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ALLRESIST

# A high contrast multilayer process for electron beam lithography using different developers

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## Motivation

Suspended structures are common elements in many devices e.g. MEMS and cantilevers for atomic force microscopy [1,2]. In high-electron mobility transistors (HEMTs) the T-gate geometry is used frequently. There are various methods [3,4] to create profiles in the electron beam resist in order to fabricate suspended microstructures by evaporation and lift-off.

The state-of-the-art process is based on a three layer stack (e.g. PMMA of different respective molecular weight) with distinct sensitivities using a one-step electron beam exposure and a single development step. In contrast to that, we present a method to fabricate suspended microstructures based on a resist stack with very large contrast by using two different developers. Our process exhibits high reliability and the different layers of the multilayer resist can be patterned nearly independently from each other.

## Functional principal

### Resist design

Top layer:

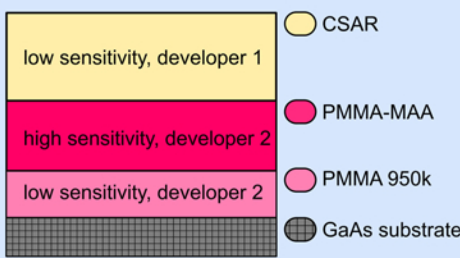
- Resist with low sensitivity that is regularly developed by using amylacetat
- **CSAR** (AR-P 6200; Allresist GmbH)
- Thickness: 230 nm

Middle layer:

- Much higher sensitivity compared to the other layers in order to create a large undercut
- Resist is developed by using AR 600-50/2 (compound of Ethanol and Isopropanol)
- **PMMA-MAA 33%** (AR-P 617; Allresist GmbH)
- Thickness: 190nm

Bottom layer:

- Resist with low sensitivity that is used to create the base of the 3D structure and is developed by using amylacetat
- **PMMA 950k 3%** (AR-P 679.03; Allresist GmbH)
- Thickness: 130 nm




### Exposure procedure

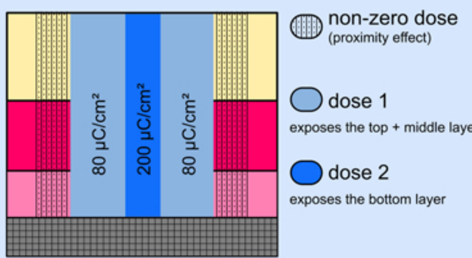
T-gate nanostructures:

The final shape is achieved by a variation of the electron dose at 30 kV and a two-step development procedure.

There is no additional exposure necessary for the undercut since a sufficient dose is already applied due to the proximity effect.

Dose to clear (2x2 µm² square):

| Resist | Amylacetat | AR 600-50/2 |
|---|---|---|
| **CSAR** *AR-P 6200* | 115 µC/cm² | 420 µC/cm² |
| **PMMA-MAA 33%** *AR-P 617* | 60 µC/cm² | 40 µC/cm² |
| **PMMA 950k 3%** *AR-P 679.03* | 185 µC/cm² | > 500 µC/cm² |




### Development procedure

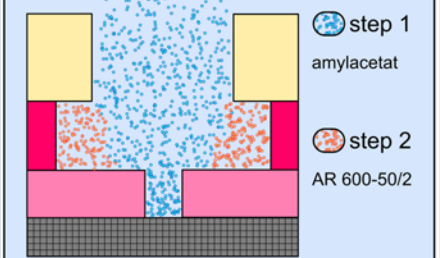
The amylacetat dissolves mainly the exposed areas of the top and bottom layer whereas the middle layer is then fully developed in a second step by using the developer AR 600-50/2 which is a compound of Isopropanol and Ethanol.

The large difference in sensitivity between PMMA 950k and PMMA-MAA (33%) allows to stop the resist development at the bottom layer if necessary.

Therefore the bottom layer can be patterned almost independently from the patterns of the other layers by locally increasing the dose.

Development recipe:

- **Step 1**: 60 s in amylacetat
- **Step 2:** 60 s in AR 600-50/2 (Allresist GmbH)
- **Rinsing:** 60 s in desionized water




## Results

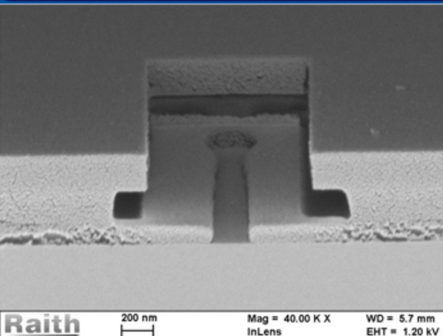



**Figure 1:** Three-dimensional resist profile for a T-gate nanostructure

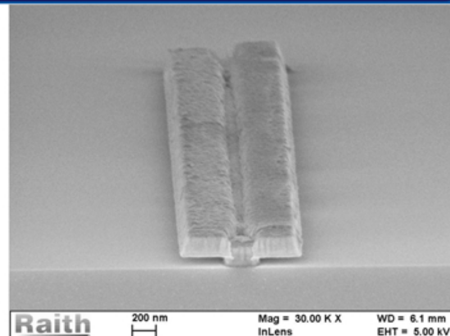



**Figure 2:** T-gate nanostructure after lift-off

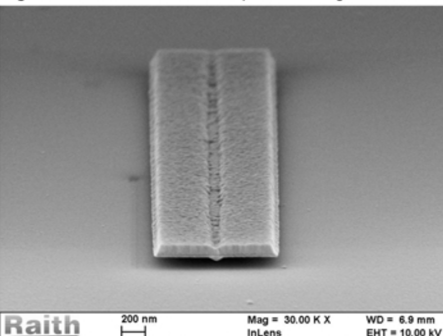



**Figure 3:** Small base T-gate nanostructure after lift-off

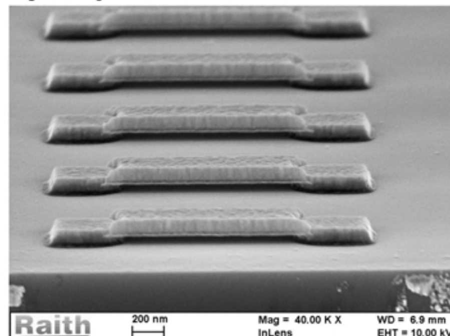



**Figure 4:** Metallic air-bridges as another possible application

## Conclusion

- We have developed a new multilayer resist system for the fabrication of three-dimensional nanostructures in a one-step electron beam exposure.
- The multilayer resist consists of three layers with **different sensitivity** and **different process chemistry**.
- The sensitivity of the three layers to different respective **developers allows a very large controllable** undercut in the middle layer.
- The low sensitivity bottom layer **can be patterned in high detail almost independently** from the pattern exposed in the two layers on top by locally increasing the dose.
- At an acceleration voltage of 30 kV the resist is ideally suited for the fabrication of T-gate structures by lift-off in **a high reliability process** with a **very large process window**.
- Due to the large contrast the resist system also facilitates **the application on uneven surfaces** where a thickness variation of the bottom layer can often be detrimental for the process outcome.

**[1]** B. W. Chou, T. D. Stowe, Y. S. Ju, K. E. Goodson, T. W. Kenny, H. J. Mamin, B. D. Terris, R. P. Ried, and D. Rugar, J. Microelectromech. Syst. 7, 69 (1998)
**[2]** H. M. Cheng, M. T. S. Ewe, G. T. C. Chiu, and R. Bashir, J. Micromech. Microeng. 11, 487 (2001)
**[3]** Kim, S. C., et al. "Sub-100nm T-gate fabrication using a positive resist ZEP520/P (MMA-MAA)/PMMA trilayer by double exposure at 50kV e-beam lithography." Materials science in semiconductor processing 7.1 (2004): 7-11.
**[4]** Borzenko, T., et al. "Metallic air-bridges fabricated by multiple acceleration voltage electron beam lithography." Microelectronic engineering 75.2 (2004): 210-215.