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INFLUENCE OF EPILAYER THICKNESS AND STRUCTURAL DEFECTS ON THE MINORITY CARRIER LIFETIME IN 4H-SiC

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Motivation

- Minority carrier lifetime limits switching characteristics of high power bipolar devices
  → thick n⁻ epilayers with bulk minority carrier lifetime τ_B of several µs needed
- Most measurement techniques determine an effective minority carrier lifetime τ_{eff}:
  - Surface recombination lifetime τ_S at the epilayer surface and at the sub-epi interface [1]
  - Bulk minority carrier lifetime τ_B

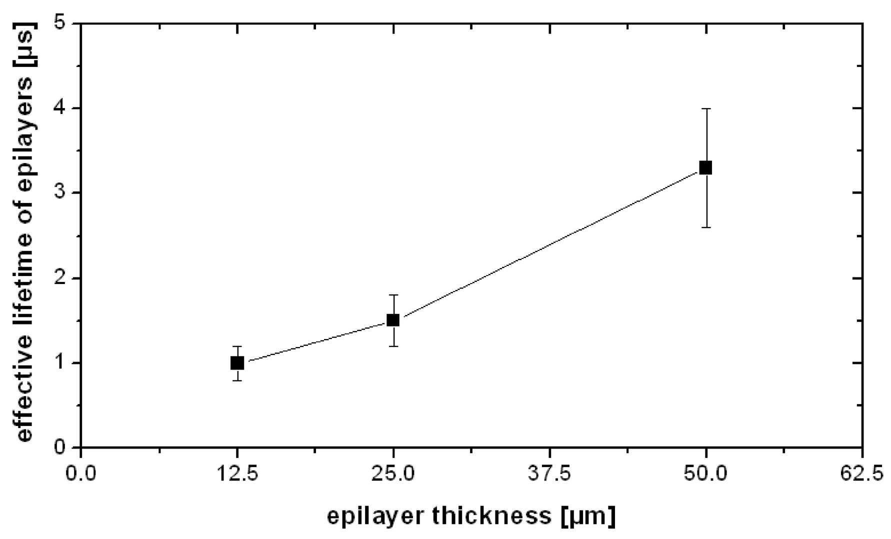
  → Distinction between bulk, surface and effective lifetime needed
- Limiting factors for bulk minority carrier lifetime τ_B:
  - Lifetime killer in n-type epilayers: [$Z_{1/2}$] defect [2]
  - For [$Z_{1/2}$] < 5 x 10^{12} cm^{-3}: other limiting factors, e.g. structural defects?
  - Structural defects like dislocations and stacking faults act as recombination centres [3]

  → Impact of structural defects on the minority carrier lifetime distribution

Experimental

- 4H-SiC homoepitaxial layers:
  - CVD growth in horizontal hot-wall reactor (EPIGRESS VP508GFR) on vicinal substrates [4]
  - All epilayers intentionally doped with nitrogen: n = (1-2) x 10^{15} cm^{-3}
  - Variation of epilayer thickness from 12.5 µm up to 50 µm
- Determination of minority carrier lifetime:
  - Microwave-detected photoconductivity decay (µ-PCD) [5]
  - SEMILAB WT2500
  - UV excitation wavelength: 350 nm → penetration depth about 30 µm [6]
- Determination of defects:
  - Structural defects by defect selective etching (DSE) in molten KOH [7]
  - Point defects by deep level transient spectroscopy (DLTS)

Effective lifetime

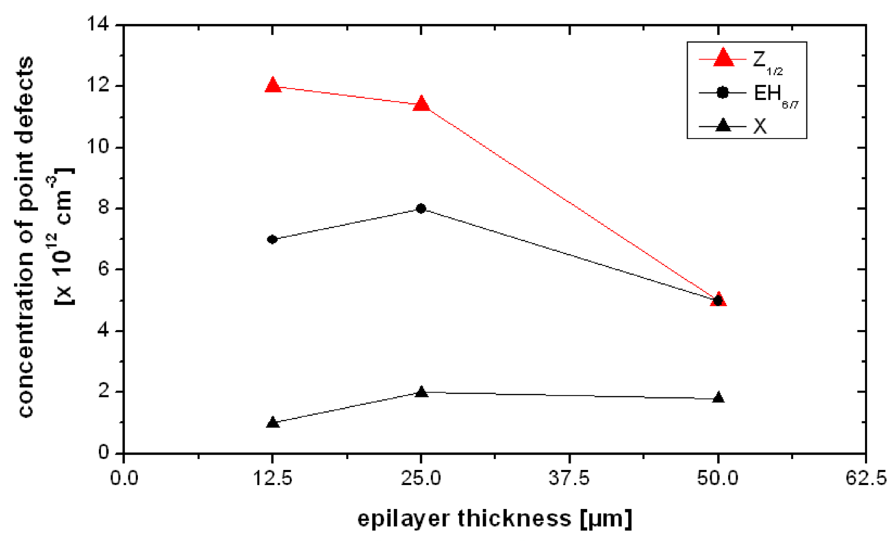


Effective lifetime τ_{eff} of epilayers

- τ_{eff} increases with increasing epilayer thickness
- Effective lifetime τ_{eff} is determined by bulk carrier lifetime τ_B and surface recombination lifetime τ_S [1,5]:

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_B} + \frac{1}{\tau_S}$$

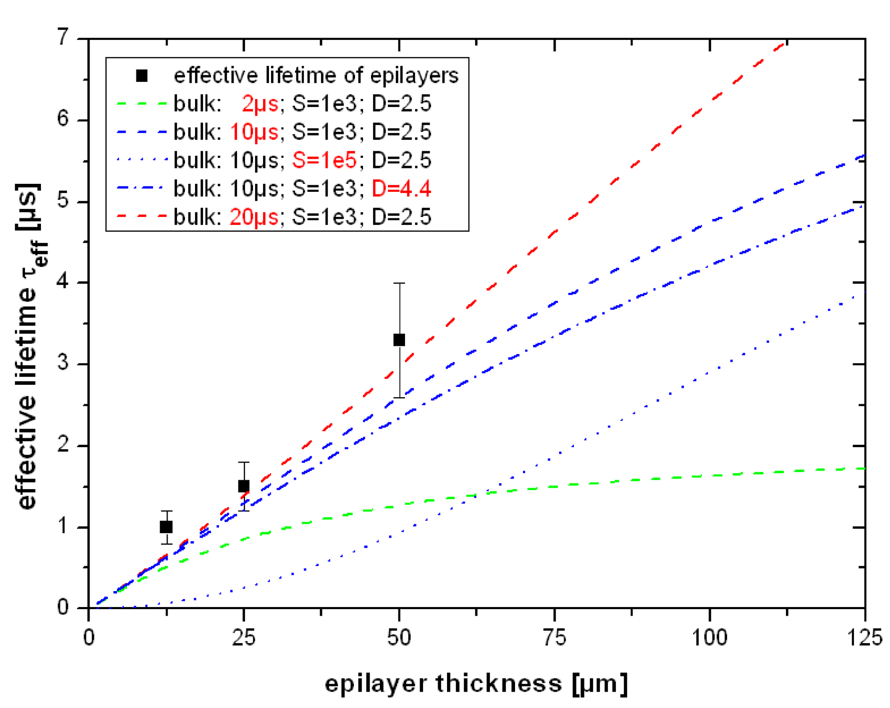
→ Is this effect really caused by improved material quality (bulk lifetime)?



Bulk lifetime τ_B vs. point defects (DLTS)

- Dominant point defects present in these n-type epilayers: $Z_{1/2}$, $EH_{6/7}$, X
- Point defect concentrations of $Z_{1/2}$, $EH_{6/7}$ decrease with increasing epilayer thickness to e.g. [$Z_{1/2}$] = 5 x 10^{12} cm^{-3}
- $Z_{1/2}$ defect does not limit bulk lifetime of 50 µm thick epilayer [2]

→ Further limiting factors for bulk minority carrier lifetime like, e.g. structural defects?



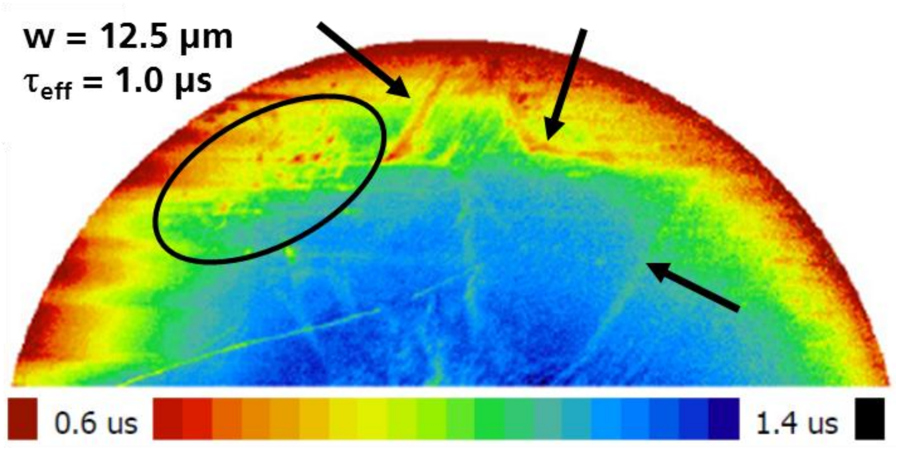
Surface recombination lifetime τ_s

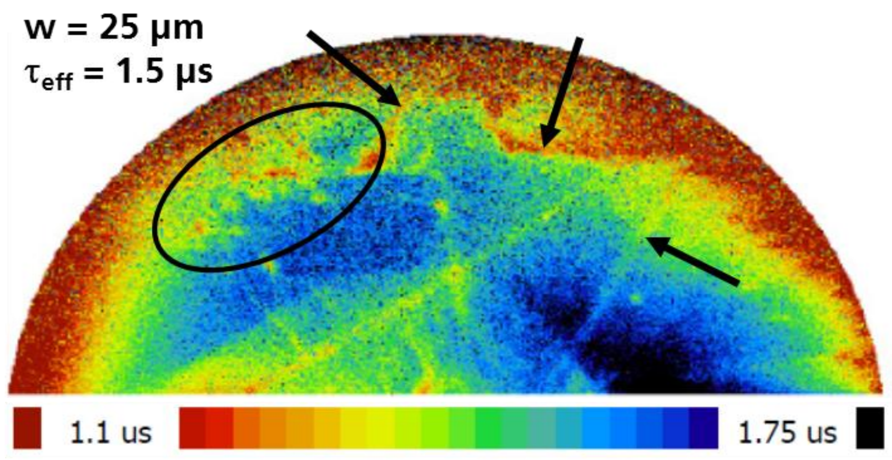
$$\frac{1}{\tau_S} = \left(\frac{w}{2S} + \frac{w^2}{D \cdot \pi^2}\right)^{-1}$$

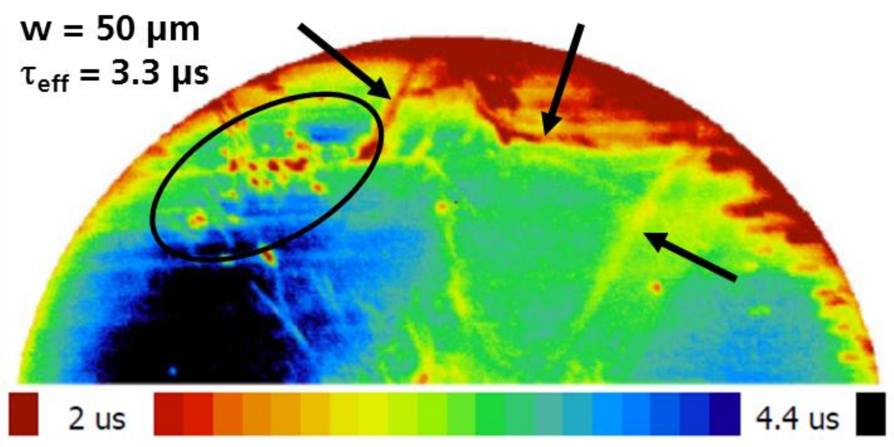
- Diffusion coefficient D_{low} = 4.4 cm²/s, D_{high} = 2.5 cm²/s [8]
- Surface recombination velocity S = 10^3-10^5 cm/s [9]
- Bulk lifetimes τ_B > 10 µs do not increase effective lifetime any more
- τ_{eff} limited by surface recombination

→ Further focus on surface recombination to improve effective lifetime τ_{eff}

Impact of structural defects





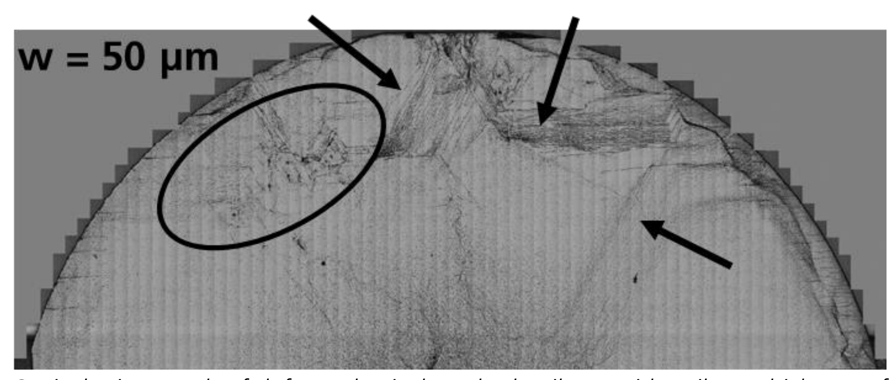


Minority carrier lifetime mappings of low n-type epilayers with increasing epilayer thickness of 12.5 µm (top), 25 µm (middle) and 50 µm (bottom). Appropriate color legend of minority carrier lifetime is given below each mapping.

Lateral distribution of effective lifetime

- Similar distribution of lifetime for three epilayers with different epilayer thickness
- Highest minority carrier lifetime in the wafer center, lowest carrier lifetime at the wafer edge (doping)
- Characteristic areas with locally reduced lifetime in all epilayers (marked by arrows and circle)
- As epilayers were grown on adjacent substrates cut from one crystal boule:

→ Lifetime distribution related to distribution of extended structural defects like e.g. dislocations?



Optical micrograph of defect selectively etched epilayer with epilayer thickness of 50 µm, highlighting areas with high dislocation density (dark gray) and lower dislocation density (light gray).

Comparison of defect and effective lifetime distribution

- Areas with higher dislocation density in epilayer (marked by arrows and circle)
- Areas with higher dislocation density correspond to areas with reduced minority carrier lifetime
- Dislocations act as recombination centers → τ_d

$$\frac{1}{\tau_{eff}} = \left(\frac{1}{\tau_{B*}} + \frac{1}{\tau_d}\right) + \frac{1}{\tau_S}$$

→ Dislocations affect τ_{eff} strongly: local lifetime killers

Conclusions and Outlook

- Bulk lifetime τ_B is really improved with increasing epilayer thickness due to decreasing [$Z_{1/2}$]
- Effective lifetime τ_{eff} is not limited by bulk lifetime τ_B but by surface recombination lifetime τ_S
- For state-of-the-art 4H-SiC material: increase of effective lifetime τ_{eff} with increasing epilayer thickness w is **mainly** due to the reduced impact of surface recombination
- Dislocations reduce lifetime of epilayers locally, but strongly

References and Acknowledgment

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