Fabrication of MEMS 4H-Silicon Carbide BAW Gyroscopes

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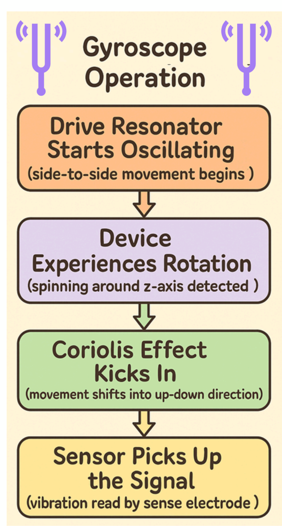
INTRODUCTION

***M**icroelecto**m**echanical **S**ystem*

MEMS Gyroscope:

- *Comprised of 2 MEMS Resonators: Drive and Sense*

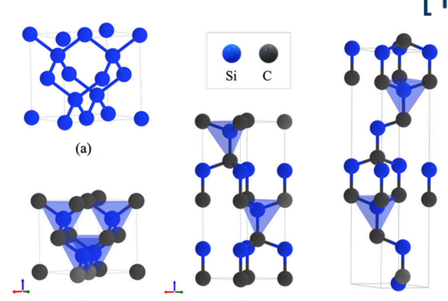
Why is 4H-SiC better?



Mechanical and Electrical Properties Comparison [1]

Property	Unit	(100) Si	(111) Si	(100) 3C-SiC	(0001) 6H-SiC	(0001) 4H-SiC
Density	Kg /m³	2230	2230	3166	3211	3210
Young's Modulus	GPa	130	174	314	450	481
Fracture Strength	MPa	47.1	31.8	800	--*	200
Yield Strength	GPa	2.7	2.7	12.0	14.3	11.8
Poisson's Ratio	1	0.28	0.26	0.237	0.207	0.205
Volumetric Heat Capacity	10^6 J/(m^3K)	1.58	1.58	2.24	2.22	1.92
Thermal Conductivity	W/cm /°C	1.3	1.48	3.6	3.5	3.7
Thermal Expansion	ppm °C^{-1}	2.6	2.6	2.4	3.4	4.1
Melting Temperature	°C	1412	1412	2830	2830	2830
Acoustic velocity	10^3 m/s	9.1	9.1	11.9	11.9	11.9
Piezoelectric Coefficient e_{33}	10^{-5} C/ cm^2	N/A	N/A	4.0**	4.0	3.4
Bandgap	eV	1.1	1.7	2.4	3.0	3.3
f.Q_{AKE}	10^{13} Hz	2 - 3	2 - 3	10 - 50	20 - 60	20 - 60

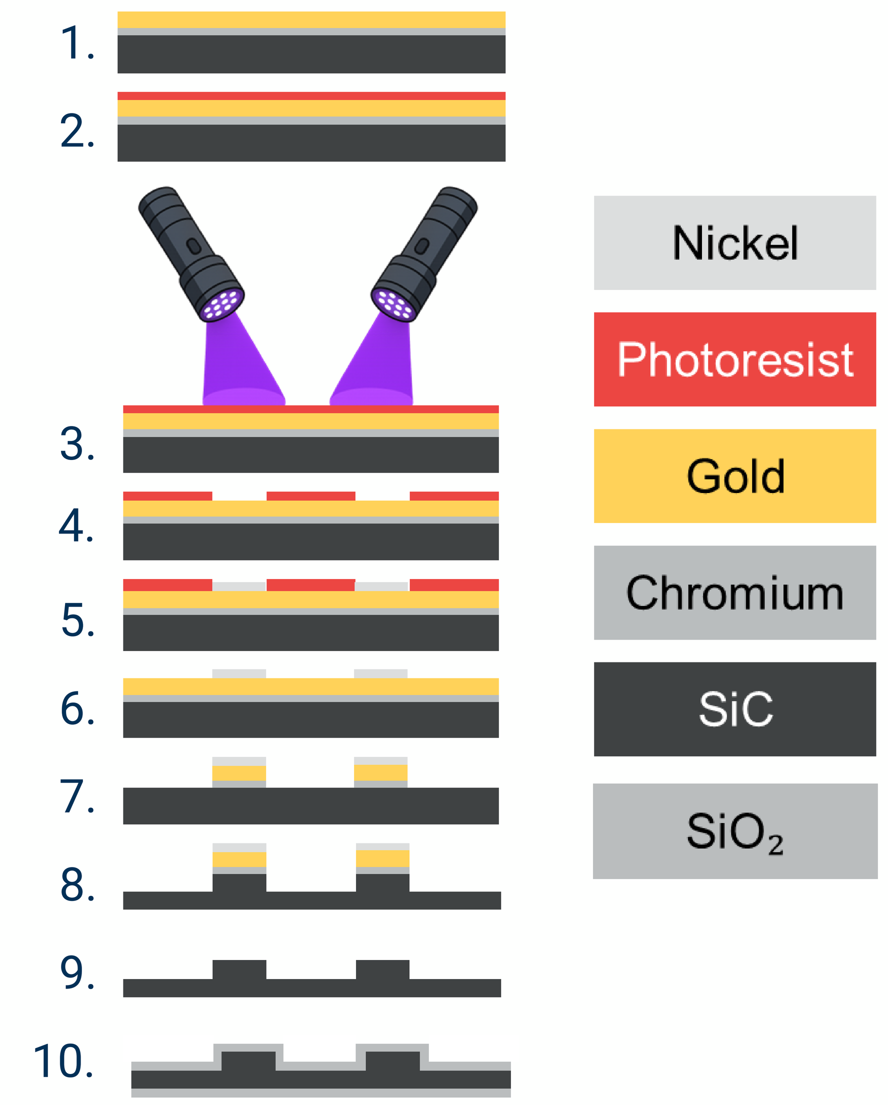
[1]

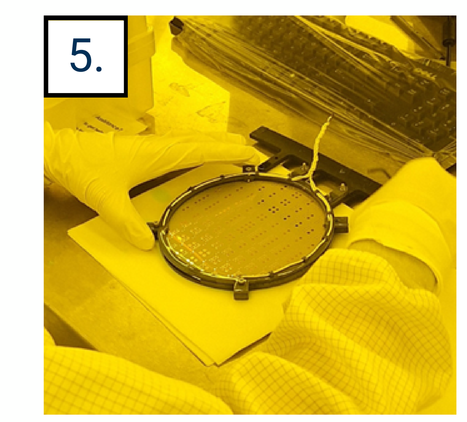


a) Si b) 3C-SiC c) 4H-SiC d) 6H-Sic

FABRICATION PROCESS

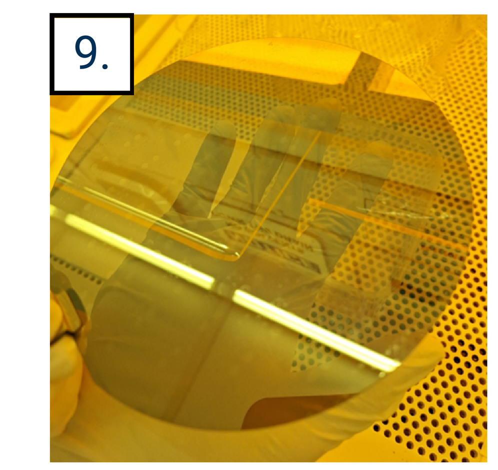
1. Deposit Seed Layer (Cr: 20nm / Au: 100nm)
2. Apply Photoresist(AZ-10XT) → Soft-Bake: 110°C for 3 min
3. Use Maskless Aligner to transfer pattern (λ = 375 nm, dose: 430)
4. Develop Wafer (AZ400K for 4 min) → Hard-Bake: 110°C for 10 min
5. Use electroplating to create a nickel mask
6. Remove photoresist with Acetone
7. Etch seed layer
8. Etch SiC
9. Remove Ni mask and seed layer
   a. Ni: 3:1 HNO_3 & H_2O_2 | Hotplate ~80°C | Until Ni is gone
   b. Au: 3:1 HCL & HNO_3 | Hotplate ~80°C | Until Au is gone
   c. Cr: Chromium Etch | No hotplate | Until Cr is gone
10. Deposit TEOS onto wafer to form SiO_2 film
    a. 5 iterations of .8 µm each
    b. Annealing is carried out after each iteration to reduce film stress



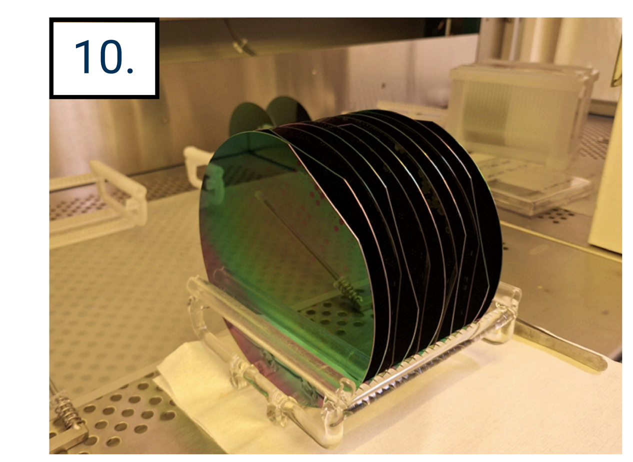


Preparing wafer for electroplating

Preparing wafer for SiC etching



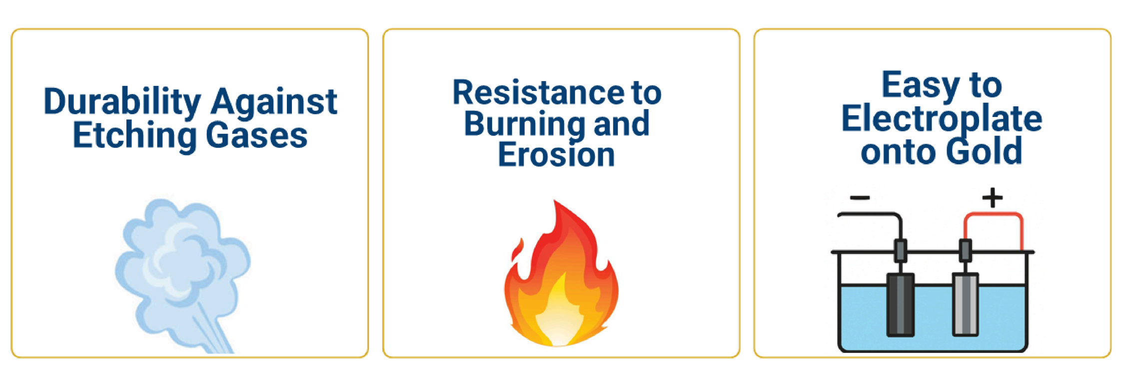
Result after Ni mask and seed layer removal



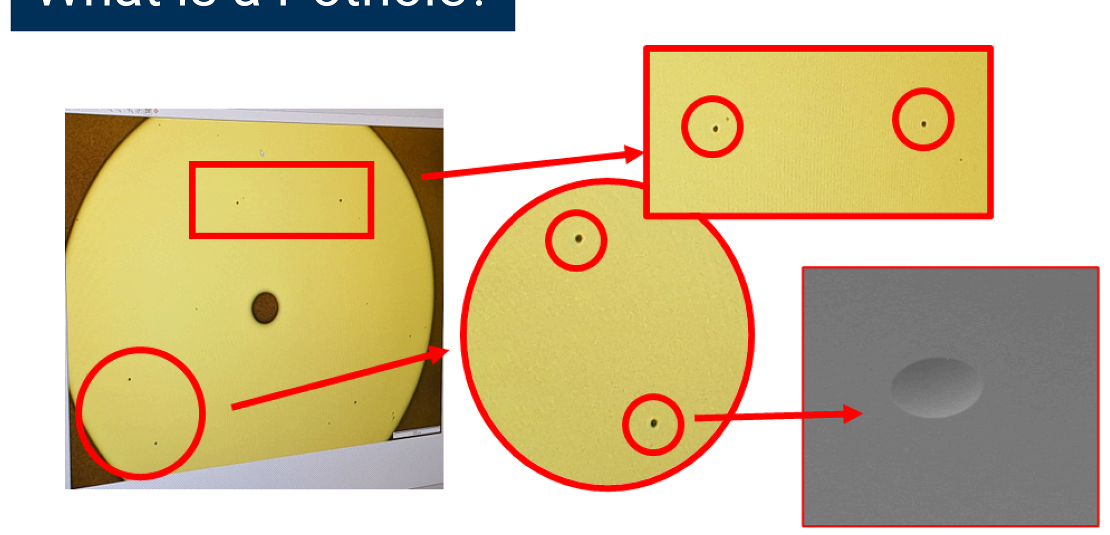
Wafers after TEOS deposition

OBSERVATIONS/RESULTS

Why use a Nickel Mask?



What is a Pothole?



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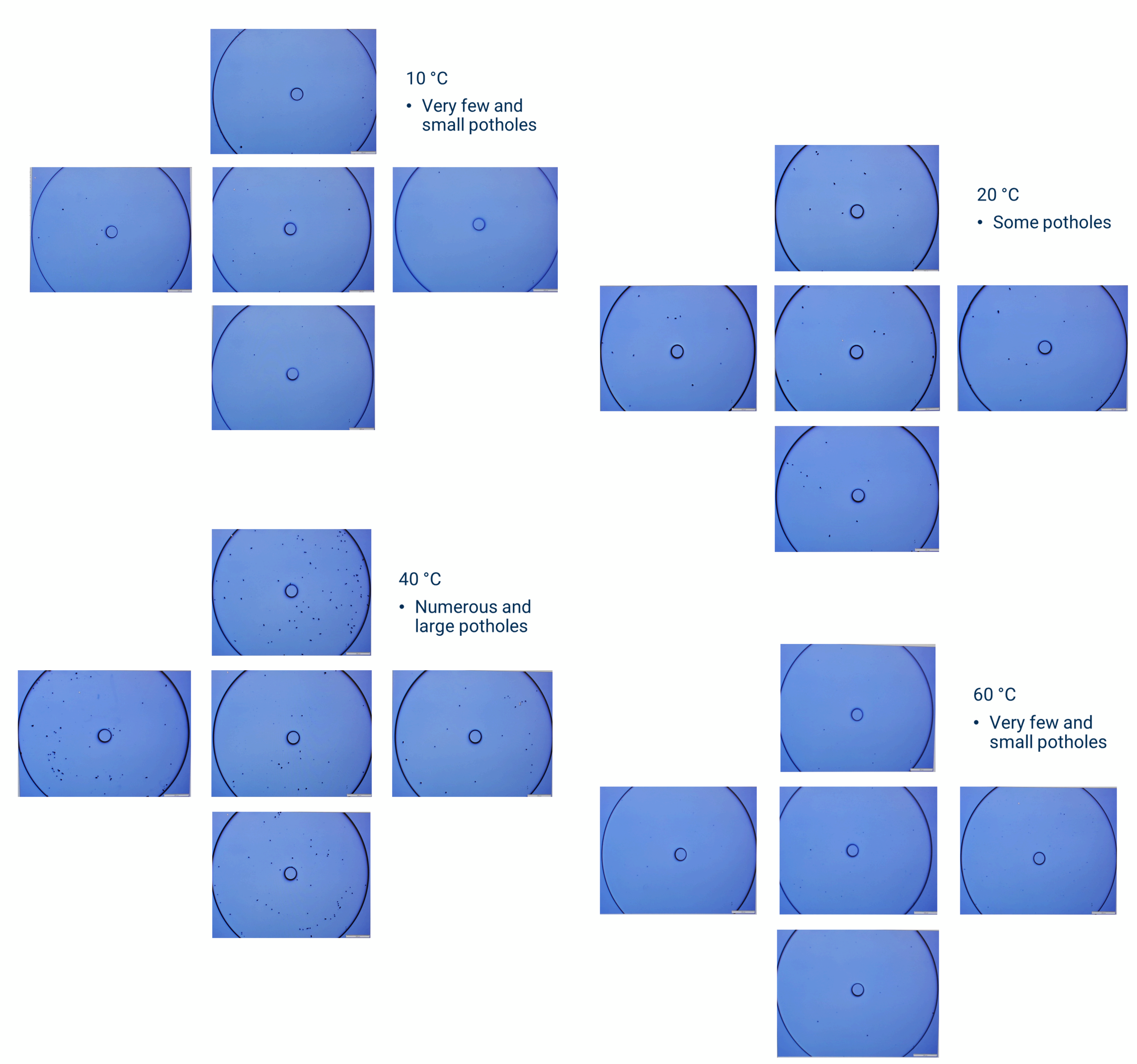
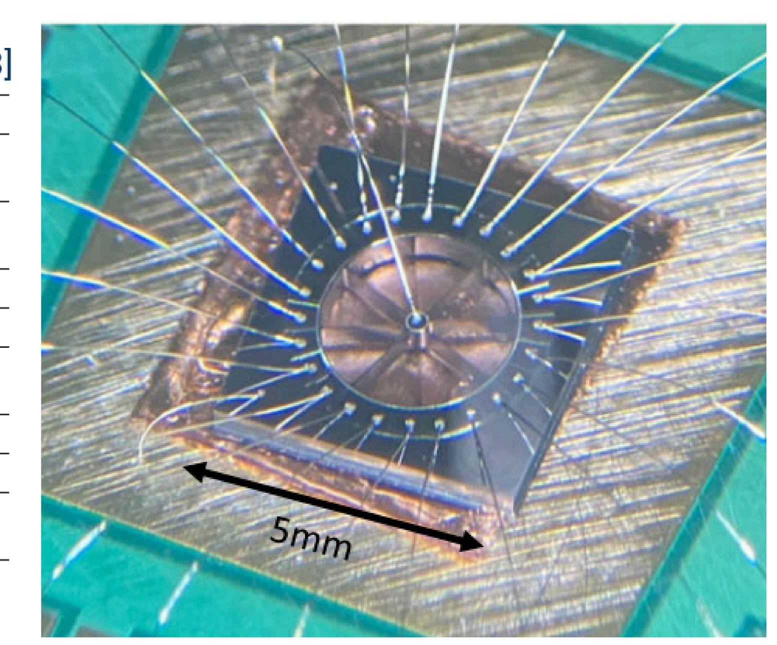
What happens if you change the elctrode temperature when etching SiC?



WHAT'S NEXT?

Parameter	Value
Size	5×5×0.5 mm^3
Center Frequency	3.011 MHz
Polarization Voltage	260 V
Ovenization	80°C
Q	4.6 ×10^6
Bandwidth	0.32 Hz (open-loop)
Driving voltage	650 mV
Scale factor	215nA·$°^{-1}$·s
Angle Random Walk	0.005°·$h^{-1/2}$
Bias Instability	0.34°h^{-1}

[3]



A diced 4H-SiC BAW gyroscope mounted on PCB with all 24 electrodes and center post wire-bonded. [1]

REFERENCES

[1] Long Y, Liu Z, Ayazi F. 4H-Silicon Carbide as an Acoustic Material for MEMS. IEEE Trans Ultrason Ferroelectr Freq Control. 2023 Oct;70(10):1189-1200. doi: 10.1109/TUFFC.2023.3282920. Epub 2023 Oct 17. PMID: 37276110.

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[3] Liu, Z., Long, Y., Wehner, C. et al. 4H silicon carbide bulk acoustic wave gyroscope with ultra-high Q-factor for on-chip inertial navigation. Commun Eng 3, 87 (2024).

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