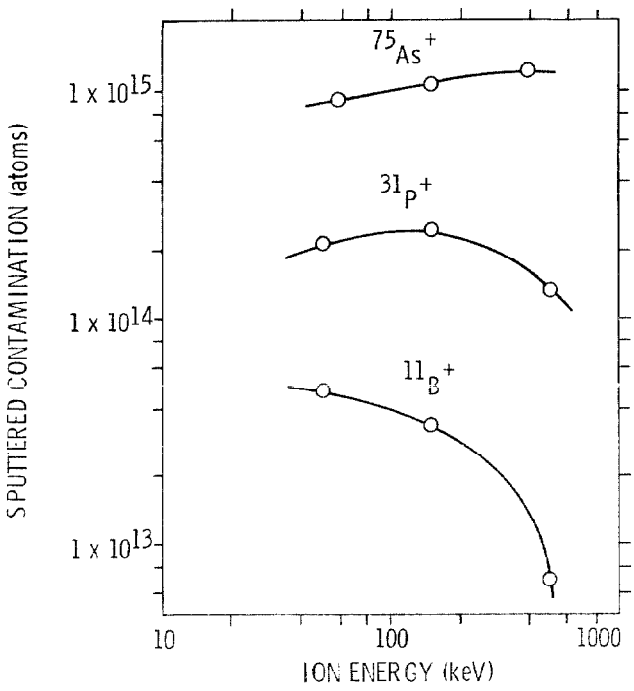

Fig. 4. Amount of sputtered contamination introduced per wafer, as a function of implanted species and energy, for fluences of 1×10^{16} ions/cm^2 and "standard target-holder geometry."

evident. The observed trends are believed to be fairly representative of the sputtering behavior of other group III and V dopant ions over this same energy range.

Finally, the effect of varying the distance from sputtering source to wafer target is shown in Fig. 5. These measurements were made with 1.25 in. (3.18 cm) wafers, and with an extended source, consisting of an activated sheet of stainless steel mesh approximately the same size as the target wafers, to reduce the time required for measurement of the collected radioactivity. The solid line of Fig. 5 represents the calculated fall-off of sputter-contamination S(x), as a function of distance, assuming isotropic sputtering from a point source located on the beam centerline at distance x upbeam from a wafer of diameter d,

$$S(x)/S(x=0) = 1 - x/(x^2 + d^2/4)^{1/2} \qquad (1)$$

It is seen that the experimentally observed data points fall off somewhat more rapidly with distance than calculated, as expected for an extended source. It is concluded that sputtered contamination arising from beam-defining apertures located more than a few wafer diameters upbeam from the target wafer is generally unimportant, and that the inverse square law may be applied for large source-target distances. Obviously, this conclusion is invalid for certain "postacceleration" implantor configurations, for which the possibility exists that material sputtered from apertures or gridded Einzel lenses located upbeam from the main acceleration tube may be unidirectionally accelerated and implanted together with the primary dopant beam into target wafers.

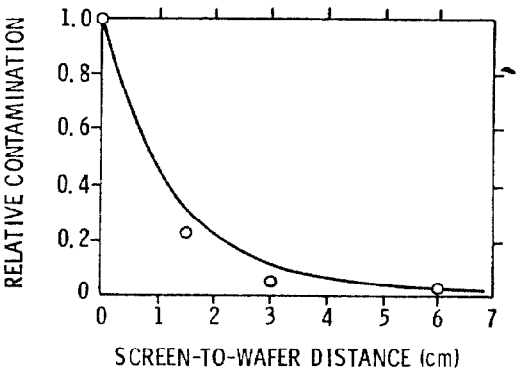

Fig. 5. Sputter contamination incurred by 1.25-in. (3.18-cm) wafers as a function of distance from an extended sputtering source, observed for $1x10^{16}$ cm^{-2} implants of 60 keV As^+ ions. The solid curve is the relationship expected for a point source using Eq. (1) and a value of d = 3.18 cm.

Acknowledgment

The author is indebted to G. Jung for assistance in carrying out the ion implantations used in this investigation.