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A novel fabrication technique of T-shaped gates using an EGMEA and PMIPK multi-layer resist system and a single-step electron-beam exposure

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A novel fabrication process of submicron T-shaped gates using an EGMEA and PMIPK multi-layer resist system and e-beam lithography has been developed. Due to the different sensitivities of the EGMEA and PMIPK resists, narrow/wide/narrow resist opening was obtained. The status of the electron scattering and the incident primary electron beams statistically construct the absorbed energy density distribution contours. The absorbed energy density distribution contours in association with the sensitivity feature of the resists and the appropriate development conditions determine the final resist profile. Only a single exposure step and a single development step are required. The simplified fabrication process of T-shaped gates significantly reduces not only the process time but also the production costs. The simple submicron T-shaped gate fabrication process studied provides a suitable technique for the mass manufacture of the advanced InP -based and GaAs -based microwave devices and circuits.

1. INTRODUCTION

InP and GaAs Field-effect transistors (FET's), such as metal-semiconductor field-effect transistors (MESFET's) [1] and high electron mobility transistors (HEMT's) [2], [3] are key devices for microwave applications. Advanced microwave FET's require low gate resistance and short gate length to achieve high gain and low noise performance at high frequency. In order to fabricate high-performance FET's, an efficient approach is to use a T-shaped gate which has a wide top to reduce gate resistance and a narrow bottom to obtain small gate length. The conventional fabrication technique of T-shaped gates utilized the PMMA and P(MMA-MAA) [4], [5] multi-layer e-beam resists with the multiple e-beam exposures and the multiple development steps. The multiple e-beam exposures and the multiple development steps increase the use of the e-beam equipment and make the process more operator-dependent which negatively impacts the manufacturing cost and the production yield of T-shaped gates. In this work, we developed a simple fabrication process of T-shaped gates with a 0.1 μm-gate length, for the first time, using a new ethylene-glycol-monoethyl-ether-acetate (EGMEA) and polymethylisopropenyl-ketone (PMIPK) multi-layer resist system with a single e-beam exposure and a single development step. The absorbed-energy-density model can explain the profile of the multi-layer resist system. The simple and efficient technique developed can significantly reduce the e-beam direct-write time and simplify fabrication process which lead to high reproducibility and low manufacture costs for mass production of microwave devices and circuits.

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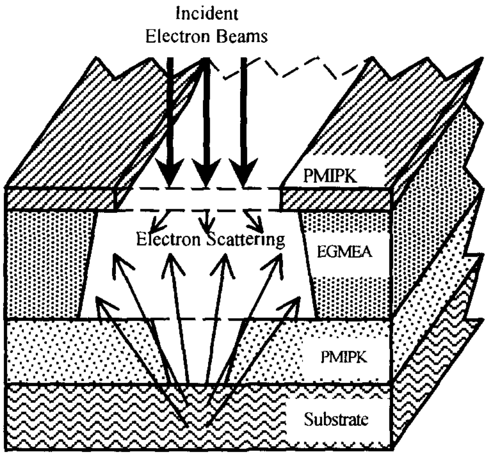
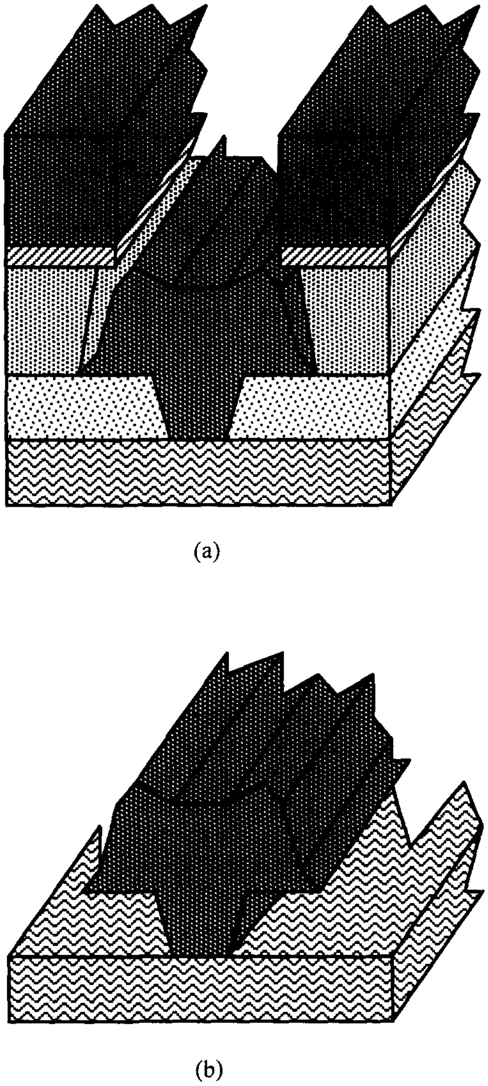


Fig. 1. Single e-beam exposure in a EGMEA and PMIPK multi-layer resist system.


(a)

(b)

Fig. 2. Formation of T-shaped gate. (a) Metal deposition and (b) metal lift-off.

2. EXPERIMENTAL

The fabrication process of the T-shaped gate used the EGMEA and PMIPK multi-layer resist system. The EGMEA resist was used for the middle layer. The PMIPK resist was adopted for the bottom and top layers. The tri-layer resist structure consists of a 290-nm bottom PMIPK resist layer, a 480-nm middle EGMEA resist layer, and a 200-nm top PMIPK resist layer. Only a single e-beam exposure step and a single development step were conducted instead of the multiple exposure and development steps conducted in the conventional tri-layer e-beam resist systems. The e-beam exposure, as shown in Fig. 1, was performed using the JEOL JBX-5DII system with an acceleration voltage of 25 kV. During the e-beam exposure step, both forward scattering and backscattering occur. The developer was a mixture of methyl-isobutyl-ketone (MIBK) and isopropyl alcohol (IPA) which can dissolve both the EGMEA and PMIPK resists. The narrow/wide/narrow opening of the PMIPK/EGMEA/PMIPK resist structure can be accurately controlled by the e-beam dosage and the development conditions due to the sensitivity differences between the PMIPK resist and the EGMEA resist. After e-beam exposure and development, deposition of Ti/Pt/Au gate metals and metal lift-off processes were sequentially conducted, as shown in Fig. 2. The deposited Ti/Pt/Au metals with a thickness of 60/100/300 nm had a total thickness of 0.46 μm.

3. RESULTS AND DISCUSSION

The contrast and sensitivity curves of the EGMEA and PMIPK resists, as shown in Fig. 3, were investigated to estimate the sensitivities of the EGMEA and PMIPK resists. The resist-prebake temperature and the resist thickness were maintained at 110 °C and 280 nm, respectively. The development time was maintained at 90 s and the developer temperature was 23 °C. The resists were exposed to different e-beam dosages. For each e-beam dosage, the thickness of remaining resist following development and rinsing was measured and normalized. It was found that the PMIPK resist had a lower sensitivity and a higher contrast than the EGMEA resist.

The basic concept behind the utilization of the EGMEA and PMIPK multi-layer resist system to form T-shaped gates is the differences in the sensitivities of the EGMEA and PMIPK resists. The profile of the EGMEA and PMIPK multi-layer resist structure was affected by the e-beam dosage and the development time. Fig. 4 depicts the dependence of the resist opening of each layer on the development time when the e-beam energy and the e-beam dosage were kept at 25 keV and 280 μC/cm^2, respectively. The beam size was approximately 65 nm in diameter. The written line pattern had a width of 1.5 μm. The mechanism of the profile formation of the EGMEA and PMIPK multi-layer resist structure was studied. During e-beam exposure, both forward scattering and backscattering occur, as shown in Fig. 1. The forward scattering results from collisions of the incident electrons with the tri-layer resist and secondary electrons are generated from the resist. The backscattering is caused by collisions of the incident electrons with the substrate and backscattered electrons are generated from the substrate. The forward scattering is weak during the e-beam exposure because of the low atomic number of the resist polymer. The backscattering of the electrons from the GaAs substrate is dominant over the forward scattering of the electrons in the PMIPK/EGMEA/PMIPK hybrid resist process due to the high atomic number of the GaAs substrate.

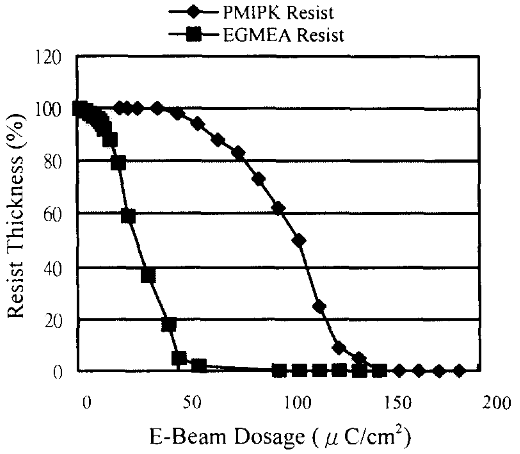


Fig. 3. Contrast and sensitivity curves of the EGMEA and PMIPK resists

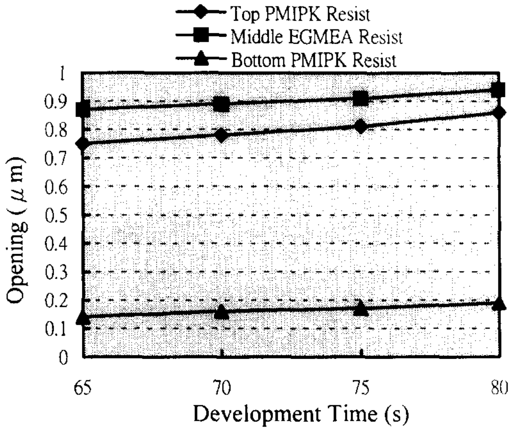


Fig. 4. Resist opening of the EGMEA and PMIPK multi-layer resist structure.

Fig. 5 shows the absorbed equienergy density (AED) contours of the EGMEA and PMIPK multi-layer resist structure. The electron scattering in the tri-layer resist results in the absorbed equienergy density contours. Both the high energy density distribution in the center region and the low energy density distribution in the side region contribute to the final resist profile and the feature size of the tri-layer resist structure. The wide opening in the middle

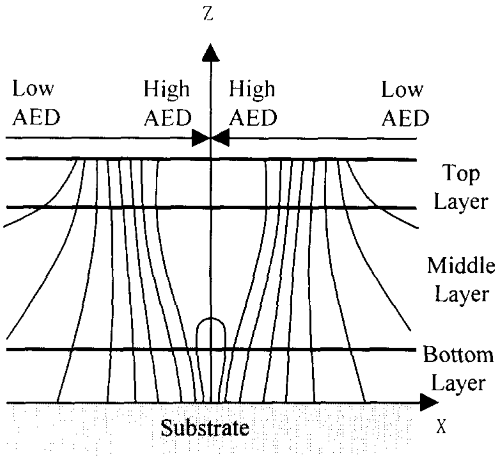


Fig. 5. Absorbed equienergy density (AED) contours of the EGMEA and PMIPK multi-layer resist structure.

layer after development is attributed to the high sensitivity of the EGMEA resist to electron beam which results in bond breaking of the resist molecules in the low energy density distribution region. Using the above mechanism of the resist profile formation as well as optimum resist, exposure, and development conditions, a 0.1-μm-gate-length T-shaped gate, as shown in Fig. 6, can be achieved with the 0.1-μm-width line pattern.

4. CONCLUSIONS

A new fabrication process of T-shaped gates has been developed using the EGMEA and PMIPK multi-layer resist system and electron-beam lithography for the first time. The simple process accomplished a submicron T-shaped gate by a single exposure and a single development step. Due to the lower sensitivity of the adopted PMIPK resist to the electron beam, the smaller opening of the PMIPK resist layer was obtained. The higher sensitivity of the EGMEA resist resulted in a wider opening in the middle resist layer. A 0.1-μm-gate-length T-shaped gate can be easily formed by the simple and low-cost EGMEA and PMIPK multi-layer resist system.

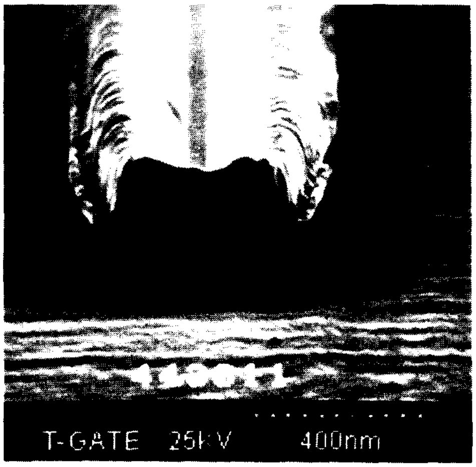


Fig. 6. A 0.1-μm-gate-length T-shaped gate formed by EGMEA and PMIPK multi-layer resist system.

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