INFLUENCE OF FREQUENCY OF RF DISCHARGE ON REACTIVE ION ETCHING OF TRENCH STRUCTURES[1)]

HAŠČÍK, Š.[2)], HORNIAKOVÁ, A.[2)], HURAN, J.[2)], Bratislava

In this work we investigated reactive ion etching of trench structures in the gases CCl_2F_2 and $CBrF_3$ in the frequency range from 20 kHz to 13.56 MHz at different RF powers of the discharge (100 W, 150 W). The influence of the changes of these parameters on the etching process properties (etch rate, selectivity, anisotropy) was investigated.

I. INTRODUCTION

Today trench structures play an important role in semiconductor technology. In order to get a high packing density of electronic circuits it is necessary to use the third dimension.

One application of those trenches in Si is the dielectric isolation of bipolar and CMOS circuits.

The other main application is for storage capacitors of modern DRAM'S [1].

In particular, a bipolar device need a deep (over 5 μm) trench for a high breakdown voltage and a high packing density. These applications require smooth, slightly tapered, and round bottom trenches (Fig. 1).

It is necessary to refill the trenches easily with Poly-Si, to prevent the stress in trench isolation and to obtain high quality silicon dioxide.

These demands can be accomplished by a reactive ion etch process, with chlorine - or bromine - based chemistries.

In this work this new dry etching process for bulk silicon with emphasis on the investigation of the frequency influence on etching of trenches is reported.

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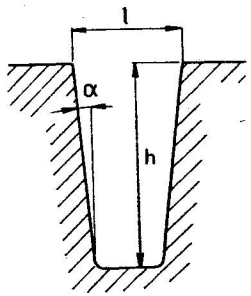
[2)] Institute of Electrical Engeneering, Slovak Academy of Sciences, Dúbravská cesta 9, BRATISLAVA 842 39, CSFR

Fig. 1. Cross section of a high quality trench etch. A trench etch should have the following attributes: The parameters l, h and should all be independently controllable.



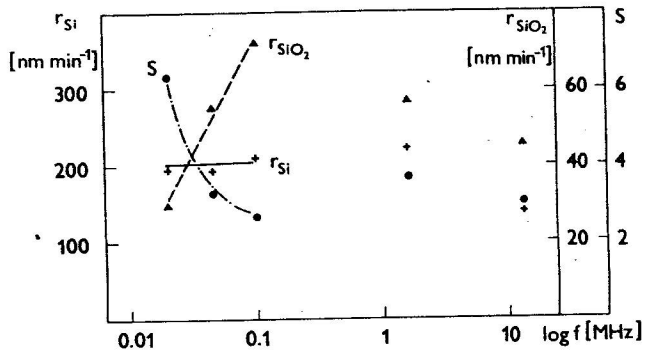


Fig. 2. Dependence of selectivity S, silicon etch rate r_s, and oxid etch rate r_{SiO_2} on the frequency RF power in $CBrF_3$ (p=10 Pa, P=100 W).

II. EXPERIMENTS

For the experiments a planar single wafer etcher, XPL 01 in RIE mode was used. The etching chamber itself and the electrodes consist of anodized aluminium. The distance between the electrodes is 24 mm and their diameter is 126 mm.

The vacuum system consists of rotary pumps, a Roots pump and a cold trap. Before the reactive gases were admitted the reactor was pumped to a background pressure of 2×10^{-2} Pa (with the cold trap use).

We choose $CBrF_3$ and CCL_2F_2 as the process gas as it forms polymer sidewall films that are mainly responsible for etch anisotropy.

To obtain the best reproducibility of the process the electrodes had to be kept at 20°C. The pressures in the chamber during the etching process in both gases were 10 Pa and 30 Pa, the gas flow was 30 cm^3/min. We changed the frequency

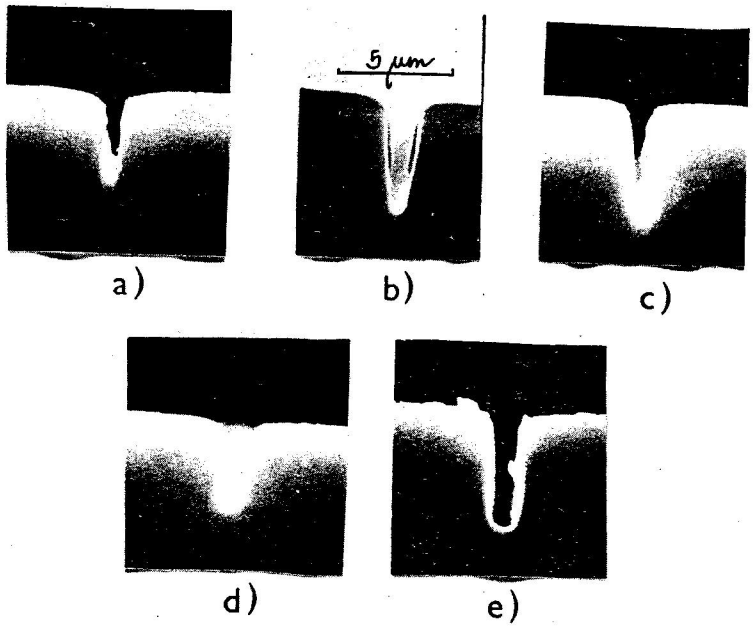


Fig. 2 a)b)c)d)e). Etching profiles of trench structures at frequencies 20 kHz, 45 kHz, 100 kHz, 1 MHz, 13.56 MHz, respectively ($CBrF_3$, p=10 Pa, P=100 W)

between 20 kHz and 13.56 MHz and the RF power of the generator (~1500 V) was 100 W and 150 W. The wafers were put on the powered electrode. The ratio of the area of the powered electrode and the ground areas (ground electrode and chamber walls) is 0.35. The substrate material and double-layer etch mask are (111) silicon and silicondioxide (1800 mm) with LP CVD nitrid (120 nm) respectively.

III. RESULTS AND DISCUSSION

a) Etching in $CBrF_3$

In the low frequency range (20–100 kHz) there was a negligible influence of frequency on the silicon etch rates, but we observed a significant influence on the oxide etch rates. The highest increase of the silicon etch rate ($r_{100kHz} - r_{20kHz}$) was 50 nm min^{-1} (Fig. 2).

The selectivity $S = r_{Si}/r_{SiO_2}$ reached peak values at the frequency f=20 kHz. Then it decreased with increasing frequency.

In the frequency region (1.6 MHz and 13.56 MHz) the silicon etch rates reached

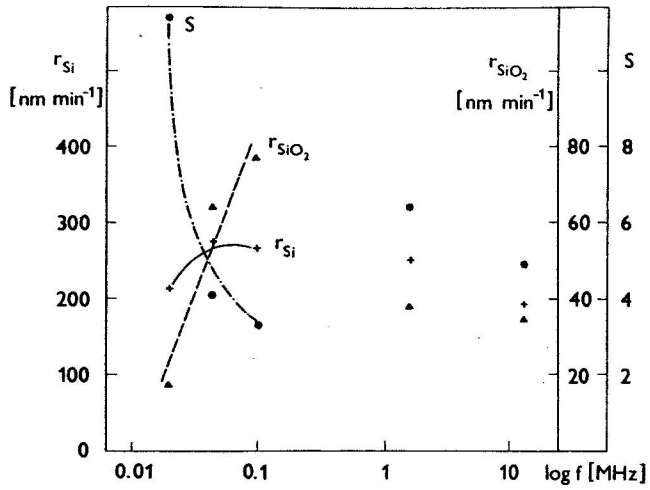


Fig. 3. Dependence of selectivity S, silicon etch rate r_s, and oxid etch rate r_{SiO_2} on the frequency RF power in $CBrF_3$ (p=30 Pa, P= 100 W).

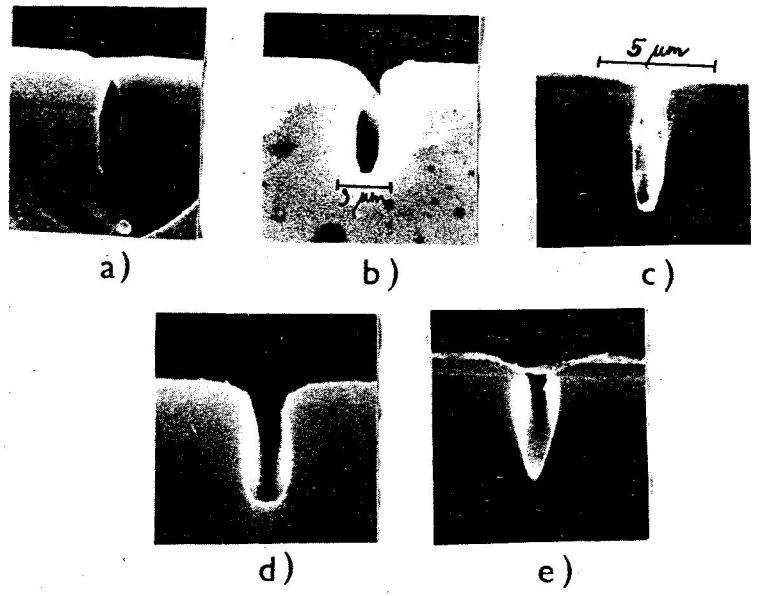


Fig. 3 a)b)c)d)e). Etching profiles of trench structures at frequencies 20 kHz, 45 kHz, 1 MHz, 13.56 MHz respectively ($CBrF_3$, p=30 Pa, P=100 W)

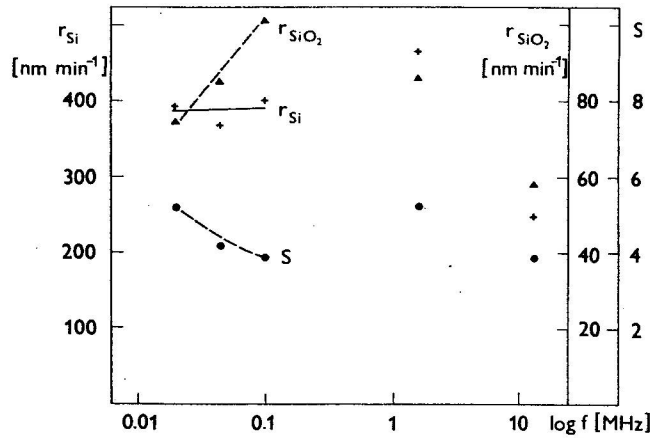


Fig. 4. Dependence selectivity S, silicon etch rate r_{Si} and oxid etch rate r_{SiO_2} on the frequency RF power in $CBrF_3$ (p=30 Pa, P=150 W.)

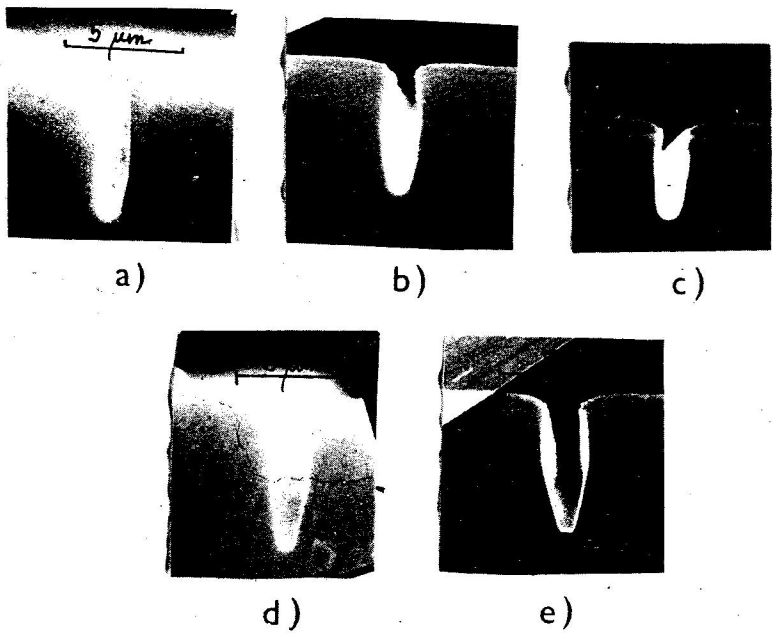


Fig. 4 a)b)c)d)e). Etching profiles of trench structures of frequencies 20 kHz, 45 kHz, 100 kHz, 13.56 MHz, respectively ($CBrF_3$, p=30 Pa, P=150 W)

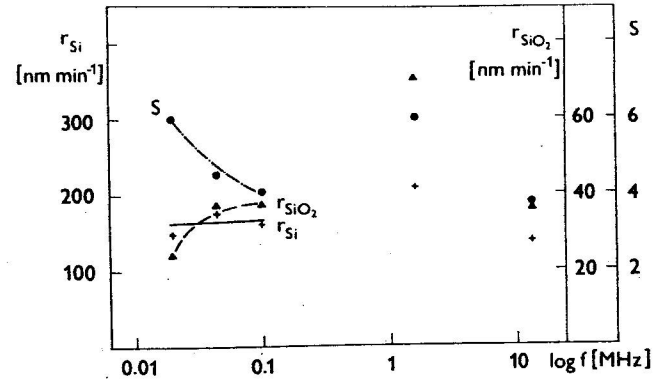


Fig. 5. Dependence of selectivity S, silicon etch rate r_{Si} and oxid etch rate r_{SiO_2} on the frequency RF power in CCl_2F_2 (p=10 Pa, P=100 W).

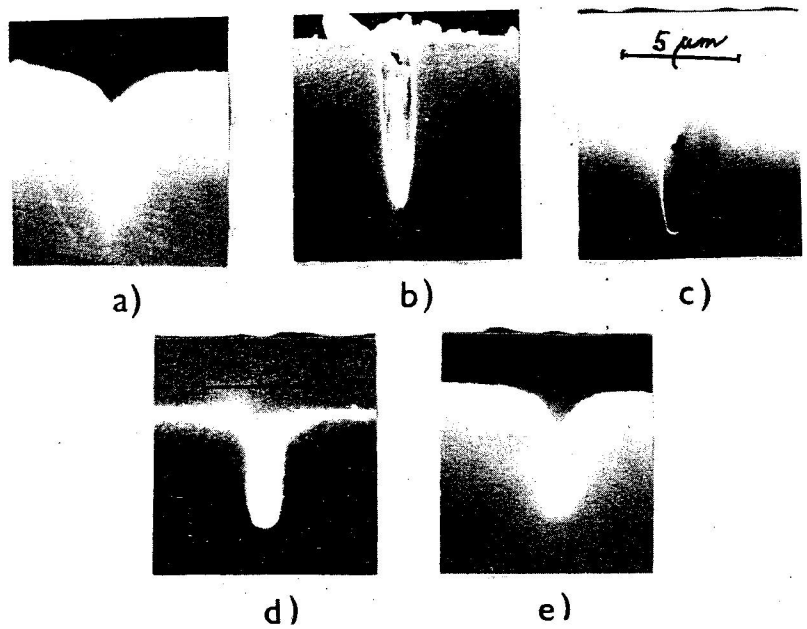


Fig. 5 a)b)c)d)e). Etching profiles of trench structures of frequencies 20 kHz, 45 kHz, 100 kHz, 1 MHz, 13.56 MHz, respectively (CCl_2F_2, p=10 Pa, P=100 W).

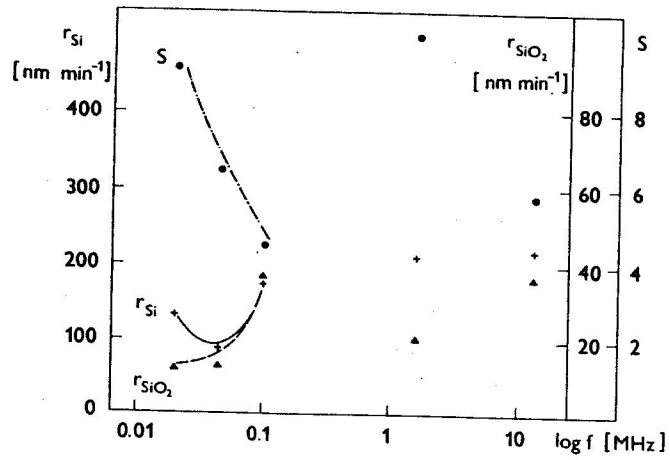


Fig. 6. Dependence of selectivity S, silicon etch rate r_{Si} and oxid etch rate r_{SiO_2} on the frequency RF power in CCl_2F_2 (p=30 Pa, P=100 W).

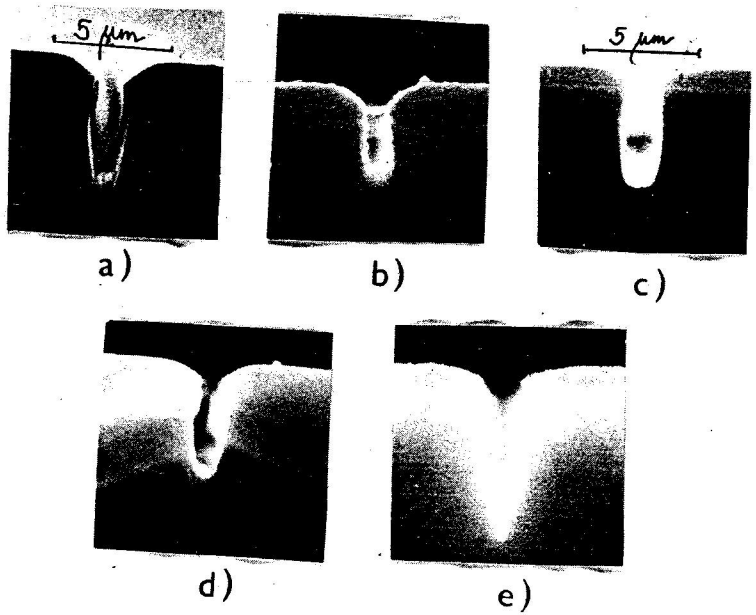


Fig. 6 a)b)c)d)e). Etching profiles of trench structures at frequencies 20 kHz, 45 kHz, 100 kHz, 1 MHz, 13.56 MHz, respectively (CCl_2F_2, p=30 Pa, P=100 W)

extreme values, the lowest was 130 nm min^{-1} at the frequency f=13.56 MHz (Fig. 2) and the highest was 460 nm min^{-1} at f=1.6 MHz (Fig. 4).

The selectivity at high frequencies was the same as that at low frequencies.

b) Etching in CCl_2F_2

In the low frequency range the frequency has a negligible influence on the silicon and oxide etch rates.

In the high frequency region the silicon etch rate reached the highest values (320 nm min^{-1}, Fig. 5). However, the values of the Si and the SiO_2 etch rates in the gas CCl_2F_2 are lower than the values of the etch rates under identical conditions in the gas $CBrF_3$. The selectivity in CCl_2F_2 decreased with frequency slower than the selectivity in $CBrF_3$.

The etching profiles are in Fig. 2,3,4,5,6 a)b)c)d)e). We observed the influence of frequency on the profiles of the trenches. The required quality of trench profiles used in VLSI was achieved in cases 2b, 4d, 5b. The etching of the trench structures was accompanied by the deposition of layers on the bottom and sidewalls. Samukawa et al. [2] analysed (AES) those sidewall deposition layers. Deposited films consist of SiO_x and carbonaceous polymers and they play an important role in the control of trench profiles. Hence, O_2 ashing and an HF solution treatment are necessary to remove the film perfectly.

IV. CONCLUSION

Fig. 6 a)b)c)d)e). Etching profiles of trench structures at frequencies 20 kHz, 45 kHz, 100 kHz, 1 MHz, 13.56 MHz, respectively (CCl_2F_2, p=30 Pa, P=100 W)

Experiments were made to investigate the role of frequency on the etching of trench structures. The results show that in the low frequency range (20–100 kHz) the influence of the power and the gas used on the silicon etch rate play a higher role than the frequency (Fig. 3.4 and 3.6). Significant changes of the Si etch rate took place only at high frequencies (1.6 and 13.56 MHz). We obtained relatively better results of selectivity when using CCl_2F_2. In the Fig. 4d are the results in the case when trench profiles and etching characteristics (etch rates and selectivity) are both satisfied. The depth of the trench in this case was 6.6 μm.

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ВЛИЯНИЕ ЧАСТОТЫ РАЗРЯДА НА РЕАКТИВНОЕ ИОННОЕ ТРАВЛЕНИЕ СТРУКТУР КАНАВОК

В работе исследуется реактивное ионное травление канавообразных структур в газах С Cl_2F_2 и $CBrF_3$ в диапазоне частоты от 20 КГц по 13,56 МГц при ВЧ разряде мощности 100 и 150 Вт. Исследуется влияние показанных параметров на свойства процесса травления (скорости, чувствительности, анизотропии).