Effect of resist sensitivity difference on the T shape profile by Monte Carlo simulation

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Nanoscale T shaped gate is the key nanofabrication technique in high electron mobility transistors (HEMTs) for the applications of microwave communications. The profile control of resist by electron beam lithography (EBL) for the footprint below 100 nm is essential for achieving various configurations (either short footprint or broad head) of the T shape. Despite numerous reports on this topic, it is hardly seen that the relationship between the T shape profile and the sensitivity ratio of the top layer over the bottom layer, which we believe, through our recent research, dominates the major feature. This work, therefore, focuses on the effect of sensitivity difference between the top layer and bottom layer on the resultant profile. Two kinds of resist stack, as shown in figure 1a, are investigated as comparisons, one is PMMA/PMMA-MAA (sensitivity ratio: 4) and the other is PMMA/UVIII (sensitivity ratio: 13), respectively.

Monte Carlo (MC) simulation by BEAMER and TRACER simulator supplied by GenISys Ltd was applied to plot the charge distributions in the resist layers. Both contrast curves and dissolution rates of PMMA on the bottom layer at various developing time were carefully measured as shown in figure 1b, 1c. Combining the dissolution rates with the simulated charge distribution, footprint profiles under various exposure dosages were calculated, as shown in figure 2. Clearly the foot profile with higher sensitivity ratio is much better defined than that with lower ratio, indicating the strong effect of top layer dose on the bottom layer profile. We can conclude that larger sensitivity difference between the top and the bottom is always beneficial to generate all kinds of shape configurations with either ultra-short footprint or very broad head. Ultimate short T shape gates by MC simulation were also attempted with the sensitivity ratio of 13 (when UVIII was used on the top). The simulation results for nominal footprint of 10 nm (figure 3a) and 4 nm (figure 3b), respectively, trying to find the theoretical limitation of the ultimate footprint. Footprint around 15 nm corresponding to 4 nm nominal width is the EBL limit by our simulation in the designed resist stack despite the 10 nm T gates reported, which was generated by combining EBL with dry etch process. It can be concluded that the sensitivity difference between two resist layers in one stack plays a key role in the T shape profile by EBL.

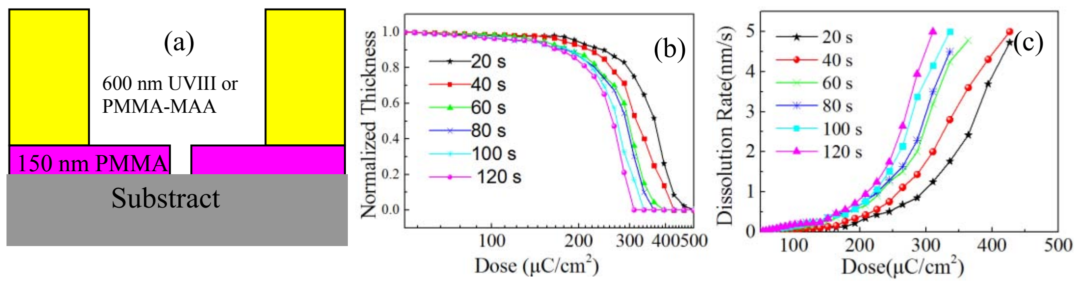

Figure 1. Resist layer stack and basic EBL property: (a) the T shape profile, (b) contrast curves, (c) dissolution rates of PMMA with different development time.

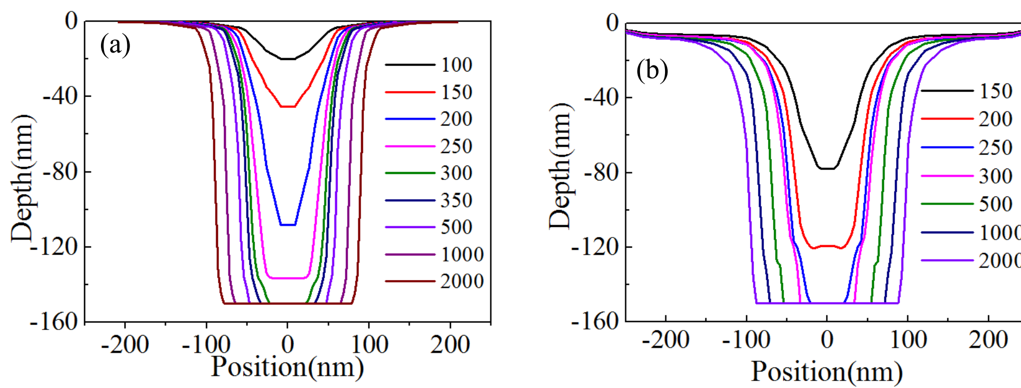

Figure 2. MC simulation results of resist profile in the foot layer of T shape gate. (a) is for PMMA/UVIII, and (b) is for PMMA/PMMA-MAA

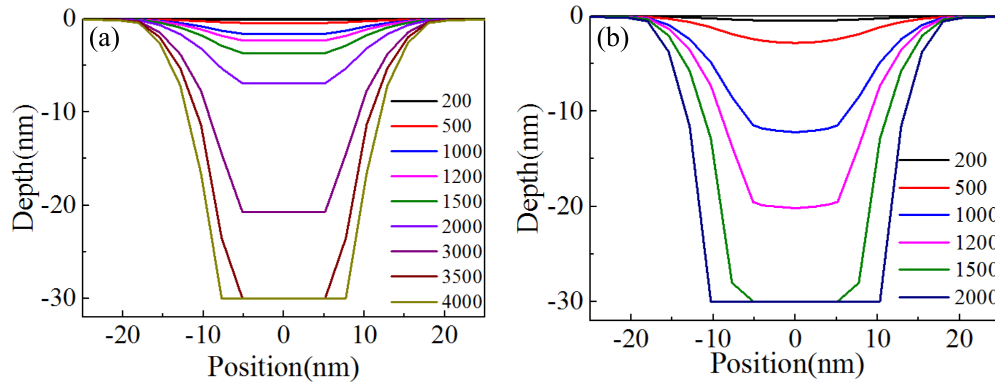

Figure 3. MC simulation results for the foot print profile with with 30/150 nm PMMA/UVIII. (a) 10 nm nominal footprint (b) 4 nm nominal footprint.