SHADOWING EFFECT IN SELF-ALIGNED CONTACTS

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Résumé. *Une comparaison entre le dopage avec arsenic et phosphore des contacts auto-alignés par implantation ionique est presentée. En utilisant la simulation bidimensional pour le profil de dopage il à été possible expliquer la haute défectuosité mesurée des contacts dopés arsenic. Son origine depend d'une insuffisant superposition entre la diffusion du contact et l'oxyde de champ, dû à un effet d'ombre dans une region critique du contact.*

Abstract. *A comparison between arsenic and phosphorus implanted self-aligned contacts is presented; by using 2D process simulations the high leakage defectivity measured on the As contacts has been explained. Its origin arises from an insufficient overlap between the contact diffusion and the field oxide, due to a shadowing effect in a critical zone of the contact.*

1 Introduction

To enhance compactness of a CMOS process architecture, self-aligned contacts are often used; a self-aligned contact (SAC) is defined as a contact larger than the active area (fig. 1a), therefore in a SAC two zones are present in which the bird's beak of the field isolation may be removed during the contact opening, leading to a short between the metal and the underlying p-isolation. To avoid this problem, that can appear also in conventional contacts when misalignment between active areas and contacts is present, a n^+ implant is usually performed after the contact opening operation, to self-align the contact itself.
In the particular case of an EPROM process, to minimize lateral diffusion and the contact-gate distance, an arsenic implant is generally considered to be the better choice [1]. However, experimental results show that similar contacts have to be considered critical due to their high leakage defectivity.

2 Experimental

The structure used to verify the leakage of SACs consist of an array of about 60000 $1.4 \times 1.6 \mu m^2$ contacts, that are self-aligned to an active area whose width is $1\mu m$. The leakage of the structure is collected by a metal cover that contacts all the SACs simultaneously. The junction depth of the As active area diffusion is about 2500Å. All the contacts have the same orientation on wafer.
To make comparisons with the behavior of standard contacts, similar structures are available in which an active area head is added to the contact.
Different contact implants have been tested, and all have been performed using a tilt angle of 7°, to minimize channeling problems; leakage currents have been measured when a reverse bias of 10 V is applied to the structure.
To avoid shadowing effects in the region below the lateral side walls of the SAC, the ion beam projection has been set parallel to the active area.
In figure 2 the leakage distributions of both self-aligned and standard contacts with an arsenic contact implant are reported; the implant dose is $5 \times 10^{15} cm^{-2}$ at 80 KeV, and the metalization is a simple AlSi. As it can be noticed, a high defectivity is exibited by the SACs, and it disappears if a head is added to the contacts.
No significant differences are introduced when the As contacts are metalized with barrier metal; as it can be shown in figure 3 the use of a double layer of Ti and TiN does not remove the high leakage tail in the SACs.
Better results are obtained by implanting the contacts with phosphorus; in figure 4 the leakage distribution is reported for a $5 \times 10^{15} cm^{-2}$ 80KeV P implant and standard metalization. A strong reduction of the SAC defectivity is evident, together with a sharper distribution of the leakage current.
In figure 5 the behavior of As contacts with barrier metal is shown , in which the As dose has been implanted half at 7° and half at −7°, to avoid residual shadowing effects. A heavy improvement in comparison with simple 7° implant is manifest.

3 Simulation and discussion

As it appears from figure 2 and 3, in which no leakage is present in contacts with head, the problem of the leakage in As implanted SACs is strictly related to the presence of the self-aligned part of the contact. Besides, the particular kind of metalization utilized, does not play any role in determining the leakage mechanism.
The experimental data could be explained if we suppose some residual shadowing effect in spite of the appropriate wafer orientation used during the contact implantation.
To verify this assumption, 2D simulations of the self-aligned contact have been performed with TITAN-4 2D Process Simulator [2]; cross sections of arsenic and phosphorus doped self-aligned contacts have been obtained in the worst case of $0.4\mu m$ misalignment between active area and contacts (mask to mask to mask misalignment). In particular, doping profiles simulations have been performed along cross sections normal and parallel to the active area. In the last case the doping profile has been obtained along a line 1500Å away from the side wall of the misaligned contact (see line A in fig. 1b).
Data are reported in figure 6 for both arsenic and phosphorus. For the arsenic case, considering the normal cross section, a small and critical overlap between the diffusion and the field oxide may be noted. This critical overlap indeed becomes a heavy miscoupling if the parallel cross section is analyzed.
Therefore the 2D simulation confirms that in a SAC exists a critical point in which the p-isolation may be contacted, leading to a leakage of the contact itself. This zone is indicated with C in figure 1b.
This problem is completely removed by the use of a phosphorus implant; as it can be noted, the deeper junction of phosphorus gives place to a larger plug below the contact, that guarantees a good overlap also in presence of misalignment and shadowing effect.
The simulated trends are widely confirmed by the SEM cross sections reported in figure 7. Also it is important to note that the As implant at 7° and $-7°$ is sufficient to eliminate the leakage current, since it eliminates the miscoupled zone . Unfortunately a similar solution is not proposable because of the related low throughput and high handling.
A 7° phosphorus implant seems to be the best choice to reduce the leakage defectivity; in fact experimental data from wafers with different P contact implants do not point out any critical dependence of the leakage current on the particular dose and energy in a wide range of variation. On the other side, the necessity of a P contact implant imposes to keep into account the spurious effects on the effective length of the adjacent transistor and on the EPROM cell writing efficiency; in fact the presence of phosphorus near the drain region of the cell (that becomes particularly important when contact to gate misalignment is present) could reflect either on a higher drain electric field either on a lower one, depending on the particular dose utilized for the implant; an example is reported in figure 8. Therefore the right dose and energy has to be carefully tuned in order to maintain a good writing performance.
Similar observations should be valid also for 0° arsenic implants; this situation, that has not been evaluated in this work, should lead to results similar to those of a $\pm 7°$ As implant. Anyway the presence of vertical and lateral channeling could affect the performance of the nearby transistors too.

4 Conclusion

The high leakage defectivity of the arsenic implanted SACs has been interpreted as due to a residual shadowing effect in a critical corner of the contact; the 2D TITAN-4 Process Simulator has turned out very useful to visualize geometries and dopings in different zones of the self-aligned contact.
It is important to underline that the entity of the shadowing non- overlap effect is strictly dependent on the particular process architecture and contact technology that is utilized. The extent of the contact over-etch, the contact reflow temperature and time and the lithographic misalignment are the most critical parameters that can affect the leakage current. The effects of critical overlap of the arsenic contact diffusion will become heavier and heavier for future process architectures in which higher compactness and new technologies with reduced diffusions will be required.
The high lateral diffusion that is obtained with P implants allows to overcome the shadowing problems; on the other side, spurious effects could be introduced. A fine tuning of the phosphorus dose and energy seems to be the safer solution. A 0° arsenic implant could also be a suitable one but a careful preliminary evaluation of the lateral channeling mechanisms is necessary.

Acknowledgments

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[1] S.Mori et al. *IEDM Technical Digest*, 835, 1986

[2] A.Gerodolle et al. *Proc. NASECODE IV conf.*, 477 - 482, Dublin, Jun. 1985

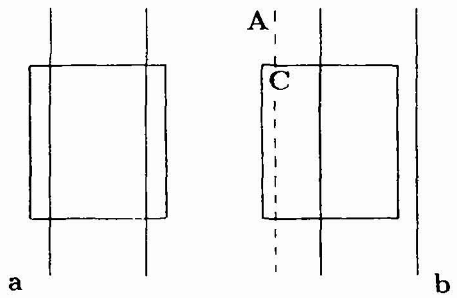


figure 1 1a) Self– aligned contact schema.
1b) The self–aligned contact when 0.4 μm misalignment respect to the active area is present. Along the line A, 2D doping profile simulations have been performed; with C the critical corner is indicated in which the shadowing effect takes place.

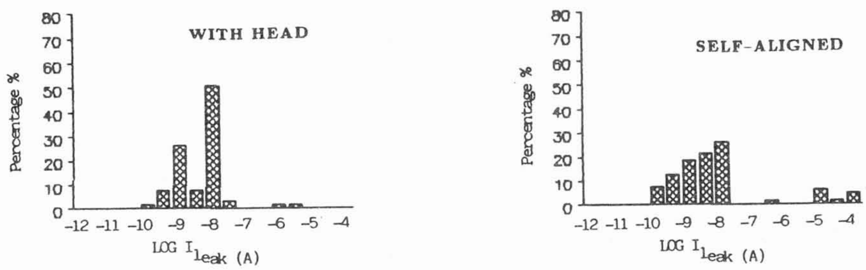


figure 2 Leakage distribution at T=300 K of 10^4 arsenic implanted contacts metalized with AlSi; the implant dose is 5×10^{15} cm^{-2} at 80 KeV and has been implanted with a 7° tilt angle.

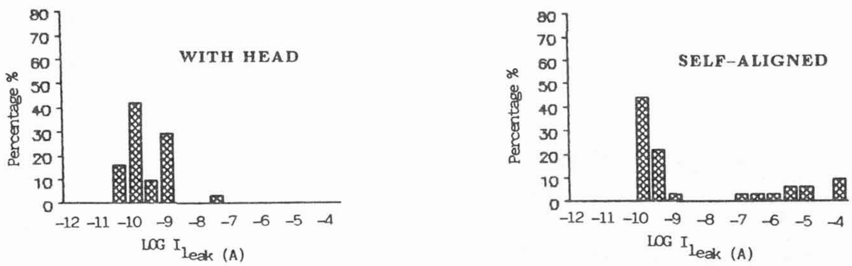


figure 3 Leakage distribution at T=300 K of 10^4 arsenic implanted contacts metalized with barrier metal; the implant dose is 5×10^{15} cm^{-2} at 80 KeV and has been implanted with a 7° tilt angle.

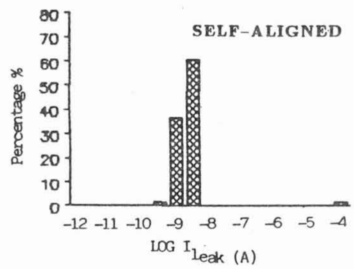


figure 4 Leakage distribution at T=300 K of 10^4 phosphorus implanted contacts metalized with AlSi; the implant dose is 5×10^{15} cm^{-2} at 80 KeV and has been implanted with a 7° tilt angle.

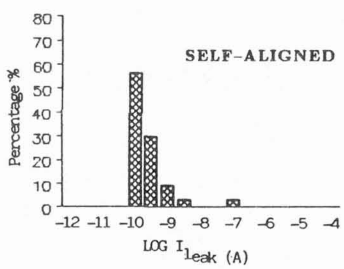


figure 5 Leakage distribution at T=300 K of 10^4 arsenic implanted contacts metalized with barrier metal (Ti TiN); the implant dose is 5×10^{15} cm^{-2} at 80 KeV and has been implanted with a $\pm 7°$ tilt angle.

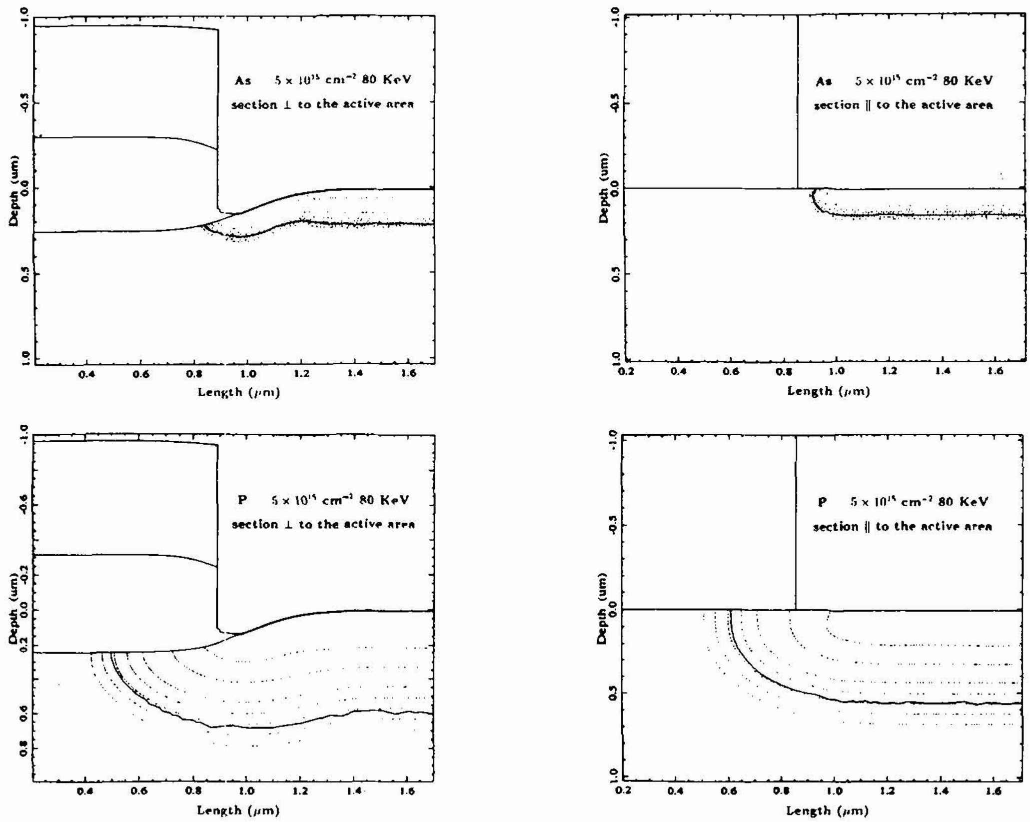
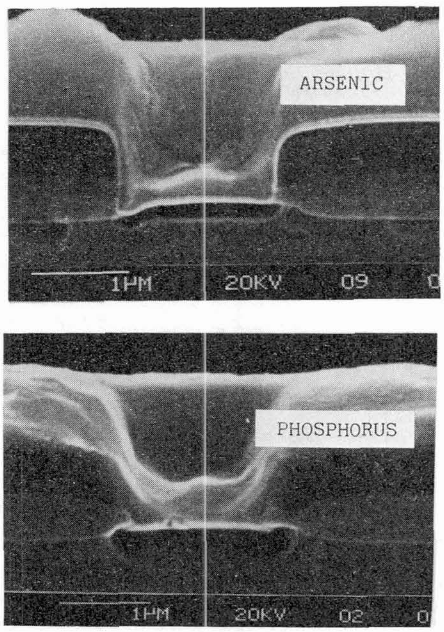


figure 6 In the upper and lower part of the figure, the simulated doping profiles are reported for As and P doped SACs respectively. On the left, the cross sections normal to the active area are shown, the parallel ones on the right.



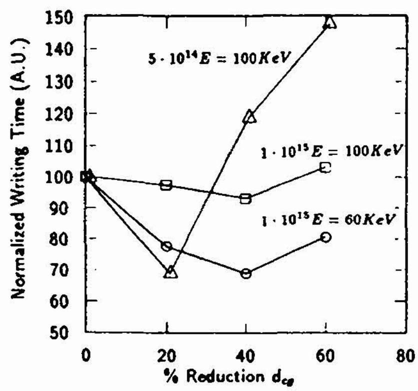


figure 8 Normalized writing time of an EPROM cell vs percent reduction of the contact–gate distance, for different doses and energies of the P contact implant.

figure 7 Cross section SEM photos for arsenic and phosphorus implanted self-aligned contacts.