Growth and characterization of IsoPure Epitaxial layers for quantum applications

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Motivation

- Precursors are decisive for epigrowth quality, growth rate, energy consumption
- Currently, planetary reactors run on ethene (C_2H_4) and trichlorosilane (TCS, $SiHCl_3$) with growth rates up to 30 µm/h and good epilayer quality

→ **We are testing alternative precursors (here: methane CH_4)** for higher growth rates and better epilayer quality (defects, doping)

- Moreover, methane is a candidate for isotopically pure $Si^{12}C$ epitaxy
  - Quantum technology based on silicon vacancy (V_{Si}) [1]
  - For best coherence times, isotopically pure epilayers are preferred
  - Qubits demand for specific ^{12}C content between 98.5 and 99.0 at % [2,3]

Epitaxial growth

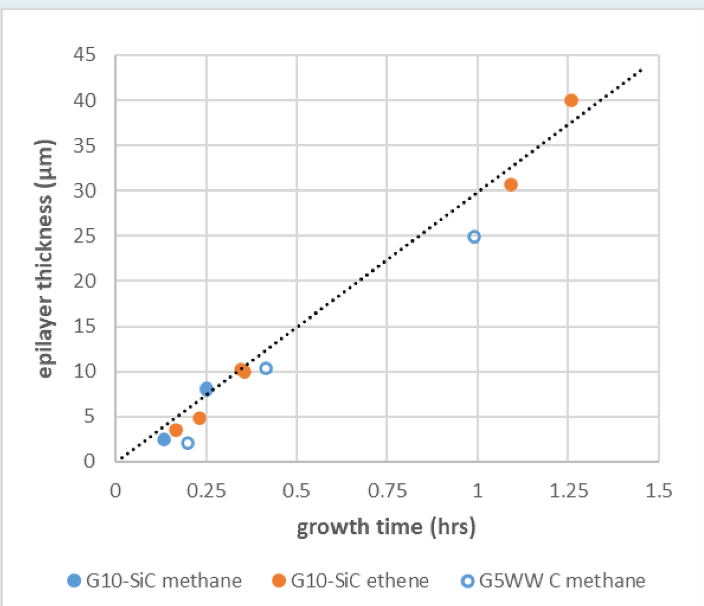
- Conventional 150 mm n-type 4H-SiC substrates from vendors A, B, C
- Epitaxy in AIXTRON planetary reactors (G5WW C, G10-SiC)
  - Si precursor: trichlorosilane (TCS)
  - Standard C precursor: ethene
  - New C precursor: methane (5.5 N, nitrogen < 4 ppm)
  - IsoPure methane with 99.99 at% ^{12}C and ultra-low nitrogen (< 3 ppm)
- Standard post-epitaxy characterization:
  - Epilayer thickness and doping profiles by FTIR-based method and CV
  - Defectivity of the epilayers by UVPL & DIC (Lasertec SICA 88)
- Advanced post-epitaxy characterization:
  - Isotope concentrations: secondary ion mass spectroscopy (SIMS)
  - Carrier lifetime measurements by µ-PCD
  - Deep level transient spectroscopy (DLTS, planned)

Growth rate

- Comparison of reactor types and carbon precursors

✓ Standard ethene based process: up to 30 µm/h

✓ New methane process: up to 30 µm/h



Carrier lifetime of epilayers

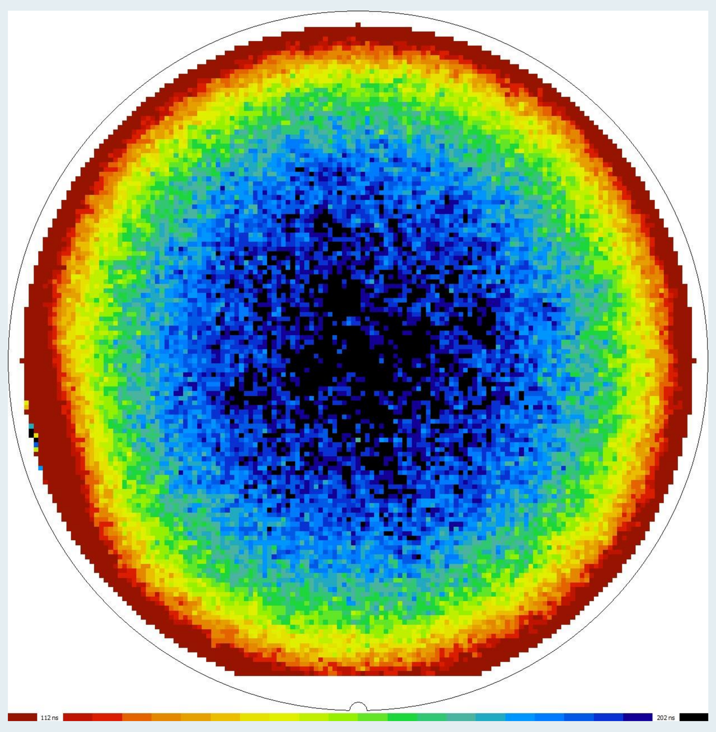
- Comparison of lifetime maps obtained from ethene and methane based processes (standard 1200 V)

✓ Typical radial symmetric lifetime distribution

✓ No larger defects (clusters, stacking faults)

✓ Comparable carrier lifetimes (163 ns)

✓ Comparable point defect contents expected

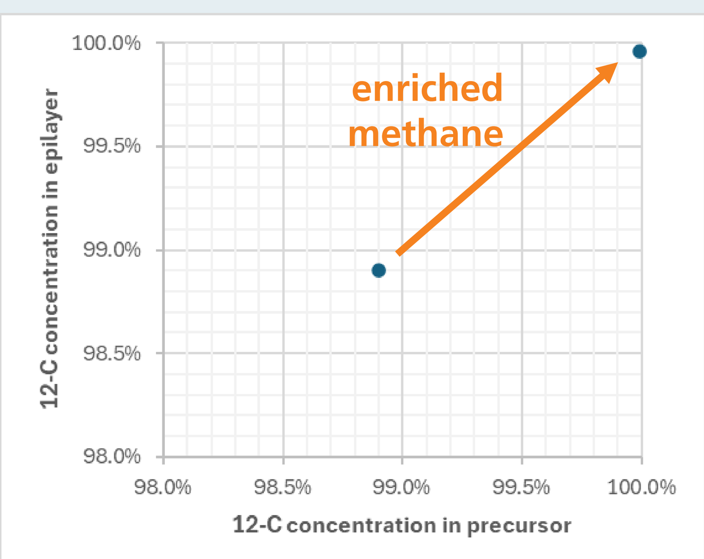


IsoPure $Si^{12}C$ epilayers (G5WW C)

- Use of isotopically enriched methane
- 26.8 µm thick epilayer, intentionally undoped on substrate from vendor C
- ^{12}C concentration: 99.96 at%

→ Almost no C exchange with reactor parts

→ **IsoPure $Si^{12}C$ epilayer grown**

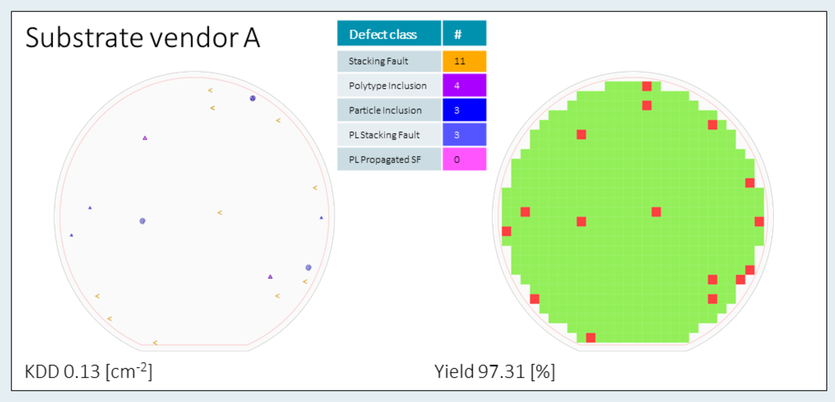


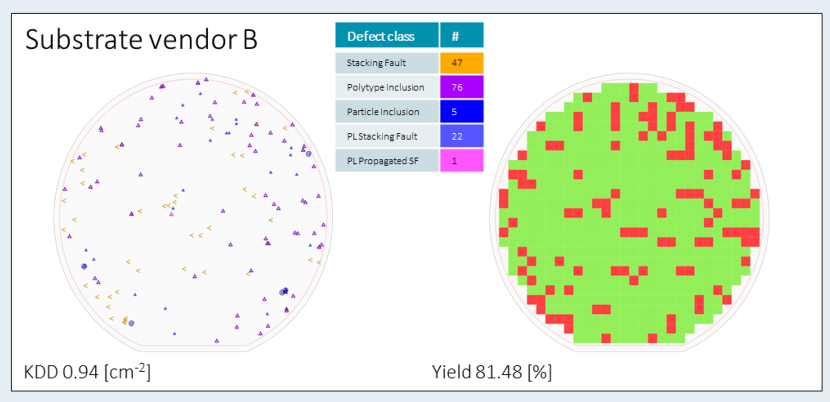
Defectivity of epilayers

- Yield maps based on 5x5 mm², 3 mm edge exclusion
- Methane based process in **G10-SiC** on substrates from vendors A and B

→ Epilayer defectivity depends on substrate quality

→ **Very low defectivity possible with methane based process**

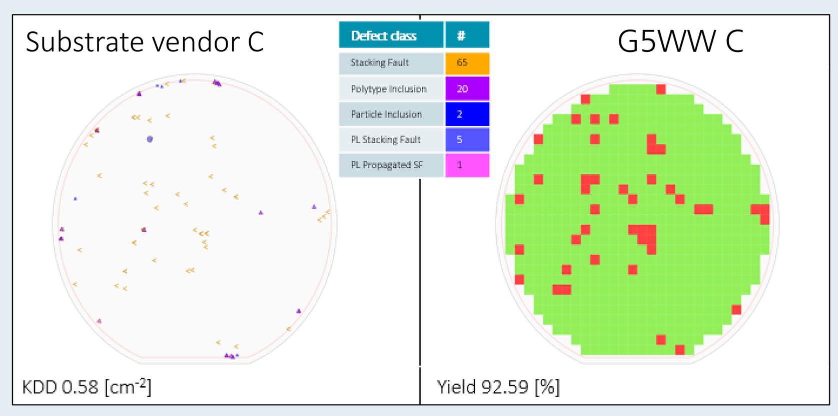




- Methane based process in **G5WW C** on substrate from vendor C

→ Comparable defectivity to G10-SiC process

→ Promising result, further process optimization will follow



Conclusion and outlook

- Methane successfully used as precursor:
  - Thickness and doping results comparable to ethene based processes
  - Growth rates up to 30 µm/h possible
  - Comparable defectivity to standard ethene process
- Next steps:
  - Higher growth rates up to 50 µm/h
  - IsoPure methane for higher ^{12}C content
  - Comparison trichlorosilane to tetrachlorosilane

Find our publications here:

1 N. T. Son, C. P. Anderson, A. Bourassa, K. C. Miao, C. Babin, M. Widmann, M. Niethammer, J. Ul Hassan, N. Morioka, I. G. Ivanov, F. Kaiser, J. Wrachtrup, D. D. Awschalom; Appl. Phys. Lett. 116, 190501 (2020); https://doi.org/10.1063/5.0004454.
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3 Bourassa, A., Anderson, C.P., Miao, K.C. et al. Entanglement and control of single nuclear spins in isotopically engineered silicon carbide. Nat. Mater. 19, 1319–1325 (2020). https://doi.org/10.1038/s41563-020-00802-6.

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