SOME APPLICATIONS OF A SIMPLE PLASMA SYSTEM

J.E. Curran
Philips Research Laboratories, Cross Oak Lane, Redhill, Surrey RH1 5HA, England

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ABSTRACT

A description is given of the construction of a plasma processing machine capable of use in the three modes (i) parallel plate plasma etching, (ii) reactive ion etching, and (iii) plasma oxidation. Brief experimental results are given for the etching of tantalum, tungsten and quartz, and for the oxidation of photoresist and gallium arsenide.

1. INTRODUCTION

In recent years several plasma etch systems have been described[1,2] and some commercial machines designed for specific production processes have become available. On this basis we decided in our research laboratory to construct simple basic plasma processing equipment for etching experiments.

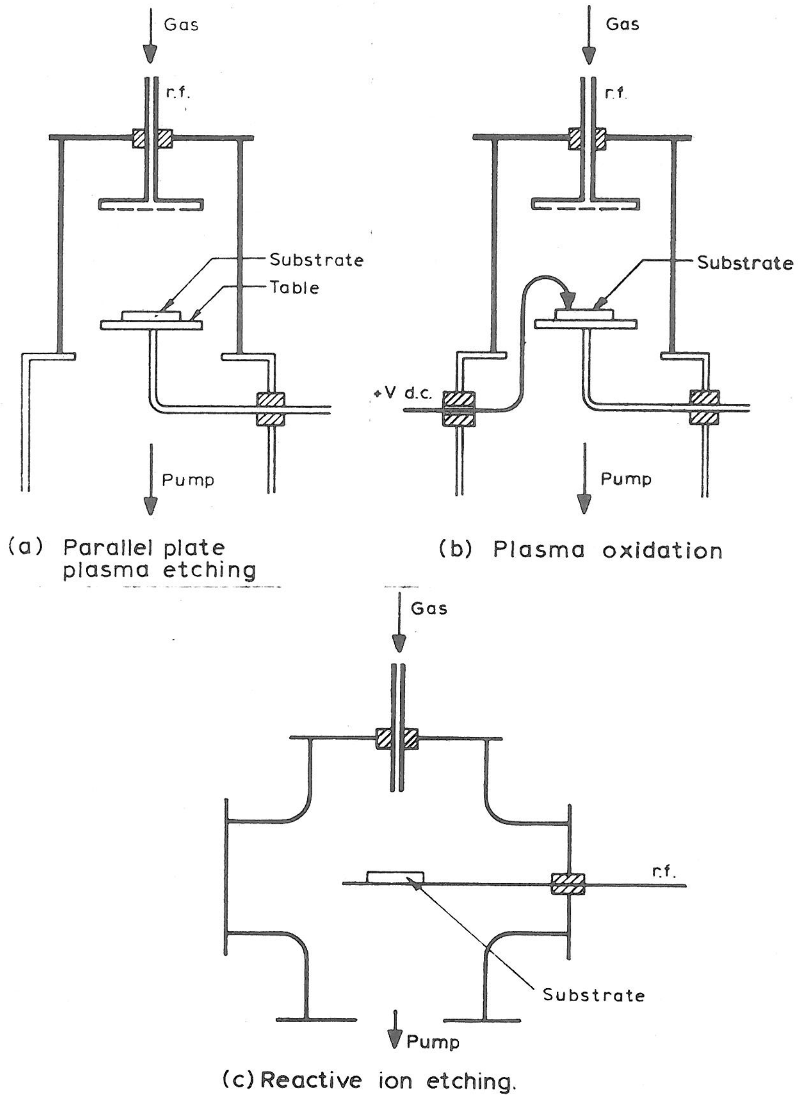
The apparatus constructed has since been used for parallel plate plasma etching, reactive ion etching and plasma oxidation to carry out the processing of tantalum, tungsten, quartz and gallium arsenide for electronic components.

In this paper we describe the construction and some maintenance problems with the machine, the various methods of plasma operation and some experimental parameter effects on etching rate and uniformity for particular applications.

2. APPARATUS

2.1 Vacuum System

A pumping table was constructed from a two stage oil rotary pump, 330 l/min, a standard 5" diameter oil diffusion pump, and for pressure measurement a penning gauge and two pirani meters were fitted. After early experience with mineral and silicone oils and CF_4 gases which caused rotary pump seizure after only a few days of operation, we converted the system to use perfluoropoly ethers in both the diffusion and rotary pump. One charge of these fluids has now operated trouble-free for several months. Similarly it has been found that corrosion resistant filaments fitted to the pirani pressure gauges has enabled effective



(a) Parallel plate plasma etching

(b) Plasma oxidation

(c) Reactive ion etching.

Fig 1.

pressure measurements in the plasma etch gases for several months, whereas standard filaments are soon destroyed.

Pyrex bell jars have been used as an upright cylinder (200 mm diameter) for the plasma etching (Figure 1a) and plasma oxidation (Figure 1b) or as cruciform cylinders (Figure 1c) for the reactive ion etching process. Nitrile polymer L rings were used to fix either Pyrex or quartz end plates to the pyrex glass systems.

2.2 Electrodes

In the case of plasma etching and plasma oxidation experiments, the electrical r.f. power was supplied to the vacuum system through a water-cooled stainless steel disc (130 mm diameter) which also served as the gas inlet system. A water-cooled stainless steel work table was used at about 8 cm vertical distance from the r.f. electrode. This table could be earthed or electrically insulated dependent on the plasma experiment.

For reactive ion etching work the same electrode was used to introduce the gases but the electrical power was supplied through a glass side port of the cruciform to a rectangular (60 mm x 120 mm) water-cooled stainless steel plate which also serves as the substrate table.

2.3 Power Supplies

A crystal controlled 13.56 MHz, 50 Ω impedance, 0.5 kW power equipment was used to supply power through an r.f. matching network to the electrode systems described. Capacitive coupling and matching of the plasma was easily achieved.

3. OPERATIONAL MODES

3.1 Parallel Plate Plasma Etching

With the equipment in this mode (Figure 1a) some early experiments were carried out to try to establish the optimum electrode-table separation, and the effects of r.f. power total gas pressure. All these experiments were carried out at a constant gas flow rate of 15 cc/sec.

Etching tungsten foils in CF_4 + 4% O_2 gas at 0.5 torr total pressure it was established that the etch rate was 5 nm/min at 100 watts r.f. power at the optimum plate separation of between 7 and 8 cm. At plate separation above or below this the etching rate dropped to 3 nm/min. Similar results were obtained when tantalum and crystalline quartz were etched under the same conditions with etch rates in the same region of 5 nm/min.

The effects of gas pressure and r.f. power were shown by experiments on the plasma ashing of AZ1350J photoresist. At a plate separation of 8 cm and using pure oxygen, the etch rate of the photoresist was a maximum of 150 nm/min at a gas pressure of 0.9 torr from the pressure range 0.2-1 torr (Figure 2a) and, as expected, varied considerably with the r.f. power applied (Figure 2b).

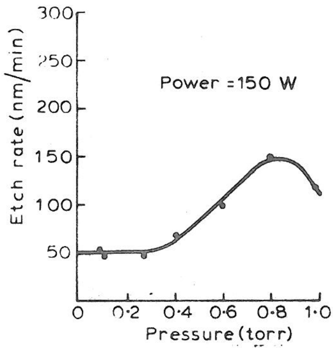


Fig. 2a Pressure Effect on Resist Etch Rate

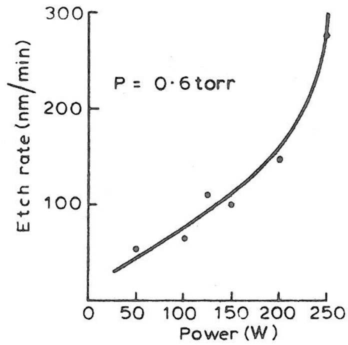


Fig. 2b Power Effect on Resist Etch Rate

3.2 Reactive Ion Etching

The electrode structure shown in Figure 1c has enabled the reactive ion etching of crystalline quartz to be studied. The etch rate varies linearally with r.f. power applied to the rectangular electrode as shown in Figure 3a but is critically dependent on the gas pressure used (Figure 3b).

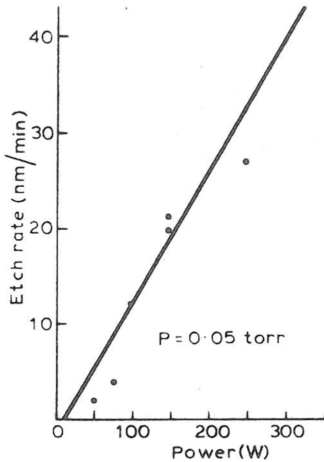


Fig. 3a Power Effect on Quartz Etch Rate

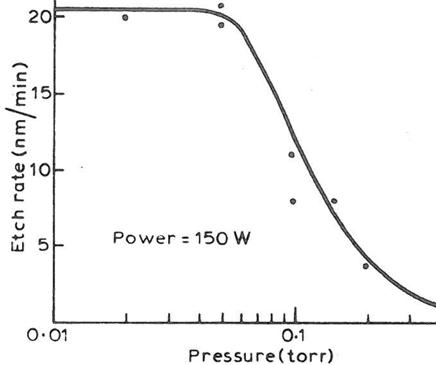


Fig. 3b Pressure Effect on Quartz Etch Rate

These experiments were carried out using CF_4 + 4% O_2 gas at a constant flow rate of 9 cc/sec and using aluminium layers as an etch mask. For comparable r.f. powers the removal rate of crystalline quartz was four times that obtained in the plasma etch mode. The uniformity of etching, measured over one sample, 20 mm x 20 mm, varied with the gas pressure from ± 3.3% at 0.08 torr to ± 23% at 0.2 torr.

This reactive ion etching of quartz was used successfully to produce surface wave resonator devices at 160 MHz by etching anisotropically, grooves 5 μm wide, 0.3 μm deep in the quartz substrate using aluminium electrodes as transducers.

3.3 Plasma Oxidation

We can report some simple experiments on the plasma oxidation of gallium arsenide. The basic result following the work of Chang and Sinha(3) is that if a positive d.c. voltage is applied to gallium arsenide contained in an oxygen plasma then surface oxidation occurs.

The assembly used was that shown in Figure 1b where the substrate table is electrically isolated from the system to allow the positive voltage to be applied to the substrate. Typical conditions for oxide growth were 200 watts of r.f. power, oxygen pressure of 0.5 torr and +50 V d.c. applied to the surface of the gallium arsenide. This gives 10 nm/min of oxide which can be used as MOS capacitor material. This process does not appear to work unless a positive voltage is applied and it must be applied to the exposed surface unless the substrate is a good electrical conductor.

Some experiments with the oxidation of thin film aluminium in this system have given inconclusive results but thin film copper is easily oxidised in this manner.

4. CONCLUSIONS

It has been demonstrated that a fairly simple system can be used to investigate basic plasma processes but it is obvious that more engineered equipments are necessary for the speed and uniformity figures required for efficient production processes.

However, the importance of total gas pressure control has been shown if reproducible etch rate and uniformity figures are to be obtained.

From the empirical results obtained it is realised that the understanding and analysis of plasma chemistry are necessary to facilitate process improvements. Some early results on optical spectra analysis seems to indicate the usefulness of the technique for this purpose.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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