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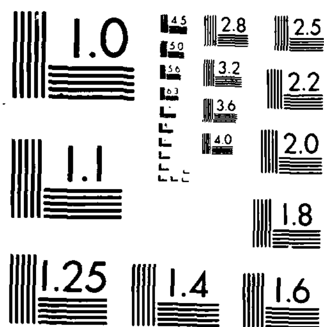

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ANISOTROPIC AND SELECTIVE REACTIVE ION ETCHING OF SiC IN CHF_3 AND OXYGEN PLASMA

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ABSTRACT

The use of CHF_3 plus oxygen plasma to achieve selective and anisotropic patterning of SiC thin films in the reactive ion etching (RIE) mode is reported. Experiments were performed using various levels of oxygen percentage (from zero to 90%), pressure (from 20 to 300 mTorr) and power (from 100W to 350W). Anisotropic etching of SiC with a vertical-to-lateral etch ratio in excess of 8:1 was measured for a CHF_3 + 75% O_2 mixture at 20mT pressure and 200W RF power. Under these conditions, the SiC etch rate was measured to be 400 A/min and the selectivity over Si was approximately 2.2:1. The effect of the cathode DC potential and emission intensity of various species in the plasma on the SiC and Si etch rates is considered.

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ANISOTROPIC AND SELECTIVE REACTIVE ION ETCHING OF SiC in CHF_3 and OXYGEN PLASMA

By

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Prepared for Publication in the Proceedings of the Materials Research Society

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I. INTRODUCTION

Silicon carbide (SiC) has become a more attractive semiconductor material in recent years due to its wide band gap, high temperature stability, high breakdown electric field and high electron saturation velocity [1]. Various microelectronic applications for SiC have been reported, including light emitting diodes [2], high temperature transistors [3], dielectric isolation [4], heterojunction bipolar [5] and MOS transistors [6] As the dimensions of VLSI devices are entering the sub-micron region, a selective and anisotropic etching process is essential in IC fabrication. In a previous publication [7], we have reported that SiC can be etched by RIE with fluorinated gases such as CF_4/O_2, SF_6/He, SF_6/O_2. The SiC etch rate was determined to be predominantly controlled by ion bombardment. This is in contrast to the etching of Si under the same conditions, where the fluorine species concentration was the rate limiting step. Our previous work indicated that useful SiC etch rates (300-600 A/min) can be achieved with a variety of fluorinated gas mixtures.

In all previous cases examined, the SiC/Si etch rate ratio was considerably smaller than unity. However, in certain device applications one needs to etch the SiC layer selectively with respect to the Si substrate. In this paper, we report the results of our investigation to obtain a SiC/Si plasma etching rate ratio greater than one.

II. EXPERIMENTAL CONDITIONS

SiC thin films were deposited by RF (13.56MHz) sputtering

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onto silicon substrates in a planar system (Veeco). A hot-pressed stoichiometric SiC composite target cathode (99.7% purity) was used at an RF power of 200W. After deposition, the films were furnace annealed at 1100°C in a nitrogen ambient for 30 minutes. N-type (4-6 ohm-cm) (100) Si wafers were used to determine the Si etch rate and oxidized silicon substrates (in steam at 1100°C) were used for SiO_2 etching. The etching experiments were carried out in a parallel plate reactor (Plasma Therm PK1241) equipped with a computer-controlled grating monochromator for measuring optical emission within the plasma. Emission spectra in the wavelength range between 200 and 800 nm were monitored through a quartz window placed on the sidewall of the chamber. The DC self-bias of the RF electrode was also monitored. The base pressure of system was less than 2.0×10^{-5} Torr. To determine the etch rate in various ambients, Al was used as a thin film mask since it is suitable for both low and high percentage of oxygen. The Al mask was subsequently removed by wet etching for step height determination by profilometer (Dektak). Samples with deeply etched patterns were used to observe the anisotropic etching phenomena by scanning electron microscopy (SEM : Nanometrics Cwickscan II). Auger electron spectroscopy (AES) was used to obtain composition versus depth profiles of both pre- and post- plasma etched SiC samples.

III. RESULTS

The etch rates were determined as a function of oxygen percentage of in $CHF_3 + O_2$ mixtures, RF power and pressure. In Fig. 1a, the SiC etch rate is shown as a function of oxygen

percentage (from 0% to 90%) in the CHF_3/O_2 mixture at a pressure of 20mTorr and a total flow rate of 20sccm. In Fig. 1b are shown the corresponding DC self-bias and the relative intensity of fluorine [F], hydrogen [H] and oxygen [O] emission at 703.7, 487 and 780 nm, respectively. The etch rates of Si and SiO_2 are found to be lower than SiC when the percentage of oxygen is higher than 35% and the etch rate of SiC reaches the maximum value, 420 A/min, at a level of 65% O_2. Further increases in the oxygen percentage result in a decrease in the SiC etch rate. The Si etch rate reaches a plateau of approximately 300 A/min at oxygen percentages between 10% and 50%. For oxygen concentrations higher than 50%, the etch rate of Si decreases rapidly. The highest SiC to Si etch rate ratio is 2.2 at 75% O_2, where the etch rates of SiC and Si are 400 A/min and 180 A/min, respectively. Fixing the oxygen composition at 75%, the pressure and power are varied to optimize the etching ratio. In Fig. 2 (a , b) the etch rate versus pressure (from 20 mT to 300 mT) is shown along with the DC self-bias and the emission line intensity of [F], [H] and [O] for an RF power of 200 W and a flow rate of 20 sccm. The oxygen and fluorine intensities at first increased rapidly with pressure (from 50 to 100 mTorr) and then tended to decrease slightly for higher pressure. The DC self-bias decreased monotonically with increasing pressure . While the etch rate of Si tended to follow the fluorine intensity ,the etch rate of SiC appears to be determined by a combination of the DC bias and [O] intensity.

In Fig. 3 (a, b) the etch rate versus power is shown along with the corresponding DC self-bias and the emission intensity of

[F], [H] and [O] for the same 75% oxygen content and flow rate of 20 sccm but at a fixed pressure of 20 mT. The etch rate ratio of SiC to Si increases from 1.8 to 2.3 with power increasing from 100 W to 350 W. The etch rate of SiC ranges between 100 A/min at 100W to 740 A/min at 350W. The SiC etch rate is seen to increase with power approximately twice as fast as the Si etch rate. This is consistent with an [O] intensity increase with power which is two to three faster than the [F] increase.

The samples which were used to mesure the etching anisotropy were etched in CHF_3 75% O_2 at 20 mT, 200 W, and 20 sccm. The vertical-lateral etch ratio is 8:1 for SiC and 4.5:1 for Si, as shown in the SEM microphotographs of Figs. 4, 5, 6, 7.

IV. DISCUSSION

The data obtained for the reactive ion etching of SiC in CHF_3/O_2 indicate that the etch rate of SiC is controlled by a combination of physical and chemical factors: (a) the DC self-bias; (b) the abundance of oxygen in the plasma. A few interesting aspects of this rather complicated process are discussed here. In the case where the oxygen percentage was varied (Fig. 1) the pressure and power were kept constant, resulting in a constant DC bias and a monotonically increasing [O] abundance. The SiC etch rate in this case appears to follow the [O] intensity curve up to 75% O_2. For higher O_2 percentage (90% O_2), even though the [O] intensity still increases somewhat the SiC etch rate drops dramatically. This could be due to the fact that the Si etch rate is very low at this point thus presenting a surface barrier layer for SiC etching.

In the case where the oxygen percentage is fixed at 75% and the pressure is varied (Fig. 2), the DC bias decreases while the [O] intensity first increases dramatically with pressure (up to 100 mTorr) and then exhibits a slight decline. In this case, the two SiC etch rate determining factors have a somewhat competing effect. Initially, at low pressures (20-100 mTorr) the rapidly increasing [O] abundance overpowers the effect of the decreasing DC bias and results in a slight increase in the etch rate. However, for higher pressures (>100 mTorr) the [O] intensity is roughly constant and the effect of the decreasing DC bias dominates, thus resulting in a rapidly decreasing SiC etch rate.

By comparison, the Si etch rate appears to be predominantly controlled by the [F] intensity. Therefore, one can generally obtain a SiC/Si etch rate ratio larger than unity by reducing the [F] intensity and increasing the DC bias and [O] intensity. The [F] intensity can be depressed by changing the gas medium from CF_4 to CHF_3 and, of course, by increasing the oxygen percentage.

V. SUMMARY AND CONCLUSIONS

In summary, we have presented the first report of reactive ion etching of SiC at a rate higher than that of Si. For CHF_3/75% O_2, the SiC/Si etch ratio is 2.2. At the same time, highly anisotropic (8:1) etching of SiC was achieved under the same conditions.

The SiC etch rate appears to be controlled by a combination of physical (DC bias) and chemical (oxygen intensity) mechanisms.

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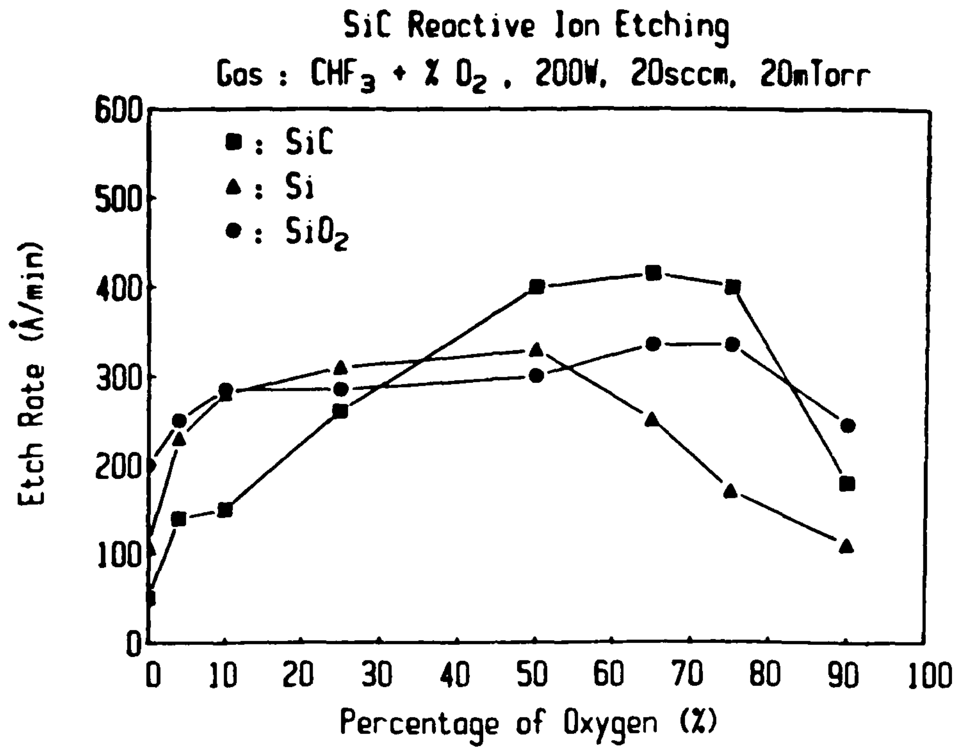
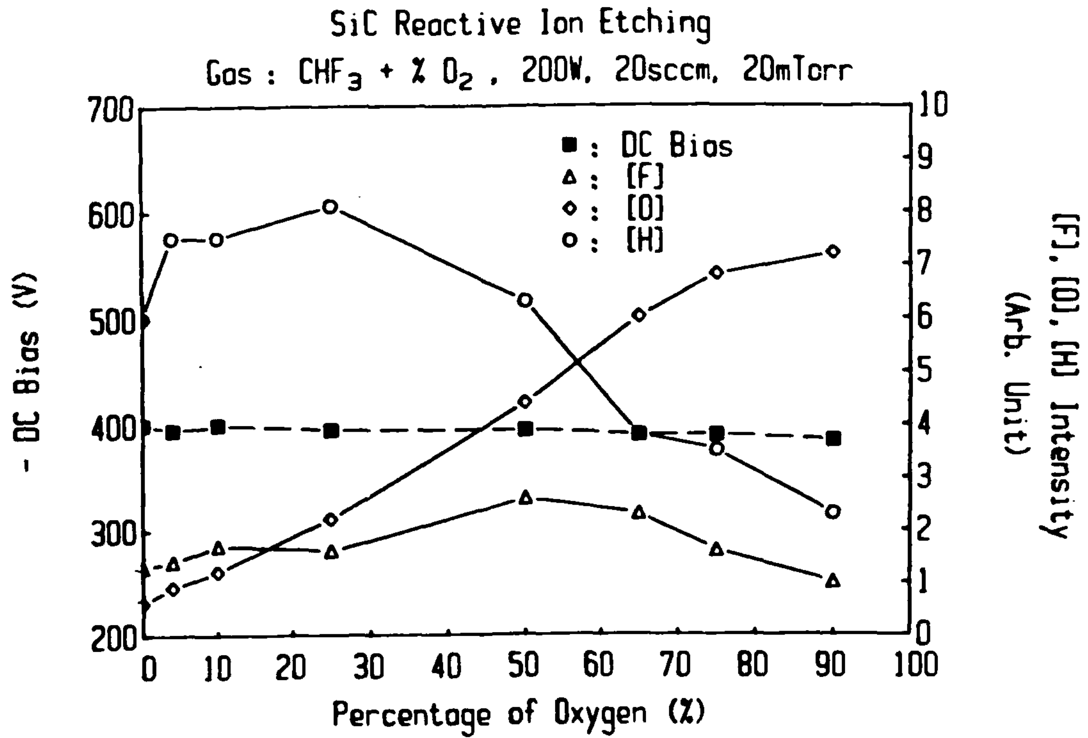
Fig. 1 (a,b)





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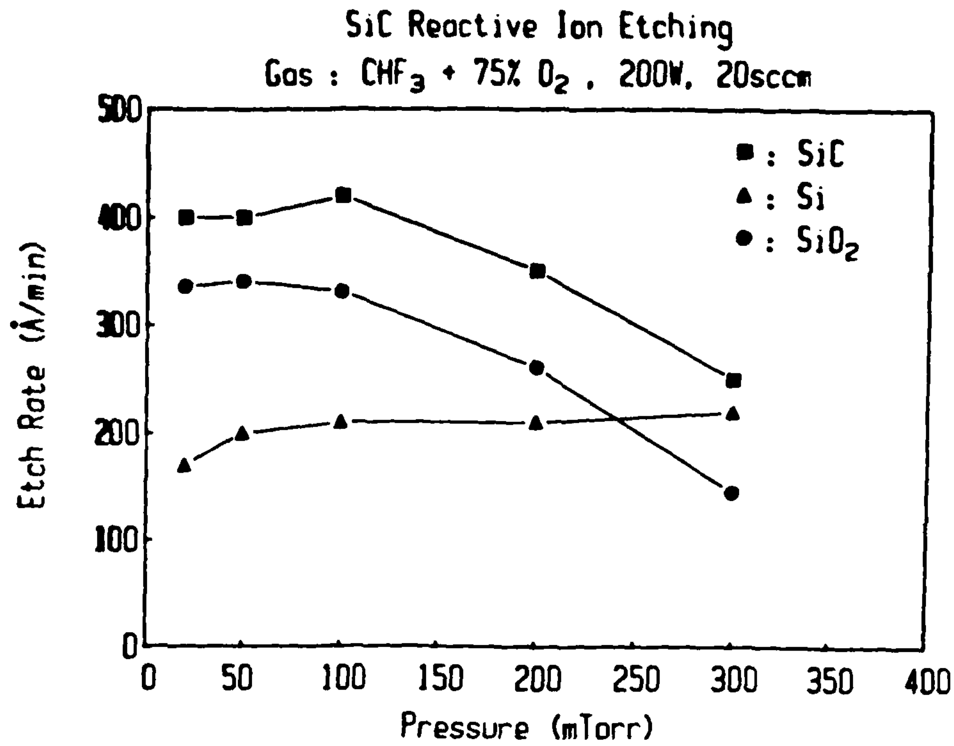


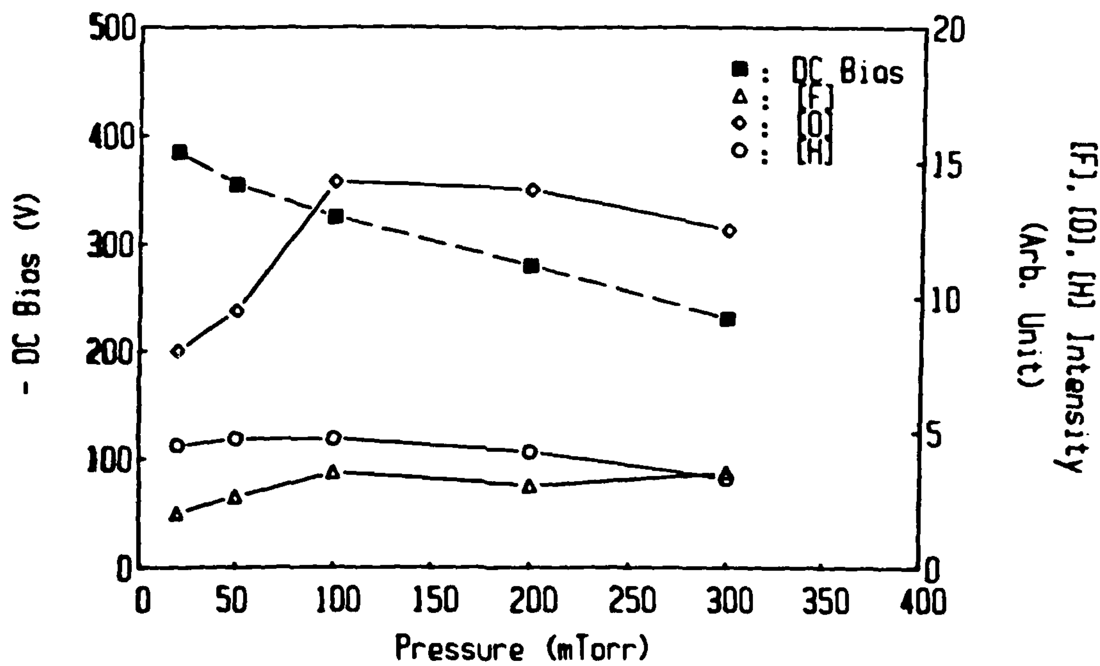
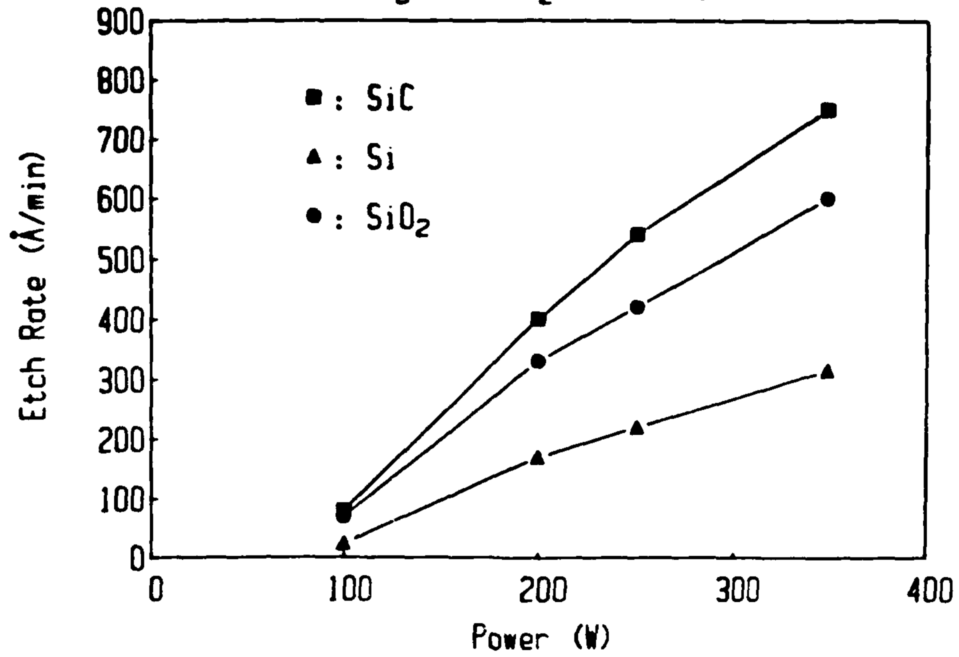


Fig. 3 (a,b)



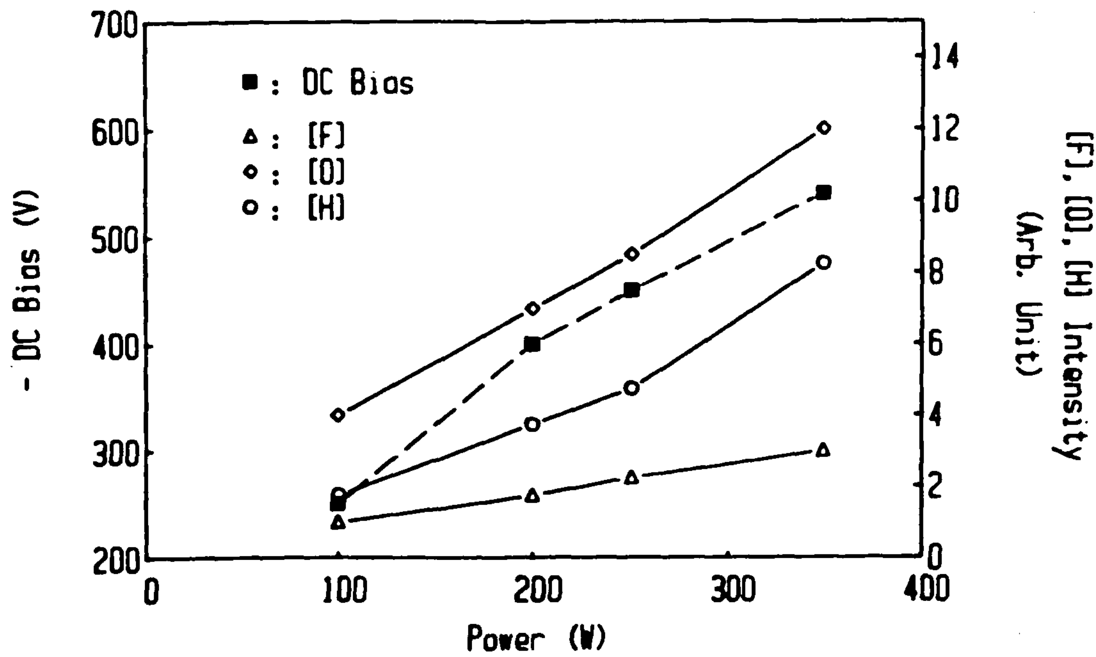
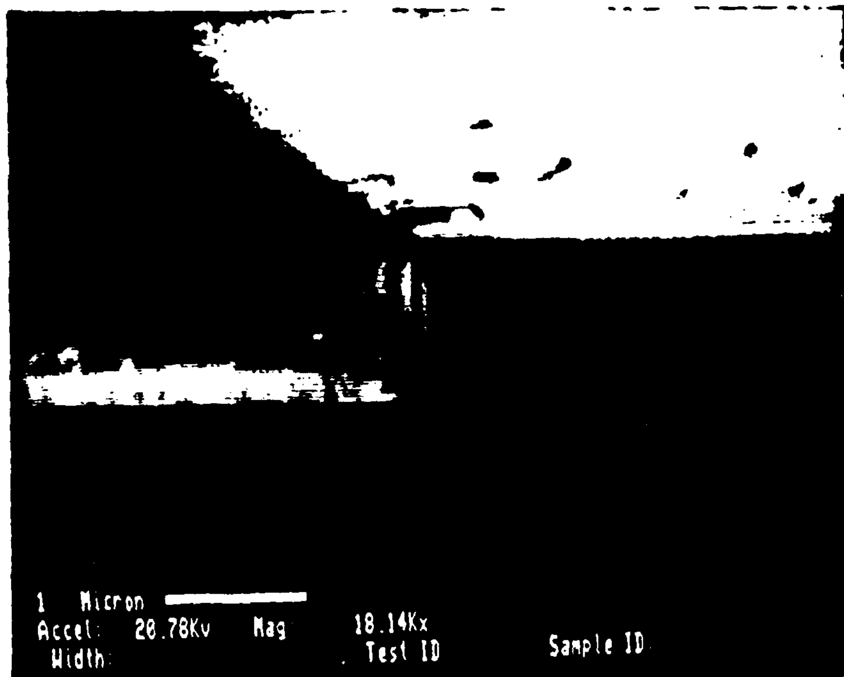


Fig. 4, 5



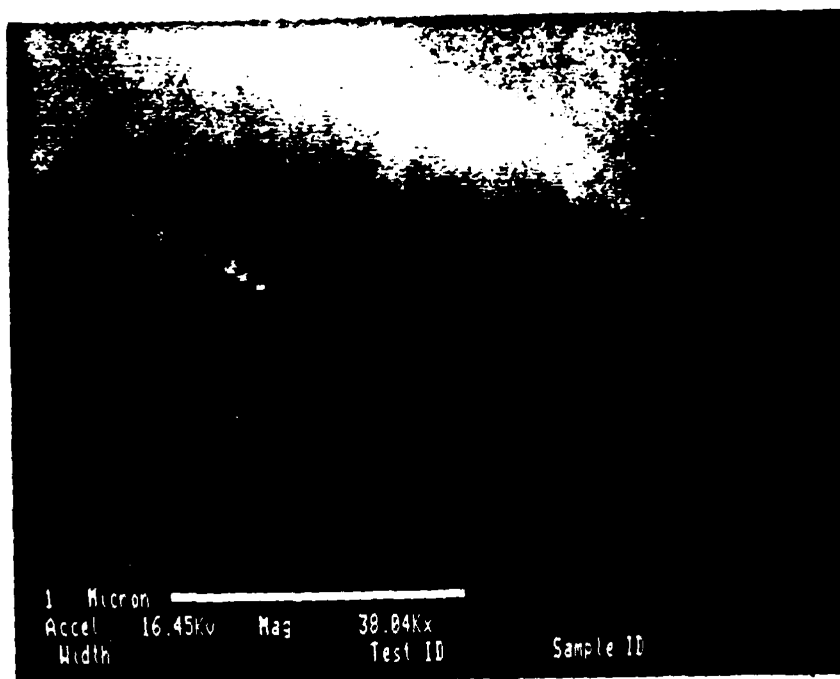
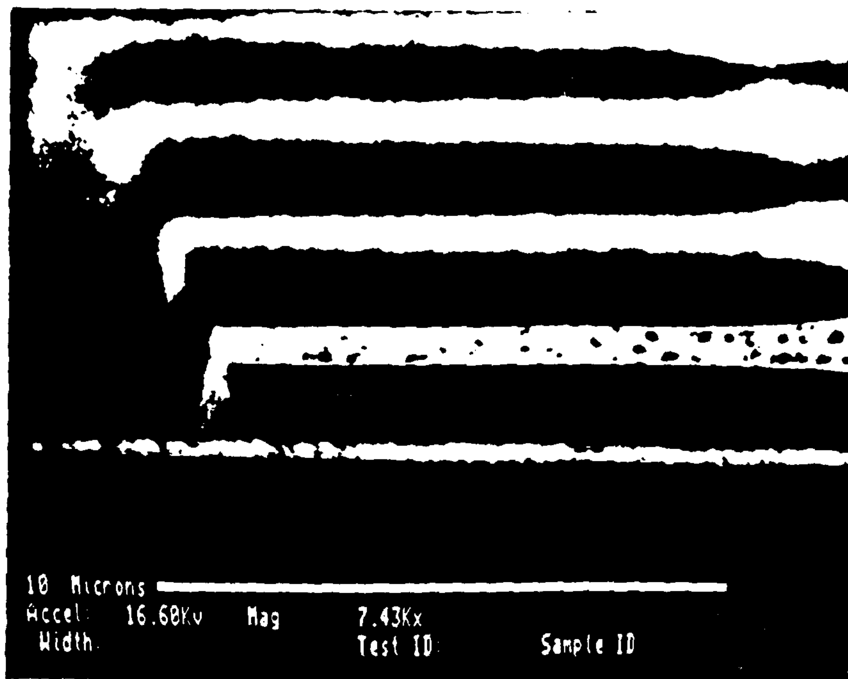


Fig. 6, 7



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