In-Plane Anisotropy of In-situ Ga etching on (010) β-Ga_2O_3 using MOCVD

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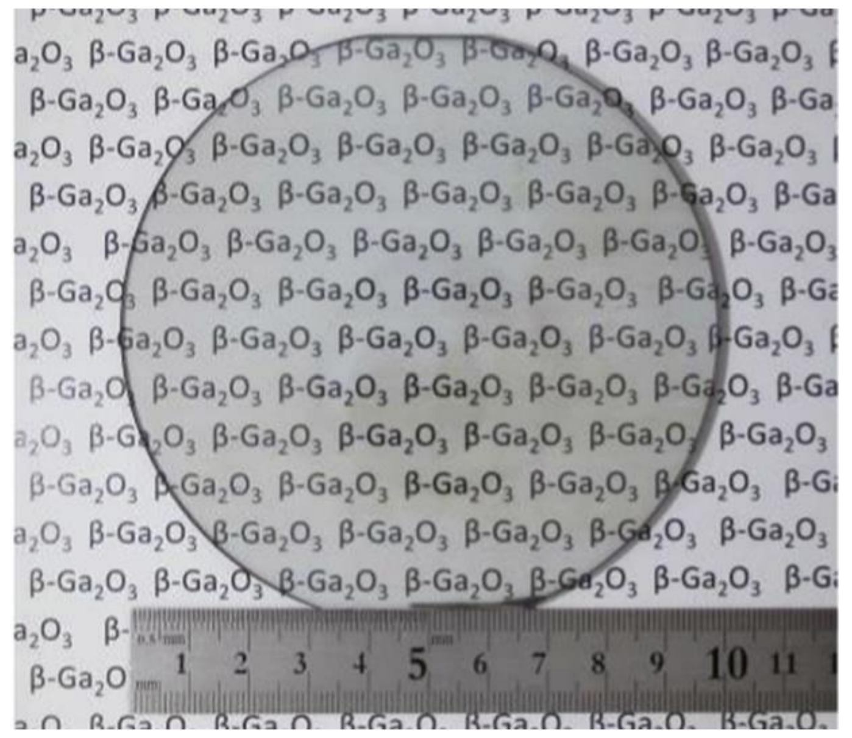
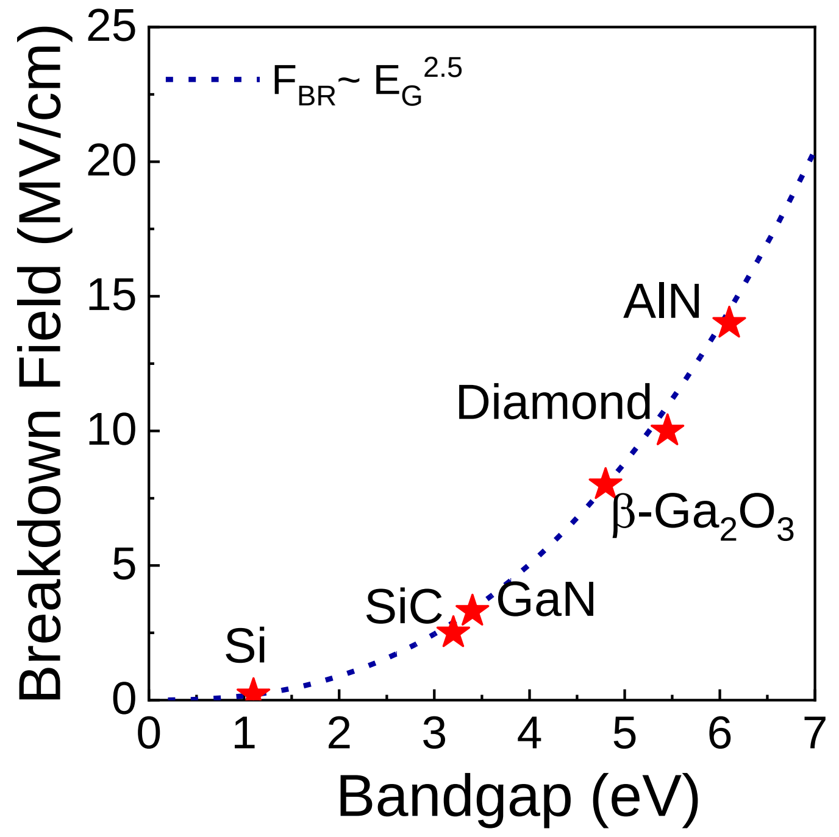
Introduction – Promise of β-Ga_2O_3

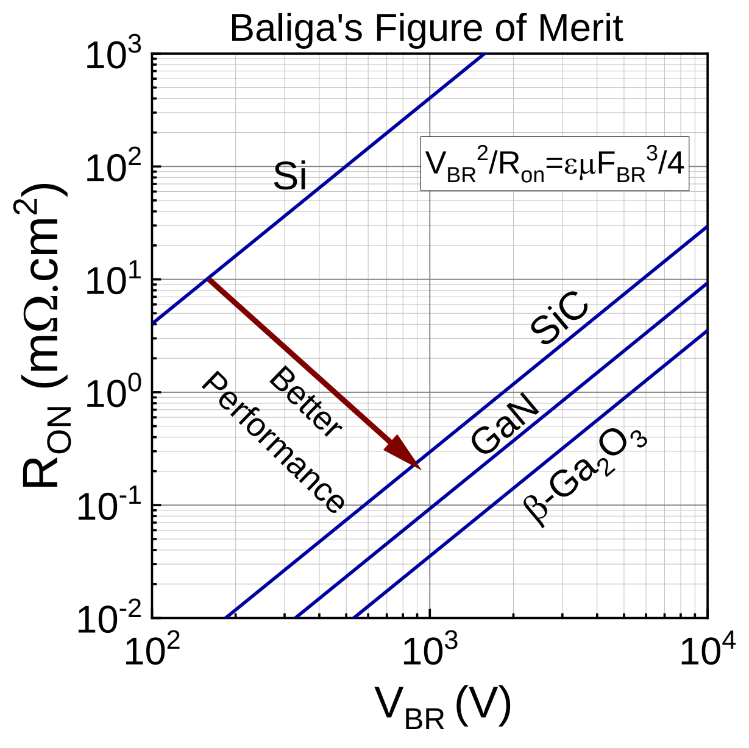
- High breakdown field strength of 8MV/cm → High BFOM of 3444.
- Availability of free substrates up to 4 inch using Czochralski, edge defined film fed growth etc.
- Wide range of controllable n-type doping from 10^{15} cm^{-3} to 10^{20} cm^{-3} using shallow donors like Si, Ge, Sn.



100 mm Ga_2O_3 (001) substrate



Breakdown field vs Bandgap



V_{Br} Vs R_{on}

Properties	Si	SiC	GaN	β-Ga_2O_3
E_g (eV)	1.1	3.3	3.4	4.8
E_c (MV/cm)	0.3	2.5	3.4	8
Doping	Both P and N	Both P and N	Both P and N	Only N
μ (cm²/Vs)	1300	800	1200	200
K (W/cmK)	1.3	4.2	1.5-2.5	0.1-0.2
Baliga's FOM	1	340	1450	3444
Bulk Substrates	Yes	Yes	No	Yes (size ~100mm)

Comparison of β-Ga_2O_3 material properties with other semiconductors

Requirement of Low-Damage Etching

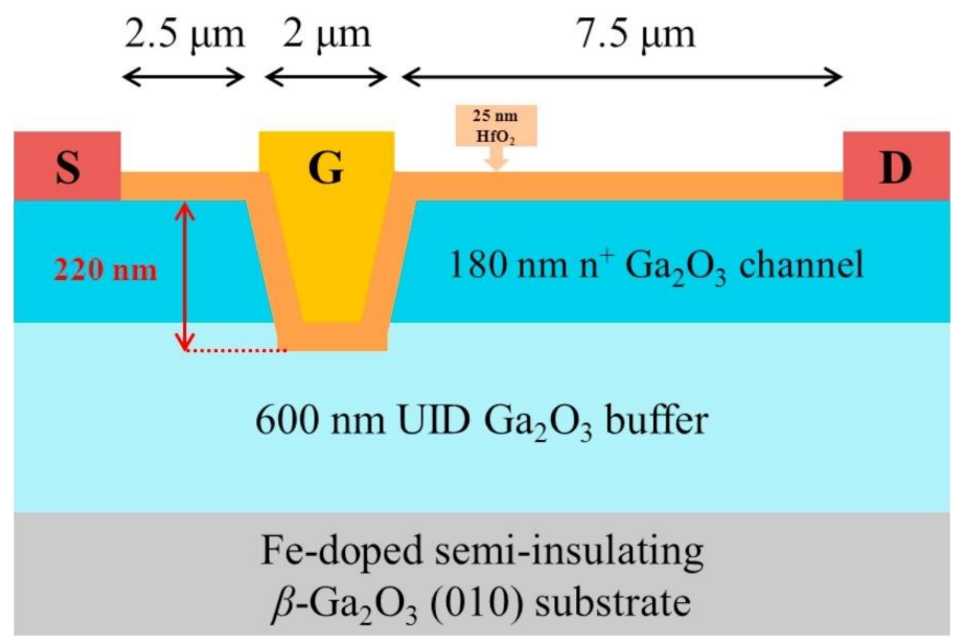
- 3-D structures like fins and trenches are required in key device structures like trench MOSFETs/SBDs, finFETs, gate recess etc.
- Damage-free etch processes are critical for fabrication these structures.
- Wet (KOH, HF, and H_3PO_4, MacEtch) and dry (BCl_3/Ar) processes have been used for etching Ga_2O_3, however each technique has its own challenges.

Key challenges with current etching techniques:

- Dry etching → Plasma induced damage, inclined and rough sidewalls.
- Wet etching → Inclined sidewalls, low controllability.

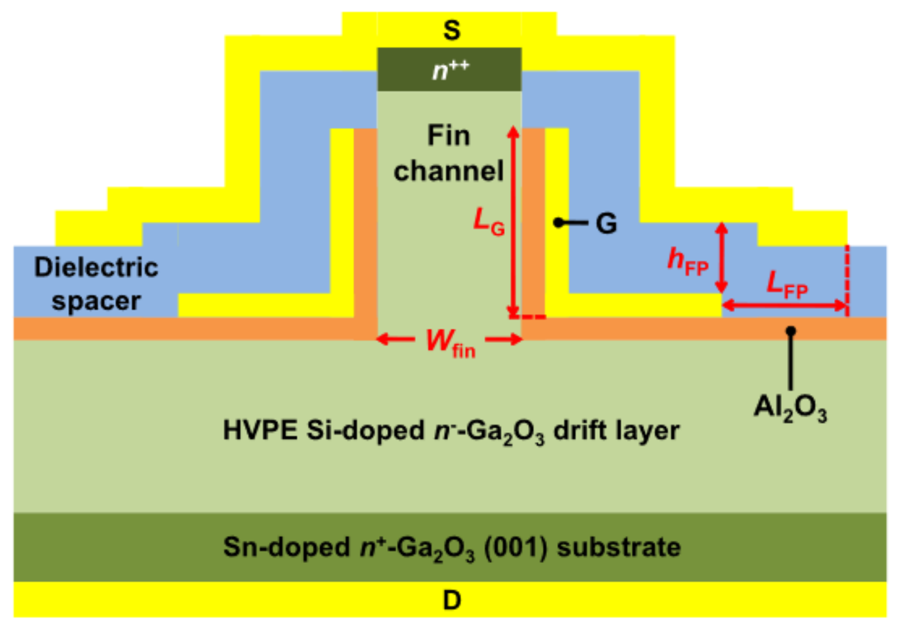
Device architectures that require damage free etching on Ga_2O_3

Yuanjie, Lv et al, *SD* 10.1016 (2018)



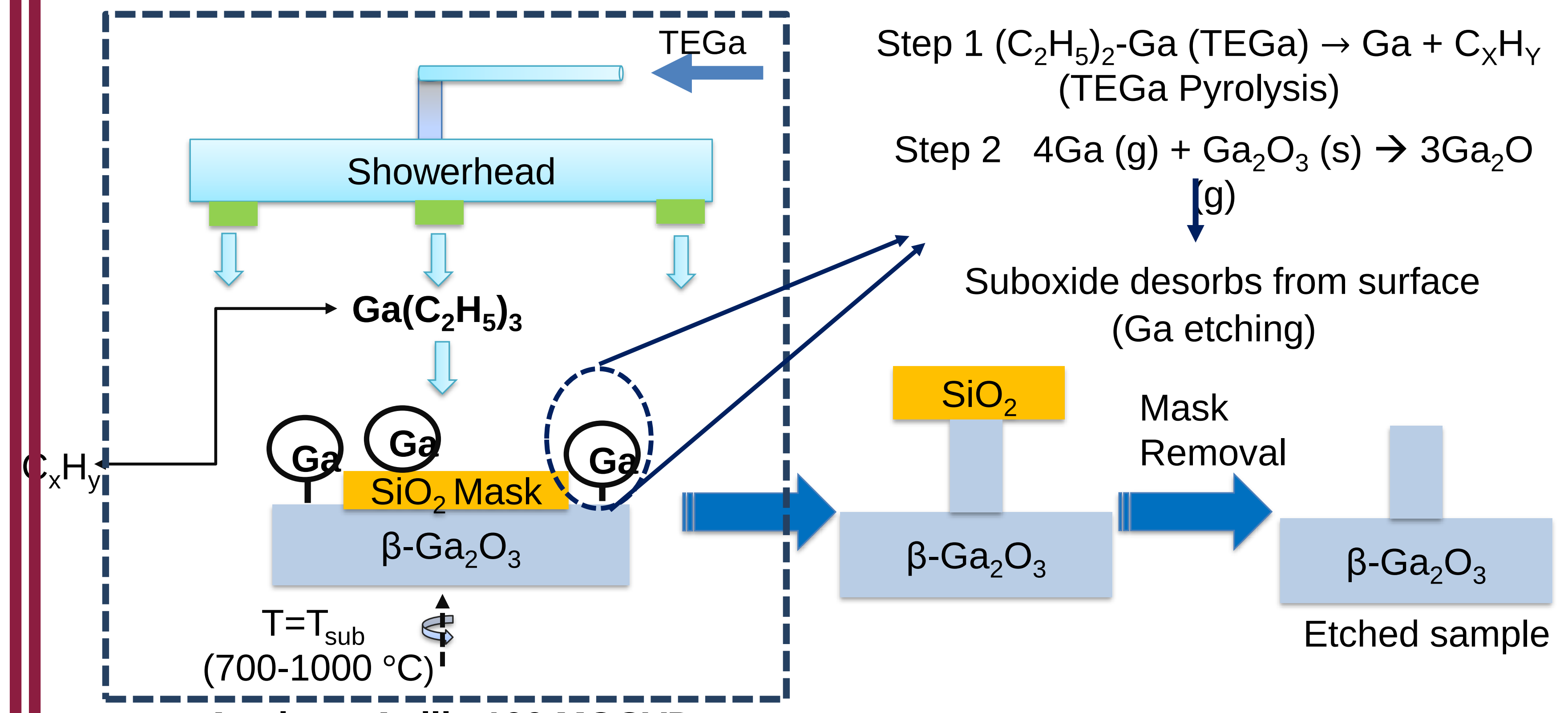
Ga_2O_3 Gate Recess

Hu, Zongyang, et al, *IEEE EDL* 39.6 (2018): 869-872.
Wong, Man Hoi et.al, *IEEE TED* 67.10 (2020): 3925-3937



Ga_2O_3 trench MOSFETs

In-Situ Ga Etching setup in MOCVD



Step 1 $(C_2H_5)_2$-Ga (TEGa) → Ga + C_XH_Y (TEGa Pyrolysis)

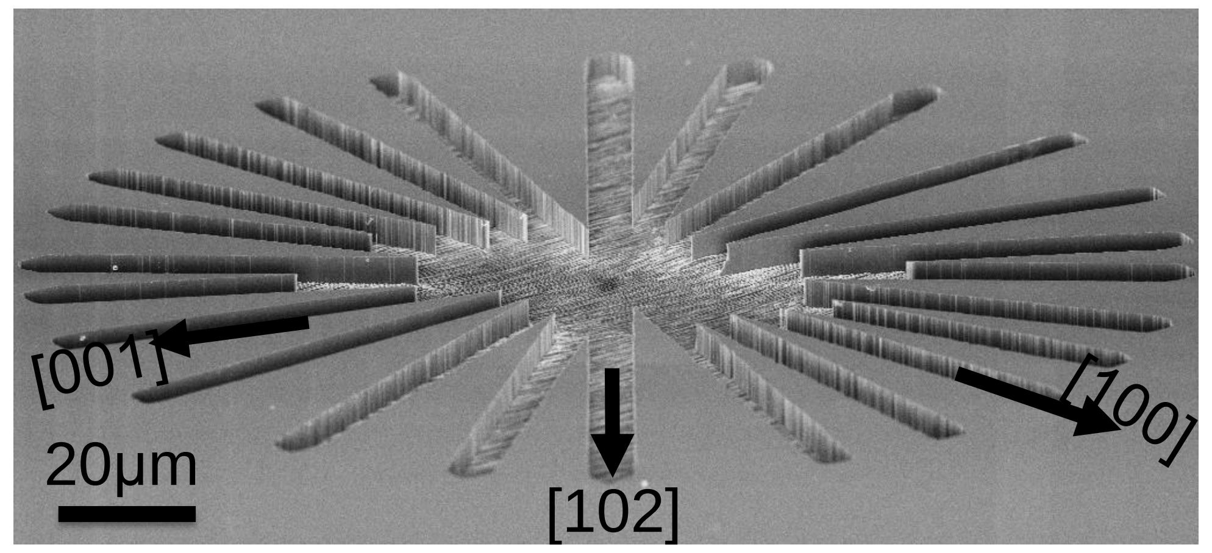
Step 2 4Ga (g) + Ga_2O_3 (s) → $3Ga_2O$ (g)

Suboxide desorbs from surface (Ga etching)

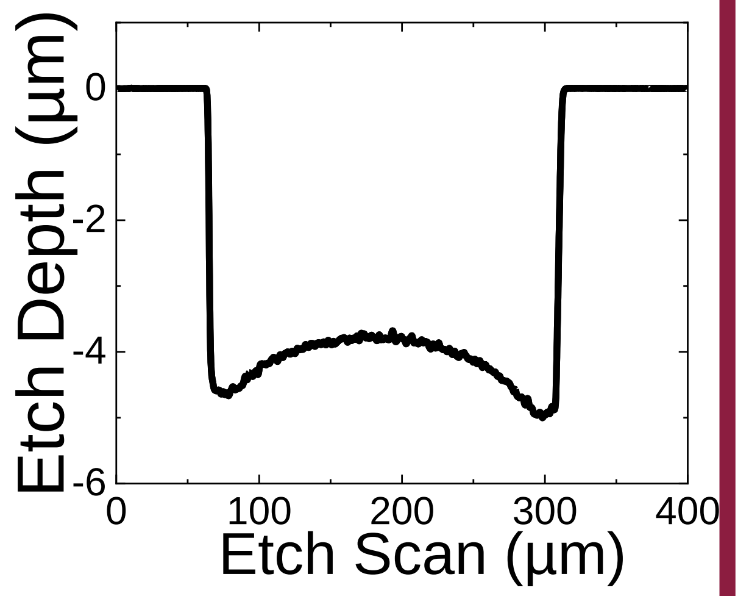
Agnitron Agilis 100 MOCVD

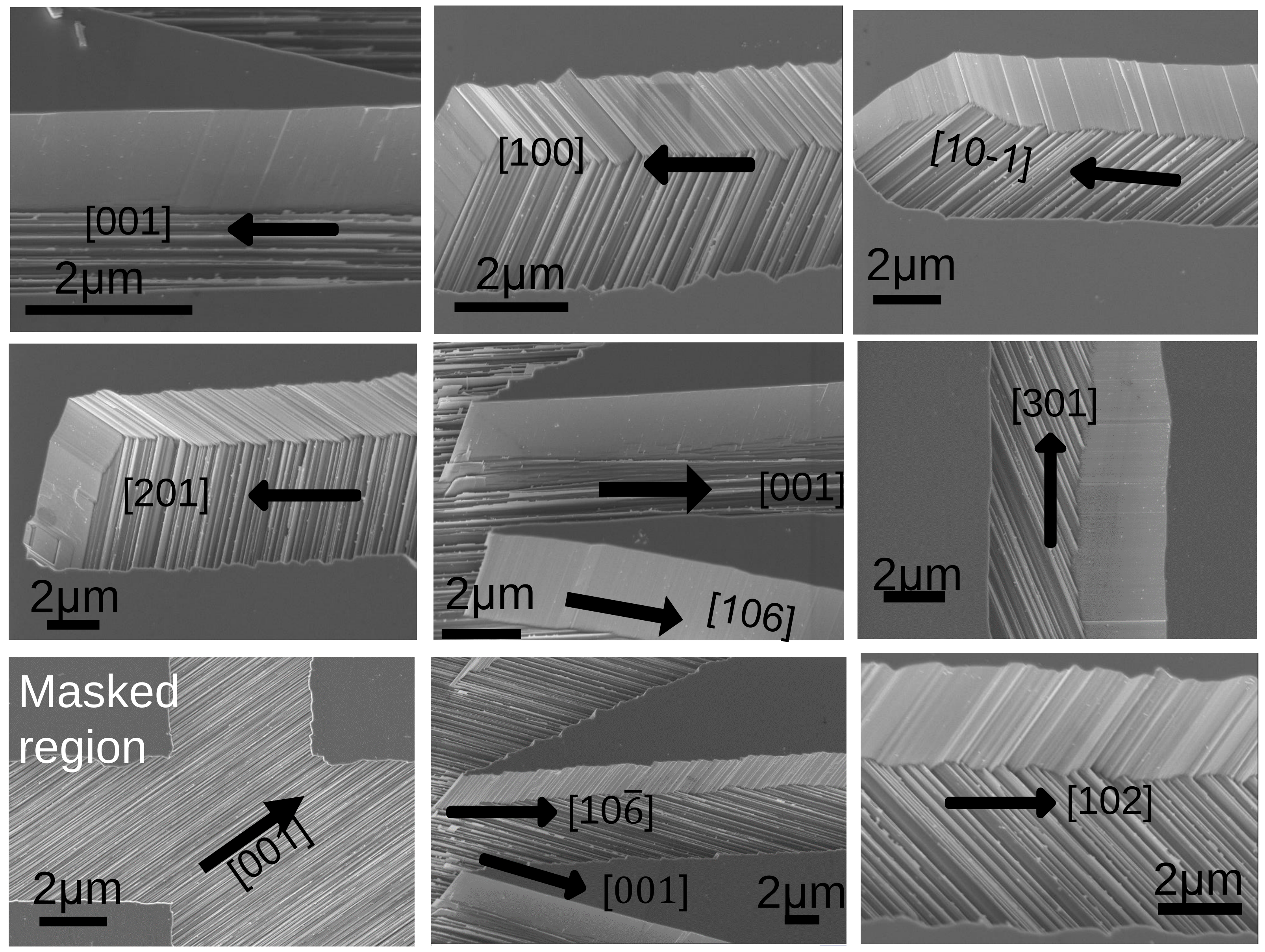
- TEGa (triethylgallium) is used to supply Ga to the Ga_2O_3 surface inside and MOCVD reactor.
- Step 1 → TEGa undergoes pyrolysis above 350 ℃ depositing Ga on the sample surface.
- Step 2 → Gallium reacts with Ga_2O_3 forming volatile Ga_2O (suboxide) which desorbs from the sample surface.

In plane anisotropy on (010) β-Ga_2O_3



Tilted SEM Image of Spoke-Wheel





Tilted SEM Image of Trench sidewalls on (010) β-Ga_2O_3

Conclusions

- Spoke wheel structures were used to investigate etch anisotropy on (010) β-Ga_2O_3.
- Vertical sidewalls are obtained in all in-plane directions based on tilted SEM imaging.
- Significant anisotropy in sidewall morphology is observed.
- Trenches aligned along [001] direction show smooth morphology due to the formation of (100) sidewall planes with low surface energy.

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