Comparison of Charge Dissipation Layers and Dose Sensitivity of PMMA Electron Beam Lithography on Transparent Insulating Substrates such as GaN

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Abstract

We compare the influence of electron-beam and thermal evaporation of a charge dissipation layer on the edge roughness and dose-sensitivity of polymethyl methacrylate (PMMA) in an electron-beam lithography (EBL) process on semi-insulating GaN. It is shown that the deposition of the Aluminum film with an electron-beam process leads to an increased sensitivity of the PMMA to small dose variations and a more than three times higher edge roughness compared to a thermally deposited Aluminum layer. The study has direct bearing on the manufacturability of mm-wave devices on GaN.

INTRODUCTION

For transparent and (semi-) insulating materials like GaN and SiC a thin metal film on top of an electron-beam resist stack can serve as a charge dissipation layer, but can also be utilized as reflective surface. Many modern EBL-systems provide automatic sample height correction. This requires the reflection of a laser beam from the sample surface. For materials transparent to the laser wavelength a thin metallic layer can provide the needed reflectivity. Furthermore, a thin metal layer on top of the resist stack is often used as charge dissipation layer to avoid beam displacement and pattern distortion by accumulated charges on the sample.

A typical choice for this metal layer is a thin (~10 nm) metallization which can for example consist of Aluminum, Gold or Chromium. For beam energies higher than 10 keV the exposure is not affected significantly by the thin metal layer [3]. Ideally the metal is removed after the electron-beam lithography without having further influence: the resist is then developed as usual and subsequent processing steps take place.

The metal-layer can be deposited by sputtering or thermal- or electron-beam-evaporation. It is often recommended not to use the electron-beam evaporation for the deposition of the charging layer "… *since x-rays and electrons in the evaporator will expose the resist*." [3]. We here characterize the differences between electron-beam and thermally deposited Al- charge dissipation films on semi-insulating GaN substrates.

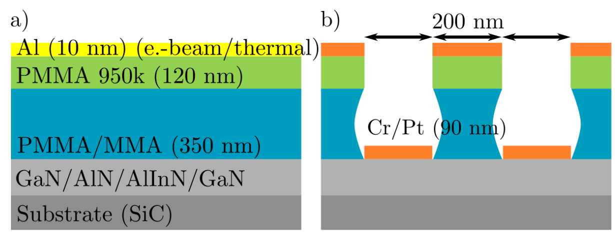

Fig. 1. (a) Before EBL: Resist is applied to the sample. The Aluminum layer is deposited either by electron-beam or thermal deposition; (b) Result before lift-off: After the EBL-exposure of a 200 nm grating the Aluminum layer is removed and the PMMA is developed. Cr/Pt is electron-beam deposited.

EXPERIMENTAL PROCEDURE

We use a semi-insulating Silicon-Carbide (SiC) wafer with an epitaxy suitable for the fabrication of GaN-HEMTs with an AlInN spacer. Two samples from the same wafer were processed in identical steps with the exception of the Aluminum layer deposition. A bi-layer of 350 nm PMMA copolymer and 120 nm PMMA 950k was applied. The lift-off is facilitated by the height and undercut of the copolymer. High resolution is maintained by the thin PMMA 950k layer.

On both samples 10 nm Aluminum was deposited: For the first sample, a Plassys MEB 550S electron beam evaporator was used at a rate of 0.5 nm/s with a sample to crucible distance of 550 mm. On the second sample the deposition was done by thermal evaporation.

Both samples were exposed with a Vistec EBPG5200 electron beam lithography system with a beam energy of 100 keV. The laser height sensor has a wavelength of 632 nm to which GaN and SiC are transparent. The exposed pattern is a grating of 200 nm wide lines, spaced by 200 nm, covering an area of 120x120μm^2. The grating is exposed on each sample in a dose range from 350 to 730 μC/cm^2 in steps of 20 μC/cm^2.

The Aluminum charging layer was etched away using AZ726 developer for 30 s and rinsing in DI-water. The PMMA layers were developed in MIBK:IPA 1:3 for 50 s. 90 nm Cr/Pt were electron-beam deposited and lifted-off in NMP. Fig. 1 shows an overview of the processing steps.

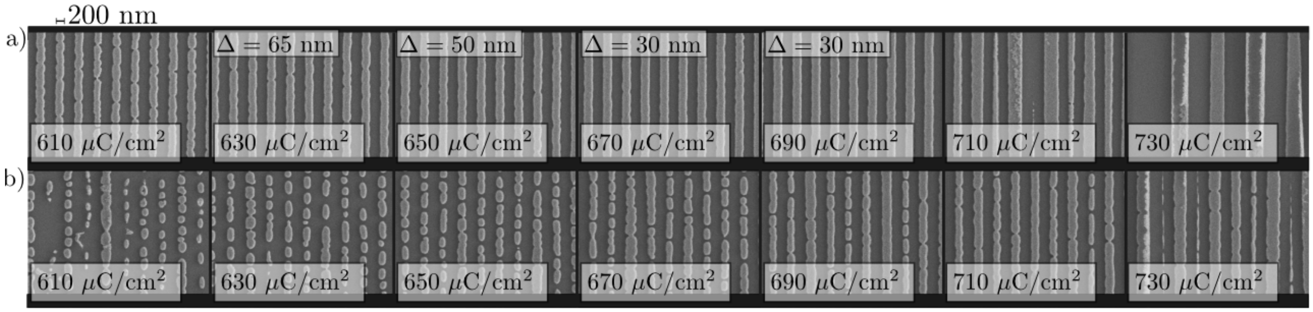

Fig. 2. SEM images of the 200 nm Pt/Cr-grating after lift-off. The gratings were exposed at different EBL exposure doses between 610 and 730 μC/cm^2 in 20 μC/cm^2 steps. The scale in all images is the same. Where no interrupted grating-lines were found the largest measured dent is given by the Δ-value; this value represents the edge-roughness of the lines. Row a) shows the results for the thermally deposited Aluminum layer. Row b) shows the results for the electron-beam deposited Aluminum layer.

Results

A selection of SEM images of the 200 nm Pt/Cr-gratings after lift-off are shown in Fig. 2.

For the thermally deposited Aluminum layer from Fig. 1a) the exposure results in acceptable 200 nm Pt/Cr-grating between 630 and 690 μC/cm^2. Below, at 610 μC/cm^2 the grating-lines thin out and show an increased edge-roughness due to an underexposure of the upper resist layer. At 710 μC/cm^2 the resist becomes overexposed and starts to collapse: This causes some lines to be broadened with neighboring lines missing. Nevertheless, a robust exposure result can be achieved for a dose of (660 ± 30) μC/cm^2. The largest edge-roughness measured at 670 μC/cm^2 is 30 nm.

For the electron-beam deposited Aluminum layer from Fig. 2b) none of the doses lead to a grating which is comparable to the ones achieved thermally. The result achieved at 730 μC/cm^2 shows similar signs of an over-exposure with several grating-lines thinned out and missing as is the case at 710 μC/cm^2 for row a). Below 690 μC/cm^2 the grating looks underexposed. Generally, the lines are discontinuous, therefore it is difficult to assign a value for the edge-roughness.

Discussion

During electron-beam evaporation a primary electron beam, typically accelerated by 10 kV is decelerated by the respective metal-crucible. The deceleration in turn heats the metal-crucible and leads to evaporation. As side-processes secondary electrons and X-rays are generated, which can influence the properties of electron-beam- and photo-resists.

A photoresist can be cross-linked due to the electron-beam deposition of a metallization as observed in [1]. During the electron-beam deposition of Platinum as pHEMT gate material PMMA blistering has been observed [2]. The cross-linking and blistering in [1] and [2] is attributed to secondary electrons generated during the electron-beam deposition. No blistering of PMMA resist has been observed here.

On the other hand X-rays can be generated during the deceleration of the electrons during the electron beam deposition. A 10 keV-energy electron corresponds to a maximum radiation energy of $\lambda_{min} = \frac{hc}{eV} = 1.24\,A$. The characteristic K-lines of Aluminum are of similar energy. PMMA can be used as X-ray lithography resist with a low sensitivity around 8 Angstrom which increases to higher wavelength.

Conclusion

PMMA can become more sensitive to small dose variations (±20 μC/cm^2 at 700 μC/cm^2 ≙ 3%) when the charge dissipation layer is deposited via electron-beam deposition. The pre-exposure during the electron-beam deposition doesn't lead to a shift of the optimal dose to a new value.

Small deviations from the nominal dose can occur during the EBL-exposure. For a robust exposure result, the variation of the obtained result should be as small as possible for a small variation from the nominal dose. The increased sensitivity to small dose variations in turn leads to an edge roughness which is much larger than in the thermally deposited charging layer case.

References

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Acronyms

AlInN: Aluminum indium nitride
EBL: Electron-beam lithography
GaN: Gallium nitride
HEMT: High-electron-mobility transistor
IPA: Isopropanol
MIBK: Methyl isobutyl ketone
NMP: N-methyl-2-pyrrolidon
pHEMT: Pseudomorphic HEMT
PMMA: Polymethyl methacrylat
SEM: Scanning electron microscope
SiC: Silicon carbide