Electron beam lithography of HSQ/PMMA bilayer resists for negative tone lift-off process

Haifang Yang a,*, Aizi Jin a, Qiang Luo a, Junjie Li a, Changzhi Gu a, Zheng Cui b

a Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, P.O. Box 603, Beijing 100080, China
b Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, UK

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Abstract

A HSQ/PMMA bilayer resist system, in which HSQ as negative tone electron beam resist top layer and PMMA as bottom layer, has been investigated for negative tone lift-off process. Patterns are first defined on the HSQ resist using electron beam lithography, and then transferred into the bottom PMMA layer using oxygen reactive ion etching. Electron beam exposure of HSQ on top of PMMA layer has been characterised, showing the PMMA underlayer has no effect on the exposure of HSQ. Optimum conditions for reactive ion etching of PMMA underlayer have been established. The undercut length in the PMMA layer is found near linearly dependence on etching time. Well defined undercut profile has been achieved in the HSQ/PMMA bilayer resist system, and good negative tone metal lift-off structures have been successfully produced.

Keywords: Electron beam lithography; HSQ/PMMA bilayer resist; Negative tone lift-off

1. Introduction

Lift-off is a standard process to create metal patterns on a substrate. In the past, nanometer scale metal patterns were produced exclusively by electron beam lithography of positive resist, notably the PMMA resist. By using multilayers of PMMA/MMA or other combinations of resists, undercut profiles can be created to obtain a better lift-off result [1–3]. However, there are applications requiring negative tone lift-off whereby majority of a substrate surface is covered with metal thin film. In this case, negative tone resist process is preferred because lift-off by positive tone resist such as PMMA will require exposure of large areas and consume long e-beam lithography time. However, negative resist is known to produce over-cut profiles, which makes lift-off very difficult.

The hydrogen silsesquioxane (HSQ) as a popular negative resist in recent years has been investigated widely due to its high resolution capability, minimum line edge roughness, excellent etch resistance and good stability under SEM inspection [4,5]. On the other hand, PMMA as a conventional electron beam resist has been demonstrated for its good lift-off performance. The HSQ/PMMA bilayer resists had been reported, showing the advantages for room temperature nanoimprint lithography [6] and as an etching mask to fabricate magnetic nanowires [7]. In this paper, we report our study on e-beam lithography of HSQ/PMMA bilayer resists for negative tone lift-off process, using HSQ as a top layer and PMMA resist as an underlayer, which combines the high resolution capability of HSQ negative resist and the good lift-off characteristic of PMMA. With the optimized etching conditions, the undercut length of PMMA underlayer can be precisely controlled, and good negative tone lift-off metallic structures have been produced.
2. Experiment

Fig. 1 shows the schematic diagram of the HSQ/PMMA bilayer resist for negative tone lift-off process. Patterns were first defined on top layer HSQ resist by electron beam lithography, and then transferred to the bottom PMMA resist layer by oxygen reactive ion etching (RIE). The process started by spin-coating PMMA on silicon samples and pre-baked at 180 °C for 60 s on a hotplate, and then the HSQ was spin-coated on the wafers and pre-baked at 180 °C for 120 s. No resist intermixing was found in the bilayer coating process. The e-beam lithography was carried out using the Raith150 system, and the exposure energy was 10 keV. The samples after exposure were developed in aqueous solutions of tetramethyl ammonium hydroxide (TMAH) (3.33%) at 22 °C for 60 s, rinsed in deionised water for about 10 s and blown dry with pure nitrogen gas. After the development of HSQ resist, the patterns were transferred to the PMMA layer by oxygen plasma etching using the PlasmaLab 80 Plus system from Oxford Instruments. The resist thickness was determined using surface profiler DEKTAK. The exposed features were inspected with the SEM function of the Raith150 system. The profile and the under-cut length of the bilayer resist were observed using the DB235 dual beam system from FEI Company.

3. Results and discussion

Although the exposure characteristics of single layer HSQ resist on silicon had been investigated extensively [8,9], there is no report on that of HSQ with PMMA as an underlayer. In order to characterize the HSQ/PMMA bilayer resist, we first investigated whether the PMMA underneath the HSQ would influence the exposure characteristics of HSQ. Fig. 2 shows the dependence of the contrast curves of HSQ resist on different thicknesses of PMMA bottom layer. From the contrast curves, one can see that the bottom layer PMMA does not affect the contrast and the sensitivity of HSQ resist, which implies that for exposure of HSQ/PMMA bilayer resist one can just use the conditions for electron beam lithography of single
layer HSQ resist. Another advantage of the HSQ/PMMA bilayer resist is that the development of exposed HSQ features, which is using alkaline developer, will not affect the PMMA layer even though it has been exposed by e-beam as well.

For the pattern transfer, there are four parameters (etching pressure, gas flow rate, etching power and etching time) that can be adjusted in the RIE system. First, the etching rate of PMMA of 200 nm thickness with different oxygen gas flow rates and pressures was investigated. The top HSQ resist pattern layer was 50 nm thickness to serve as etching mask. Other etching parameters were: etching power was 100 W and etching time was 60 s. The experimental results are shown in Fig. 3. From Fig. 3a, one can see that the PMMA etching rate first increases with the increase of working pressure and then drops as further increase of the pressure (constant gas flow rate of 20 sccm). At fixed etching pressure (50 mTorr), the dependence of PMMA etching rate on the gas flow rate is shown in Fig. 3b. Similar to the dependence on etching pressure, the etching rate changing with the gas flow shows the same trend but less pronounced. We also measured the etching rate of HSQ resist using the same etching condition. It was about 4 nm per minute, demonstrating that HSQ can act as an excellent etching mask for the pattern transfer. Through the SEM observation, we found that the profile of the HSQ/PMMA bilayer resist shows the same near-vertical profile despite etched at different etching pressures and gas flow rates. It seems that these two conditions do not affect the profiles of the bilayer system, but only the etching rate.

Next, the dependence of the undercut length of HSQ/PMMA bilayer resist on the etching time was investigated while other parameters were fixed (20 sccm gas flow, 50 mTorr etching pressure and 100 W etching power). The etching time was defined as the time of extra etching after the HSQ pattern has been fully transferred into PMMA, i.e. over etching time. Fig. 4 shows the SEM images of HSQ/PMMA profiles of 200 nm line and 400 nm pitch grating structure at different over etching times. Fig. 4a is the image taken just when the HSQ pattern had been fully transferred into PMMA, before noticeable undercut appears. Further increasing the etching time, undercut appeared and became significant as the over etching prolonged, as shown in Figs. 4b–d. The undercut length was measured to increase linearly with the increasing of over etching time, and the undercut rate was about 20 nm/min. Fig. 5 shows some typical negative tone lift-off results using HSQ/PMMA bilayer resist on silicon wafer, on which the deposited metal was chromium and the thickness was about 80 nm.

Fig. 4. The profile for HSQ(50 nm)/PMMA(200 nm) bilayer structure changed with the over etching time: (a) no over etching; (b), (c) and (d) are the 60 s, 120 s and 180 s over etching, respectively.
4. Conclusion

Electron beam lithography of HSQ/PMMA bilayer resists for negative tone lift-off process was investigated. It has confirmed that the bottom PMMA layer does not influence the contrast and the sensitivity of the HSQ resist on silicon wafer. Oxygen plasma etching of PMMA underlayer has been characterized. It is found that the etching rate of the PMMA resist increases initially with the increase of the gas flow rate and etching pressure and then drops. With the optimized etching conditions, the undercut length of PMMA underlayer increases near linearly with the etching time, which implies that precise control of undercut profile can be achieved through controlling the over etching time. Successful negative tone lift-off chromium film has been demonstrated using the HSQ/PMMA bilayer resists system.

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References