Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

First Engineering Scientific Conference
College of Engineering –University of Diyala
22-23 December. 2010, pp. 57-66

EFFECT OF OXYGEN ON SI ETCH PROFILE USING DC SF6 PLASMA MICROMACHINING

Shrok Abdullah and Abd-allsatar Ali
Ministry of Science and Technology, Baghdad – Iraq

ABSTRACT:- Plasma etching with tapered profile structure (high aspect ratio structures) in silicon is an important step in manufacturing capacitors for memory devices and integrated components of microelectromechanical systems. In these applications, the goal is to etch an isotropic deep features with high etch rates and with tapered profile while maintaining good uniformity. This study presents a utilization of SF6/O2 glow discharge plasma in silicon etching. The effects of etching gas (SF6) pressure and addition of oxidation gas ratio on the etching rates have been investigated. In plasma etching; the balance between feature sidewall passivation and feature bottom etching lead to anisotropic etching. Since plasma etching process depends on the chemical reaction, its rate is dependant on the diffusion rate of the reactive species generated by the plasma to the etch front and the etch products away from the etch front which affected by the sidewall passivation. Results show that in such plasma process, both etching and passivation reactions occur at the same time. These etching and passivation reactions lead to taper etch profiles when O2 ratio was 10%. Visualization of profiles for N-type and poly-type Si wafers using optical microscopy is complimented by plasma etching rate. Key words: SF6plasma, micro etching, taper profile.

1. INTRODUCTION

Although the plasma equipments investment is high, plasma etching becomes a widely accepted standard micromachining process and their equipments introduced rapidly in these applications. This is due to etching advantages achieved by this process; etching anisotropy, faithfully transfer ability of the defined mask pattern into silicon, cleanlines and compatibility with other vacuum processing technologies and finely the higher etching rates achieved in the newest plasma etcher (1). Silicon etching with tapered profile structure is an important step in capacitors manufacturing for memory devices and integrated components of microelectromechanical systems (MEMS). The goal in these applications is to achieve deep tapered etch profile anisotropically with high etching rates while maintaining the good uniformity (2).

One of the requirements for solar cells or the wafer MEMS devices micromachining is the backside contact. Duong Ngo explained the main micromachining process steps as shown in Fig.1. The three main steps are: plasma 2 etching of tapered via holes for the electrical contact to the front end pads, the 3-D lithography to create the contact window in this via holes, and the metallization to redistribute of the solder mask and pads connections.

A tapered sidewall is needed to have good uniformity in the coverage and metallization steps, since vertical sidewall features with sharp corners unfeasible to have good spray coating or sputtering processes (3). Many methods were developed to have tapered etch profile in Si wafer. Bosch process is one of this method where an etch process based on continuous cycling of passivation and etch steps. Cryogenic plasma etching: where the combination of blocking layer formation and reduction of this layer by the radical reaction is another method. The low temperature limitation makes it unusable for most applications (4). A new method was developed based on using fluorine as a reactive gas with different passivation gasses (SF6/O2/passivation gas) to have a tapered profile by one etching step (3).

The balance between feature sidewall passivation and feature bottom etching lead to anisotropic etch process. Since plasma etching process depends on the chemical reaction, it`s rate is dependant on the reactive species (generated by plasma) diffusion rate to the etch front and the diffusion rate of etch products away from it. The rates of diffusion to and from the etch front are reduced relative to the silicon structures shallow so the etching rate reduces as the etch depth increases (5). Changa (5) suggest a sketch to illustrate the taper profile formation as shown in Fig. 2. During passivation process the sidewall passivation film will be thicker at the top of the feature due to it`s longest plasma exposure time, while the bottom of the feature has seen plasma only briefly. When this sidewall passivation removed by reactive species, the sidewalls of the feature will be slightly tapered. Janna (6) reported wide varieties of parameters that greatly affect the plasma physical characteristics and subsequently affect the surface modification and etch profile obtained by plasma chemistry. These parameters classified as processing parameters, i.e. gas types, treatment time, applied voltage and working pressure. And internal plasma parameters: i.e. F• species in ion flux, F/O ratios, the ion energy and their distributions angle

2. EXPERIMENTAL WORK

The etching experiments were performed at low pressure home built D.C glow discharge plasma system shown in Fig.3, using high purity Sulfur Hexafluoride SF6 as an etching gas. Oxygen gas at different ratios was added to the reactive gas to study the effect of these additions on the etching rate and the etching profiles. The optimum SF6 plasma etching conditions (i.e. discharge voltage and electrodes inter-distance) were obtained from the I-V characteristic curves in previous work, which found the optimum applied voltage 1.3kV at 1.65e-1 mbar SF6 working pressure and 2.8 cm electrodes inter-distance for etching N-type Si wafer for 30 min (7). N-type and poly-type Si wafers were ultrasonically cleaned in ethanol bath, dried and weighted in four digits balance, positioned on cathode electrode after adhered to 160 µm thickness glass mask with opened straight lines pattern of 160 µm width.

After evacuating the chamber to the desired pressure (approximately 2.5 e mbar) the etchant gas with or without oxygen gas was flowed through mechanical needle valves, the discharge voltage of (1.3-1.4 kV) are applied for 30 min. Silicon wafers etching rates were obtained by weight loss method. The etch profiles obtained in Si wafers were investigated by optical microscope (Nikon Eclipse ME600 Type 120) attached to image processing and analyses software (Lucia version 4.81).

3. RESULTS AND DISCUSSION

In this work, silicon wafers were etched using fluorine base gas SF6 and O2 as etcher and passivity gases subsequently in a home built DC glow discharge plasma. Anisotropic profiles and tapered feature with depths in excess of 80 µm were achieved. The effect of O2 concentration on both etch rate and etch profile was investigated with assistant of etch profile images over a range of O2/SF6 ratios. The most important species in plasma processing are created when electrons collide with neutral gas molecules. The resultant from these collisions are: dissociation (radicals), ionization (as SF5 +) and excitation according to the energy required for each process (6). In SF6/O2-Si process system oxygen passivity the silicon surface with silicon oxide layer while (SF5 +) ions etched these passivation making it possible for the F• radicals to etch the silicon substrate (3) as illustrate n Fig.4 (1). Figure 5 shows that SF6 working pressure have a great impact on the etch rate which increased linearly up to 0.1 mbar then become saturated. The phenomena have been discusses as: etch rates are highly dependent on the concentration of fluorine gas, provides the plasma environment with the available F• (active free radicals) and ions, which increase the etching rate. This result is acceptable to many references: Generally, as the gas amount increase its free radicals and ions etching increased resulting in an increased etching rate, when this gas pressure increases to a certain amount a decrease in the mean free path of the plasma components is observed and increasing in ions scattering lead to saturation in etching rate (8and 9). From these results we obtained the appropriate SF6 working pressure (1*10-1 mbar).

Etching rate is affected by O2/SF6 gas ratios as shown in Fig.6. The addition of O2 (the passivation gas) in small amount tend to decrease the etching rate to its min. value at 10 % this etching rate change its behavior and become increasing gradually up to its max. value at 15% the decreased again. These results in agreement with Bond results (6) who found peaks in etching rates for CHF3:O2, SF6:O2, and NF3:O2 plasmas at 60%, 20%, and 30% O2 ratios, respectively. The increase and eventual decrease in the etching rate is again as he suggested believed to be related to the increase in reactive F*, removal efficiency of etching products, dilution of the reactive gas, and lower C, S, and N-O reaction efficiency. In our work the etching rate tend to behave in the same like manor. The small amount O2 addition tends to decrease the etching rate due to the balance between etching and passivation reaching the optimum balance at 10% O2. The reactive F* concentrate increasing in the etch grove, ion shadowing and side wall charging tend to increase the etching rate up to its max. value at 15% O2. This etching rate decreased again related to the dilution of the reactive gas at high O2 concentrations. Our results indicate that the O2 at different ratios in plasma environment act as a primary factor affecting etch profile for N and poly Si types as shown in Figures 7, 8, and 9, the etch profile take a tapered shape at O2/SF6 =10**%** for poly type as shown in Fig.5, which indicate that oxygen passivation is in a balance to fluorine etching. The SF6 to O2 ratio in the feed gas determines the balance between etching and passivation, which controls the etch rate and feature profile shape (5).

O2/SF6plasma chemistry tends to generate bowing in silicon when the etching rate is high enough than passivation Fig.8 and 9. The possible causes of the overhang are: sidewall charging - the passivation layer (if SiO formed) acts as an insulator so the ions colliding with the sidewall will leave their charge which is difficult to compensate with electrons. This charging can repel the next ions at the topside of the features resulting a nonuniform etching profile. Ion shadowing, when ions arrive under an angle the topside of the features will block ions from etching the area under the mask layer. The bowing can be minimized when: the sidewall passivation layer is SiO2, increasing the energy of the ions before entering channels, adding extra based passivation gasses [3]. Increasing the applied voltage (as external plasma parameters) increases the ion average energy, which increases the etching rate and improves feature anisotropy (5). Etch profile anisotropy can be controlled through appropriate variations of O2/ SF6 ratios and discharge voltages (6). Fig.10 shows comparison between the etched lines top view images for N type Si wafer at different O2/ SF6 ratios. Passivation residue has been identified from surface brightened when etching process is lower than the passivation process as in A (at O2/SF6 =30%); in B there is a remarkable etching over the etch line (at O2/SF6 =5%).

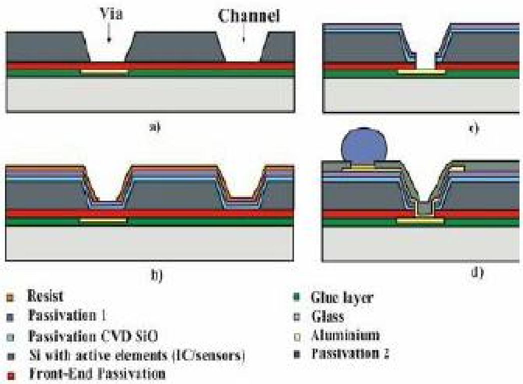


Fig. (1): Schott Ip, via contact technology for wafer level packaging of image sensors. Step.

a): plasma etches of tapered via holes and channel structures in silicon.
b): deposition of passivation and IDL (Inter Dielectric Layer) layers. c) Plasma etching of back-end passivation/IDL layer/front-end passivation layer. d) Sputtering of contact metal for redistribution. Solder mask and bumping (3).

4. CONCLUSIONS

Plasma etching is a high precise technology in microelectronic fabrication. It was found that the tapered profile meet an economical goal and a technological attitude SF6 plasma used for Si wafer etching with high etching rate, which increased with SF6 working pressure. Oxygen addition to the etching gas plays as an important factor in the etching rate and etch profile. In O2/SF6 plasma the etching and passivation reactions take place in the same process. Etch profile anisotropy can be controlled through appropriate variations of O2/ SF6 ratios and discharge voltages, small O2 amount reduce etching rate and achieve taper etch profile when O2/SF6 ratio was 10%

5. REFRENCES

1. Bhardwaj J., H. Ashraf, A. McQuarrie" Dry Silicon Etching For MEMS" Presented at the The Symposium on Microstructures and Microfabricated Systems at the Annual Meeting of the Electrochemical Society, Montreal, Quebec, Canada. May 4-9, 1997.
2. Hopkins, j.h.ashrf "The Benefits Of Process Parameter Ramping During The Plasma Etching Of High Aspect Ratio Silicon Structure "proceeding of the materials research society .fall meeting. Boston Massachusetts. USA. December 1998.
3. Ha-Duong Ngo , Andre Hiess" Plasma Etching of Tapered Features in Silicon for MEMS and Wafer Level Packaging Applications"(2006), Journal of Physics: Conference Series 34 271–276
4. Online Information Alcatel Vacuum Technology, France, www.adixen.fr.
5. Changa J. P." Plasma–Surface Interactions" Sep’Oct 2003, J. Vac. Sci. Technol. A 21Ñ5Ö,
6. Janna Rea Bonds “Sic etch development in a lamtcp 9400se ii system" December 2002,Mississippi State, Mississippi,
7. Allami Shrok, Ebrahim munther "Silicon Wafer Surface Modification And Etching By SF6 Plasma And Study The Effect Of He And O2 Addition” 2008, annual report/ministry of science and technology /Baghdad –iraq,
8. Russ A. Morgan, Plasma Etching in Semiconductor Fabrication, Plasma Technology, 1986, vol. 1, pp. 24-36, Amsterdam:Elsevier,.
9. Yih P.H., V. Saxena, and A.J. Steckl, “A Review of SiC Reactive Ion Etching in Fluorinated Plasmas,” 1997, *Phys. Stat. Sol. B*, vol. 202, pp. 605-642.

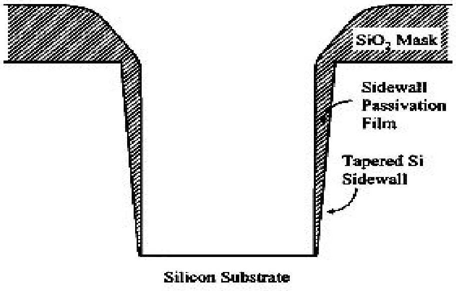


Fig.(2): Schematic of the sidewall passivation film (5).

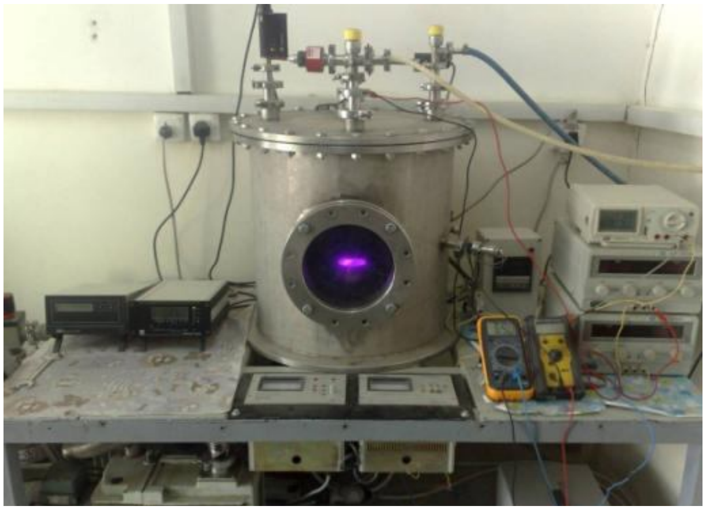


Fig.(3): Home built D.C glow discharge plasma system

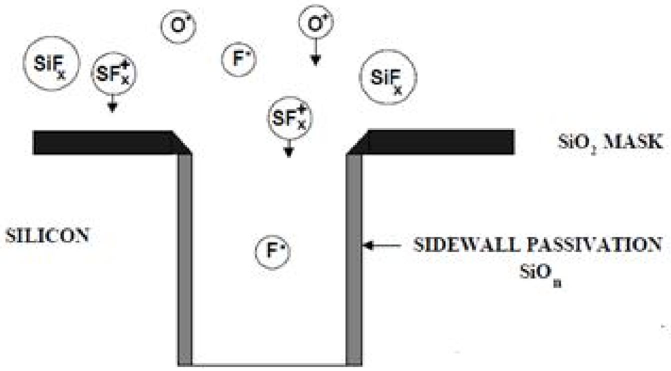


Fig.(4): Simulation side wall passivation (1).

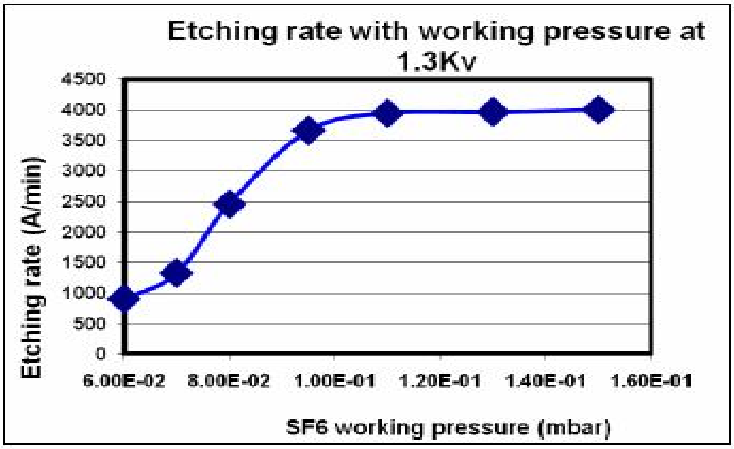


Fig.(5): Effect of SF6 pressure on the N type Si wafer etching rate at constant discharge voltage 1.3 kV.

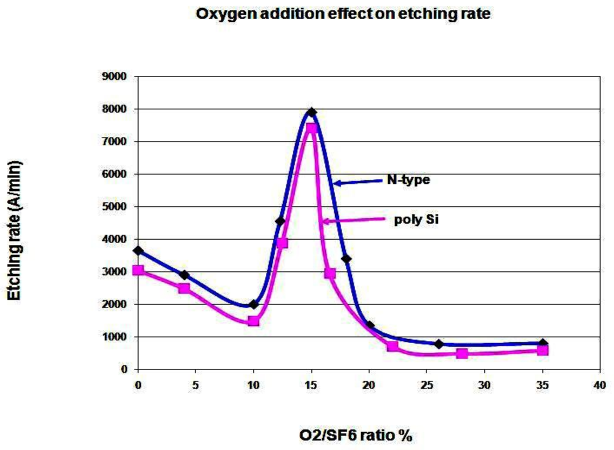
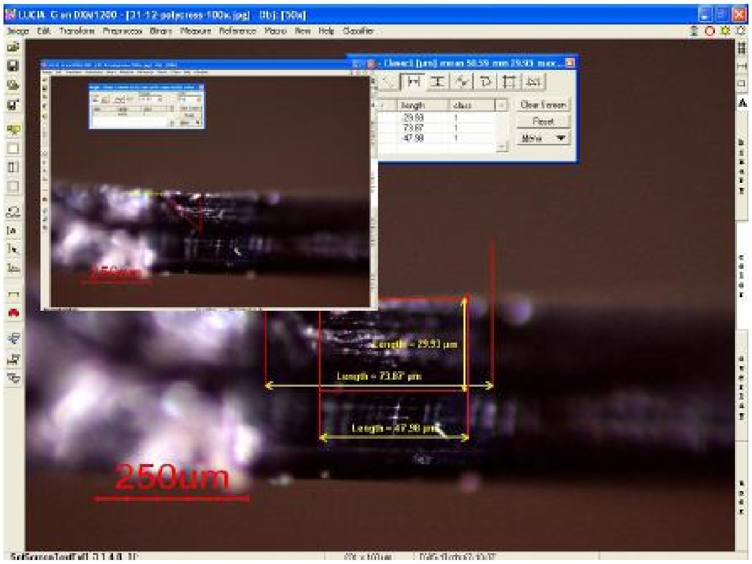
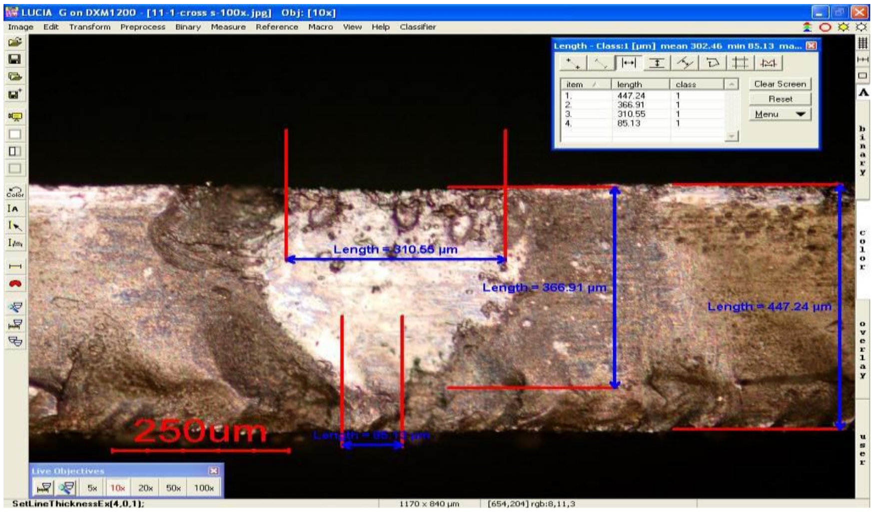


Fig.(6): The Si wafer etch rate versus O2 concentration in O2/SF6 plasma.



length	class
29.93	1
73.67	1
47.98	1

Fig.(7): Poly type Si wafer etched in O2/SF6 =10% at 1.4 kV (depth 79.93µm angle 45°).



Length - Class:1 [µm] mean 302.46 min 85.13 ma...

item	length	class
1.	447.24	1
2.	366.91	1
3.	310.55	1
4.	85.13	1

Fig.(8): N type Si wafer etched in O2/SF6 =14% at 1.4 kV depth 366µm, angle 36.18 °).

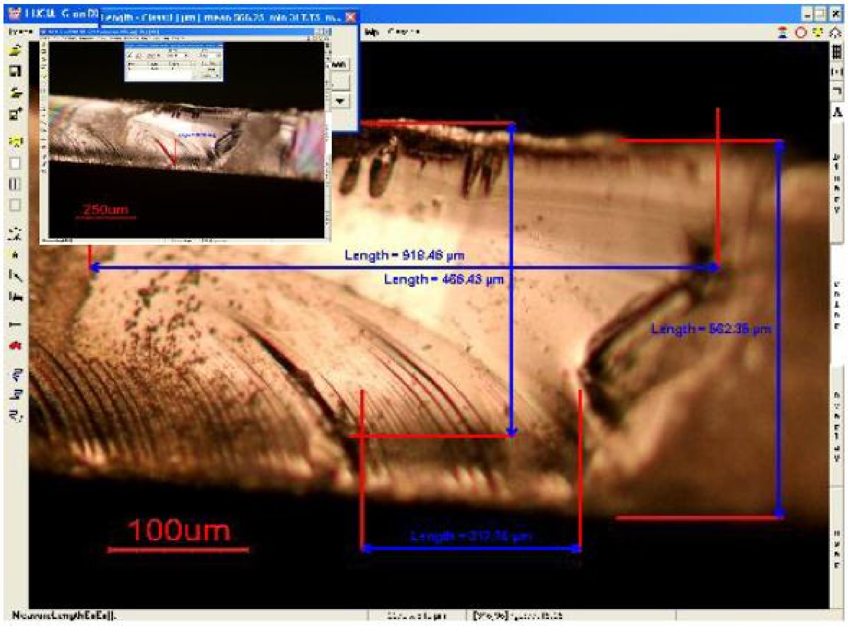
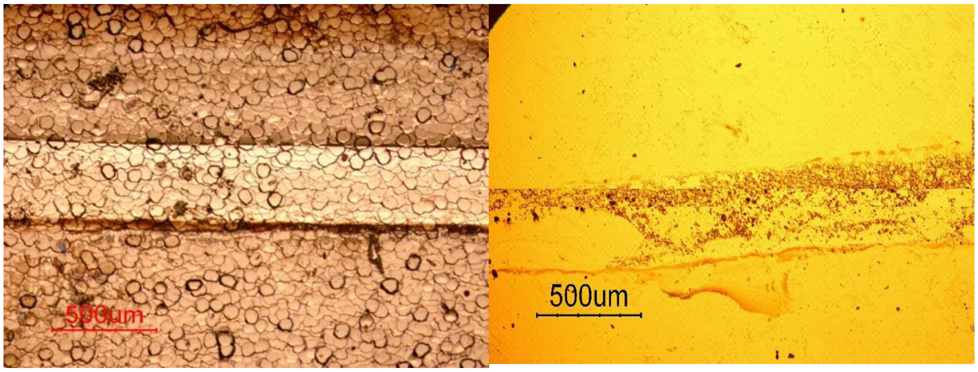


Fig. (9): poly type Si wafer etched in O2/SF6 =14% at 1.4 kV (depth 466 µm, angle 36.76 °)



A B

Fig.(10): Si wafer N type etched at 1.4 kV in A- O2/SF6 =30% B- O2/SF6 =5%.

تأثير إضافة الأوكسجين لبلازما غاز سادس فلوريد الكبريت ذات التيار المستمر على اشكال اخاديد حفر في السيليكون

د.شروق عبدالله عيدان اللامي
وزا رة العلوم والتكنولوجيا - بغداد/العراق

عبدالستار علي
وزا رة العلوم والتكنولوجيا - بغداد/ العراق

الخلاصة

يعتبر حفر اخاديد في السيلكيون ذات مقطع مائل خطوة مهمة في تصنيع المتسعات لوحدات الذاكرة والعناصر المتكاملة للانظمة الالكتروميكانيكية الدقيقة . ان الهدف من هذه التطبيقات هو الحصول على اخاديد عميقة مائلة المقطع غير متكاثلة وبمعدل حفر عالي والمحافظة على التجانس

عرضت هذه الدراسة امكانية الاستفاده من بلازما التفريغ المتوهج للمزيج الغازي SF_6/O_2 في حفر شرائح من السيليكون . تم دراسة تأثير ضغط غاز الحفر SF_6 ومعدل اضافة غاز الاكسدة على معدلات الحفرز نحصل على الحفر غير المتماثل بالبلازما عن طريق التوازن بين تكوين الطبقة الخاملة على جدران الاخدود (اكسدة الجدران) وحفر قعر الاخدودز وبما ان الحفر بالبلازما يعتمد على التفاعلات الكيمياوية فان معدل الحفر هذا يعتمد على معدل انتشار نواتج البلازما الفعالة الى مقدمة الحفر وانتشار نواتج الحفر بعيدا عن مقدمة الحفر والذي يعتمد على خمولية الجدران ز بينت نتائج عملية البلازما, بان كل من عمليتي الحفر والاكسدة تحدث في نفس الوقت تؤدي عمليتي الحفر والاكسدة معا الى الحصول على المقطع المائل عند نسبة الاوكسجين 10% .