Sub-100 nm Lithography with Using Pulsed Plasma Graft-polymerized Styrene and E-Beam Excited Plasma

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1. Introduction

There are great interests in a sub-100 nm lithography and more fine pattern fabrication for a future integrated circuit and quantum electronic devices like as a single electron transistor (SET) working at a room temperature. To realize such a quantum device fabrication, there are several approaches with and without a conventional lithography [1-4].

The lithographical technologies for such a fine pattern fabrication, namely the resist processes and etching processes must be improved significantly. For the resist, the thickness of resist film must be decreased from 100 to a few 10 nm. Therefore a spin coated resist system have several problems that an uniform coating becomes very difficult for such a thin layer and the thickness is too thin to sustain the film during the plasma etching. To solve the problems, a new resist system and a new etching method must be developed. We proposed a pulsed plasma polymerized resist and an electron-beam excited plasma (EBEP) etching.

The pulsed plasma polymerization is a dry resist coating method proposed by us and the resist coating was performed uniformly to a thickness of nanometer level [5]. For the process, we previously developed several reactors and improved the resist characteristics. 0.5 micron lines and spaces pattern fabrication at 2 mC was attained for the plasma polymerized styrene resist by a gas flow type reactor [6]. The pulsed plasma graft-polymerization is an advanced technology for the resist formation [7]. Practically the resist sensitivity was improved to 60 μ C for the film thickness of 2 μ m [5]. However the developed pattern size was limited to a few μ m because of the electron-beam patterning system. In this paper, we evaluated the resist by a new electron beam patterning system with decreasing the resist thickness.

For the etching, we adopted a new concept plasma excitation method. Usually the plasma must have a moderate condition for the fine structure etching, namely low pressure plasma and low ion energy. There are several plasma sources, for example ECR, ICP, Helicon Wave Plasma, and so on, however they must keep a high power level to sustain the plasma at the low pressure like as 1 mTorr level or more lower pressure. Therefore we proposed a new concept plasma generation, namely an electron beam excited plasma (EBEP) [8-10]. It was proved that the EBEP has a profitable characteristic for the plasma etching.

2. Experimental

Plasma polymerization was carried out by a capacitively coupled pulsed RF plasma [7]. As a monomer, styrene vapor was used for the film formation, where the film is expected to work as a negative resist. The patterning on the resist was performed by an electron-beam patterning system, JBX-6000SG (JEOL).

The EBEP reactor was composed with an electron-beam source and a reaction chamber. Thermally emitted electrons from a tungsten filament were used as an E-Beam source. The E-Beam was transferred into the reaction chamber through an interface film. For the transfer, the electron-beam was accelerated to a few thousand eV for the interface film of 1 micron, where a polyimide thin film was newly developed as a thermally stable film. To evaluate the EBEP etching reactor, a conventional resist system was used. Whereas a chemically amplification negative resist, SAL610 (Shipley) was used and sub-100 nm pattern was fabricated by the electron-beam patterning system. CF_4 was used as an etching gas because the gas is widely used for the etching of Si wafer. Si wafer was a phosphate-doped n-type

<100> with a thickness of 400 μ m.

(a) Electron-beam delineated patterns

(b) Developed resist patterns taken by a SEM

Fig. 1. Electron-beam delineated patterns

3.Results and Discussions

3.1.Pulsed Plasma Polymerized Styrene Resist

The pulsed plasma graft-polymerized styrene film was formed as followings, initially a pulsed plasma polymerized styrene film is coated on the substrate and then the film is exposed to a styrene vapor after turning off the discharge. The initial pulsed plasma polymerized styrene was formed at a discharge frequency of 13.56 MHz, a pressure of 0.5 Torr, an on/off ration of 1:9 at a pulse period of 1 sec in a styrene vapor. After that, graft-polymerization was carried out for 0-200 min in styrene vapor. The obtained film thickness was 200

nm. The resist was patterned by an electron-beam patterning system at the doses from 50-500 μ C. The patterned resist was developed by the hexane and acetone mixture(the ratio was 10:1) for 30 sec.. The patterned structure formed at 500 μ C is shown in Fig. 1 taken by SEM, where delineated and developed pattern are indicated in the same figure. The 200 nm pattern structure was recongnized in the photograph, and 100 nm patterns was not be resolved in the figure. The 50 nm pattern was disappeared form the substrate during the processes.

In the previous experiment, we developed 500

nm pattern clearly in the film formed by an gas flow type reactor. From the experience, the improved pattern resolution for the finer pattern structure will be realized if the polymerization condition will be optimized.

3.2.EBEP Etching

In the previous experiment, the transmitted E-Beam current through the interface was not exceeded 1 mA, so the plasma could not be excited only by the E-Beam. For the experiments, polyester film of 1 μ m was used as an interface. The film melts at around 100 C. In order to increase the transmitted E-Beam current, the interface material was replaced by polyimide and a new ultra thin interface film with 1 μ m thick was fabricated by a spin coating method with using polyimide solution, SP-811, Toray Co. Inc.. The transmitted E-Beam current was recorded to be 3 mA. However the E-Beam could not excited the plasma in the reaction chamber. Therefore, the curing temperature of polyimide thin film was changed from 350 C to a lower temperature. For the interface treated at 300 C, the transmitted E-Beam excited the plasma successfully.

The 50 nm lines and spaces resist pattern was fabricated on the chemically amplified negative resist, SAL-601 ER-7 from Shipley Far East Ltd. with using the E-Beam patterning system JBX-6000 SG(JEOL Co.) where the resist thickness was decreased to 55 nm by optimizing baking and curing conditions.

The plasma etching through the resist pattern was performed under a negative bias voltage of 191 V in the E-Beam excited plasma of CF₄ at a pressure of 20 mTorr, an transmitted E-Beam acceleration voltage of 6 kV, a transmitted E-Beam current of 1 mA. Through 50 nm resist pattern, Si wafer etching were successfully performed as shown in Fig. 2, where the resist is still remained on the Si wafer after the resist stripping, but it was confirmed that the resist pattern was transferred to Si wafer.

The experimental results that the resist with a thickness of 55 nm sustained the pattern structure during the plasma etching is important. This fact means that the plasma was maintained at the lower level to prevent the damage of the resist. It is expected that the plasma will be utilized in a future for a nanometer pattern fabrication.

4.Conclusion

In the experiments, a new resist of pulsed plasma graft-polymerized styrene showed an improved resist sensitivity of 50 μ C and 200 nm pattern structure and a new plasma etching method realized a 50 nm pattern etching on silicon wafer with using 55 nm thickness of the resist of SAL-601 ER-7. However the plasma polymerized resist was not evaluated for the new etching reactor in this study. However the possibility of use was confirmed by the experiments.

Fig. 2. 50 nm Pattern after EBEP Etching

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