A Novel, High Quality SiGe Graded Buffer Growth Process Using $GeCl_4$

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Outline

- Motivation – Process Goals
- Dependence of TDD on Process Variables
- Ge Source Selection
- Process Results
- Conclusions

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Motivation – Process Goals

Commercial viability of SiGe graded buffer : A template for wafer-scale biaxial strained Si or heterointegration

Requirements for SiGe graded buffer include:

High Quality Layers

- **Low threading dislocation density (TDD)**
- **Low dislocation pileup density (DPD)**
- **Low particle/defect counts**

High Throughput Process

- **High growth rate**
- **High reactor uptime**

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Dependence of TDD on Process Variables

$$\rho_t \sim R_{Gd} * R_{Gr} * \exp(U/kT)$$

- **Problem:** Traditional SiGe graded buffer growth methods require long process times (>1 hour) to achieve low TDD (and DPD)
- **Solution:** Growth at higher temperature opens option of high growth rate

Ref.: E.A. Fitzgerald, et al., Mat. Sci. Eng B67, 53-61, 1999.

Conventional SiGe Epitaxy

- **Problem:** High temperature (>800 °C) growth of SiGe with GeH_4 creates severe reactor coating
- Additionally, higher growth rate (more Si, Ge source) increases the coating
- Chamber coating can flake off and also cause quartz devitrification
  - Impacts wafer quality
  - Reduces reactor uptime
- **Solution:** Ge source with higher decomposition temperature

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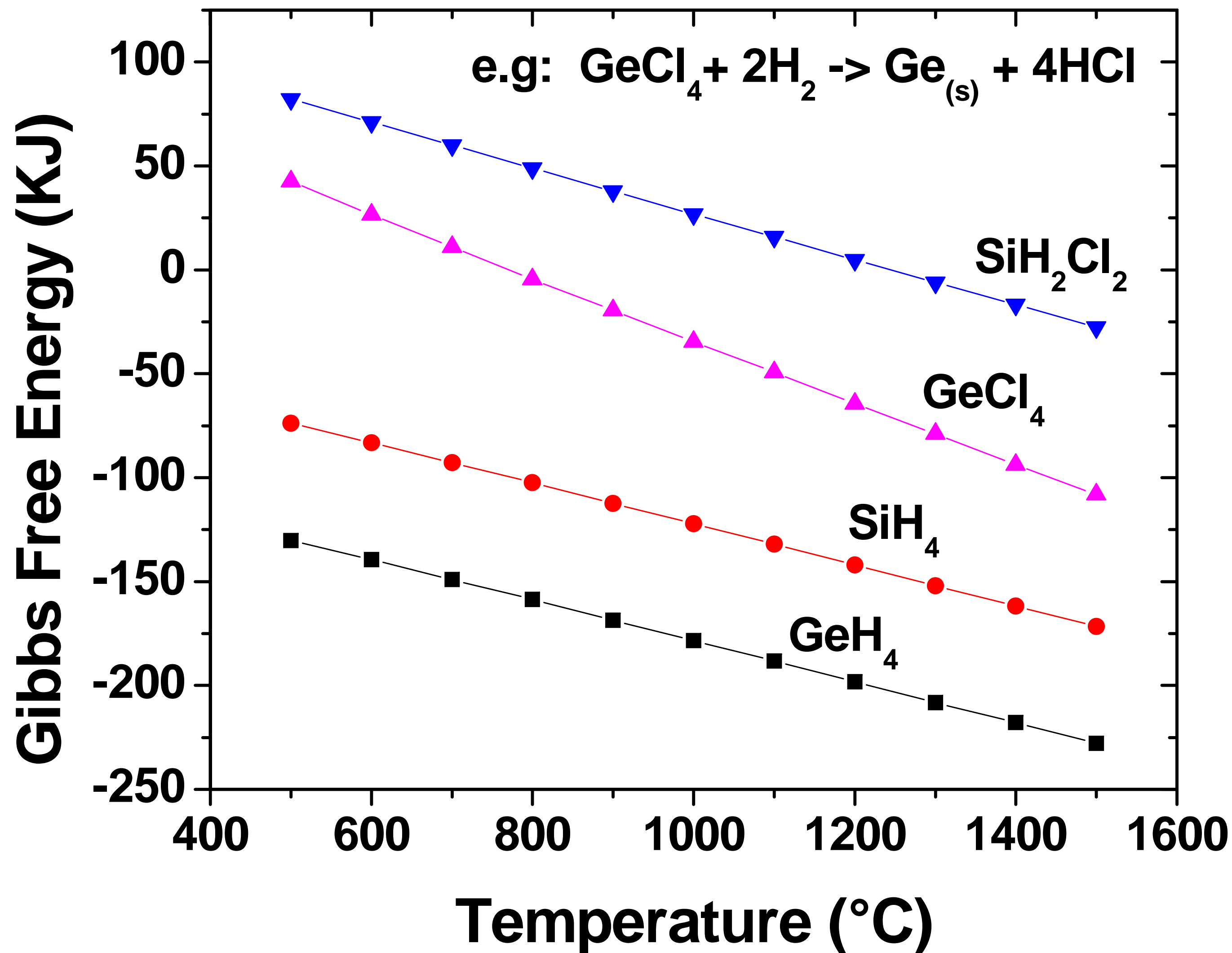
Ge Source Selection



- $GeCl_4$: Chlorinated Ge source has a higher Gibbs free energy of the decomposition reaction

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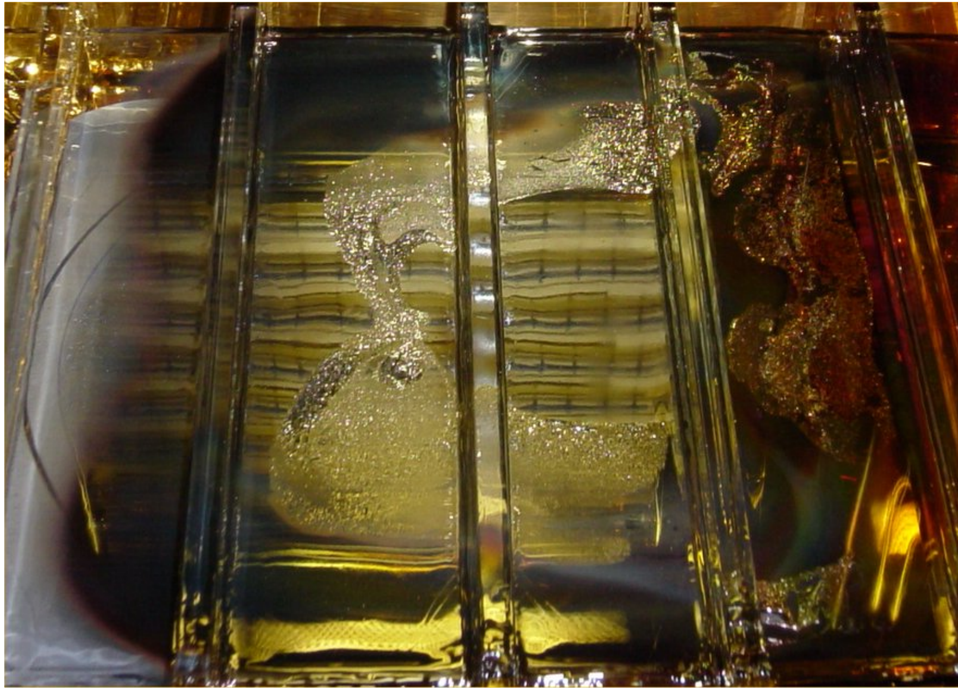
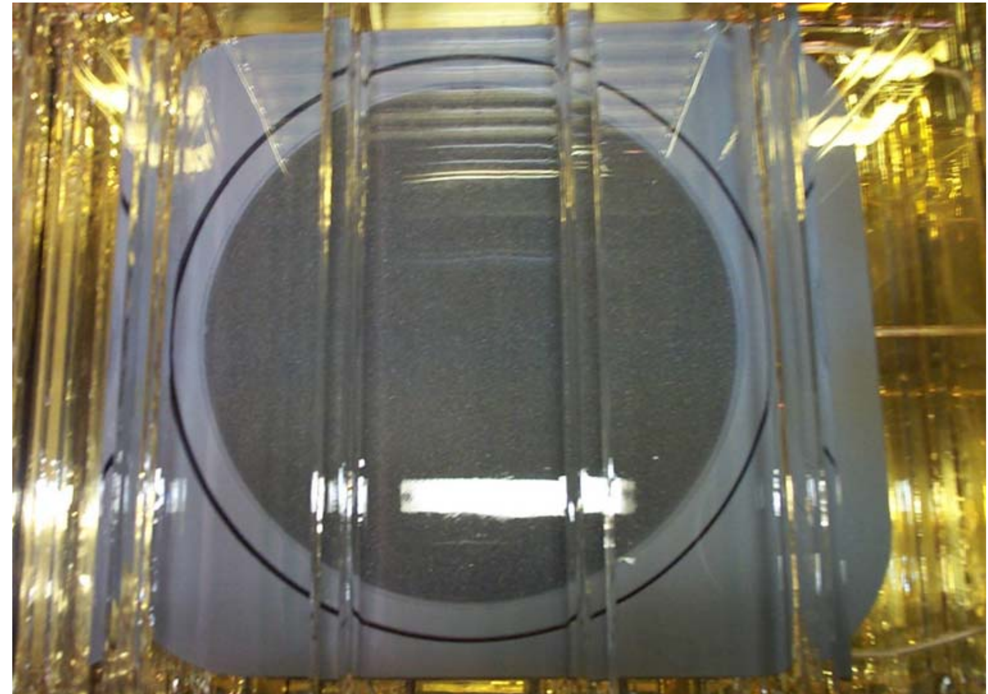
Reactor Coating – GeH_4 source vs $GeCl_4$ Source

Conventional GeH_4 process



- Severe reactor coating
- High particle levels
- SiGe graded buffer at 875 °C
- Total thickness: 4.5 µm

Novel $GeCl_4$ Process



- No reactor coating
- Low particle levels
- SiGe graded buffer at 1075 °C
- Total thickness: 4.5 µm

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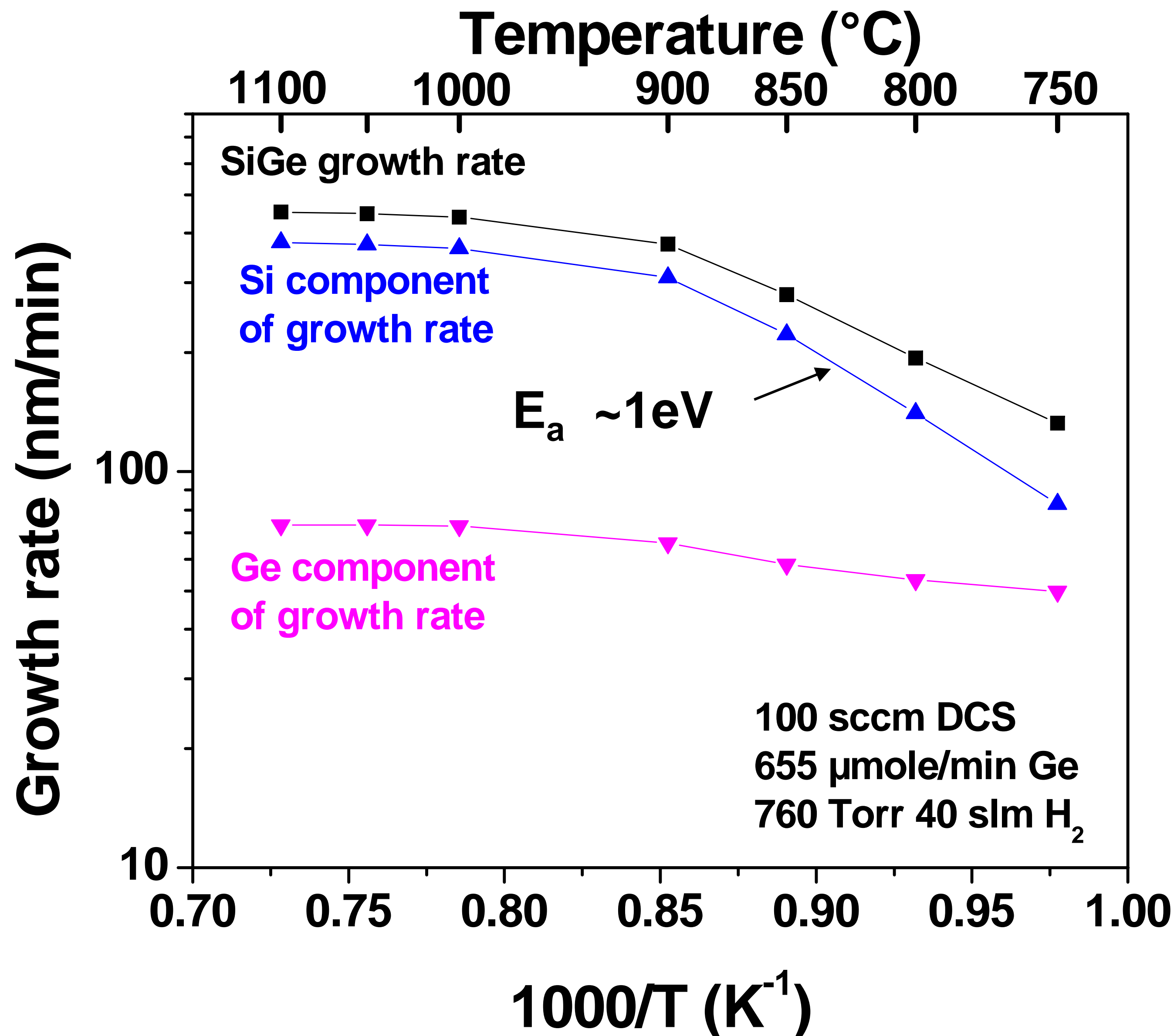
Growth rate vs. Temperature (GeCl4)



- E_a ~ 2 eV for Si only with SiH_2Cl_2 (DeBoer, Kamins, Agnello, Hartmann)

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Growth rate and Composition vs. Temperature (GeCl4)

Temperature (°C)

1100 1000 900 850 800 750

SiGe growth rate

Si component of growth rate

Ge component of growth rate

%Ge

100 sccm DCS
655 μmole/min Ge
760 Torr 40 slm H_2

Growth rate (nm/min)

10 100

%Ge in SiGe

10 15 20 25 30 35 40

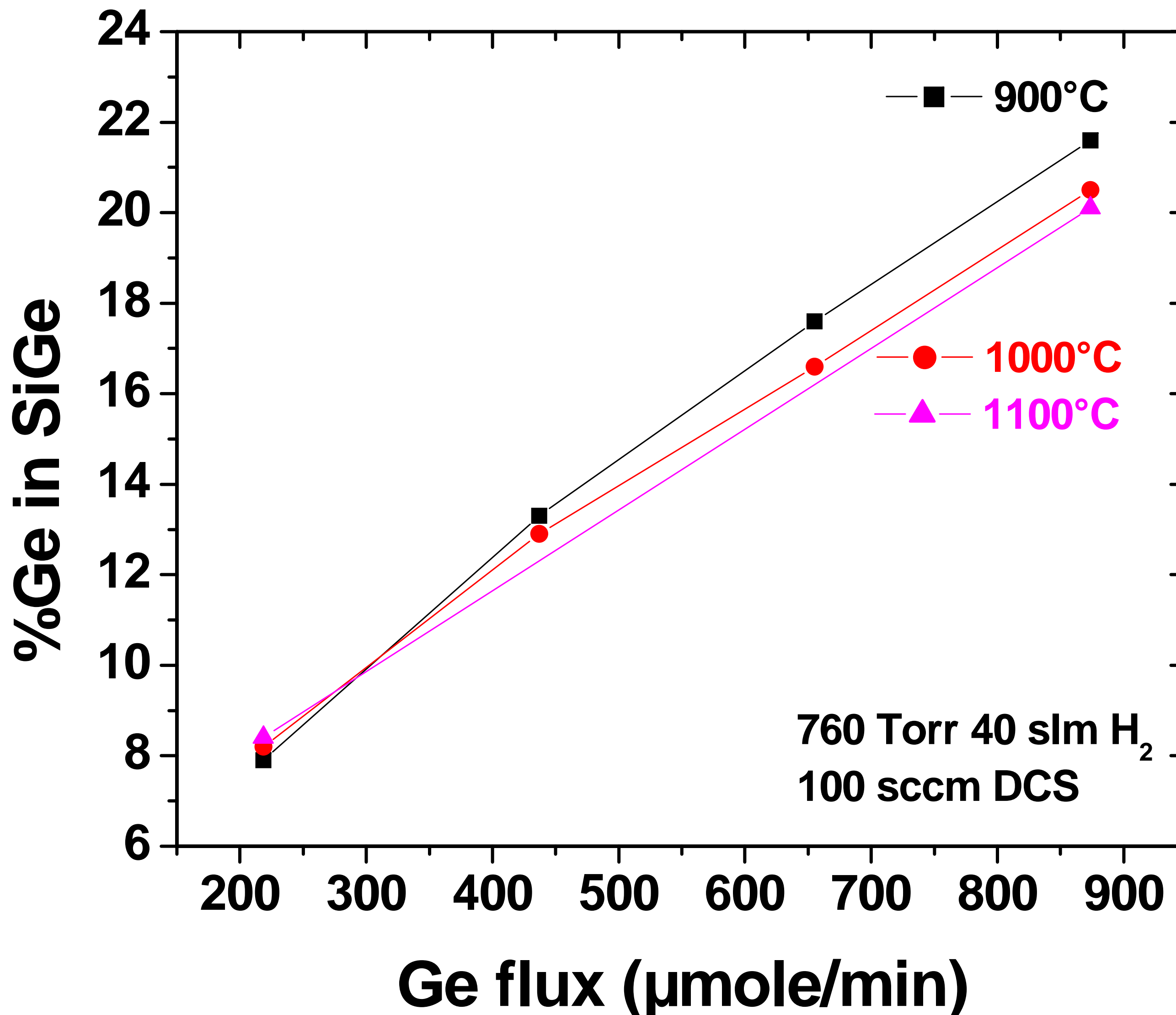
0.70 0.75 0.80 0.85 0.90 0.95 1.00

1000/T (K^{-1})

- Similar behavior at 760 and 80 Torr

Effect of Temperature and $GeCl_4$ Flow on Ge Content

- **%Ge: Ge flux increases % Ge but temperature has less effect in the range of 900-1100 °C**



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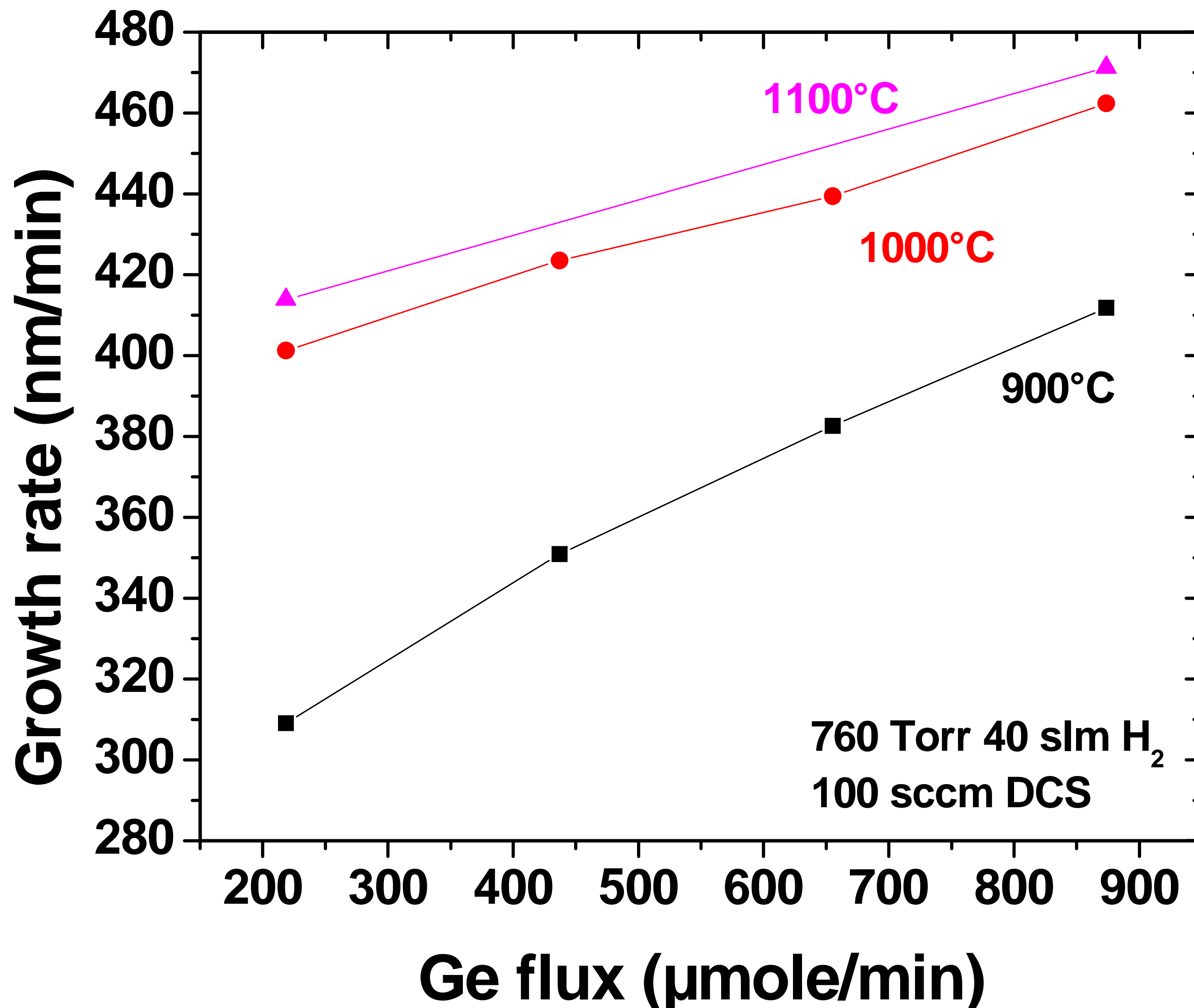
Effect of Temperature and $GeCl_4$ Flow on Growth Rate

- **Growth rate: Ge flux and temperature increase growth rate in the range 900-1100 °C**



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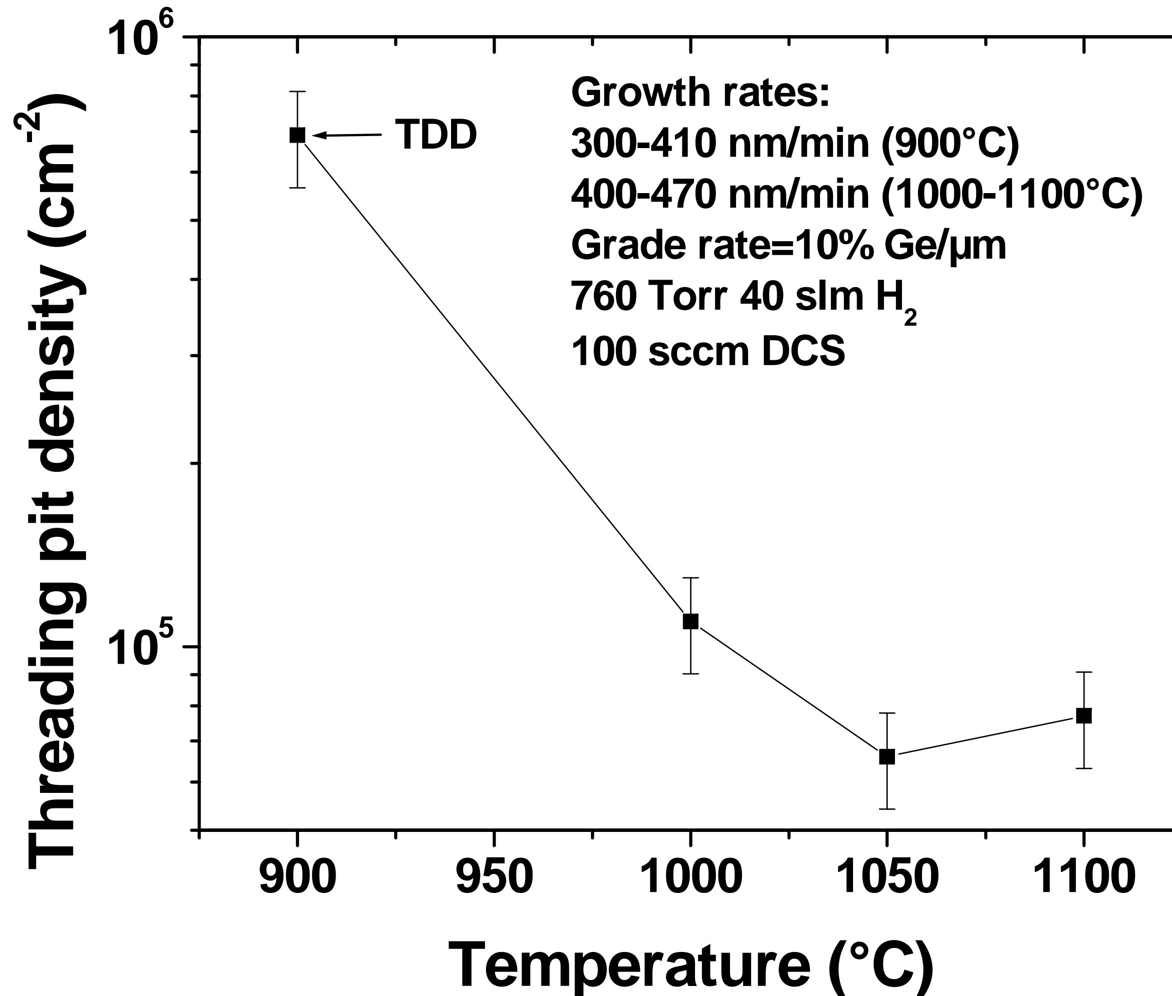
Effect of Temperature on TDD and DPD

- **Increased temperature (>900°C) reduces TDD**



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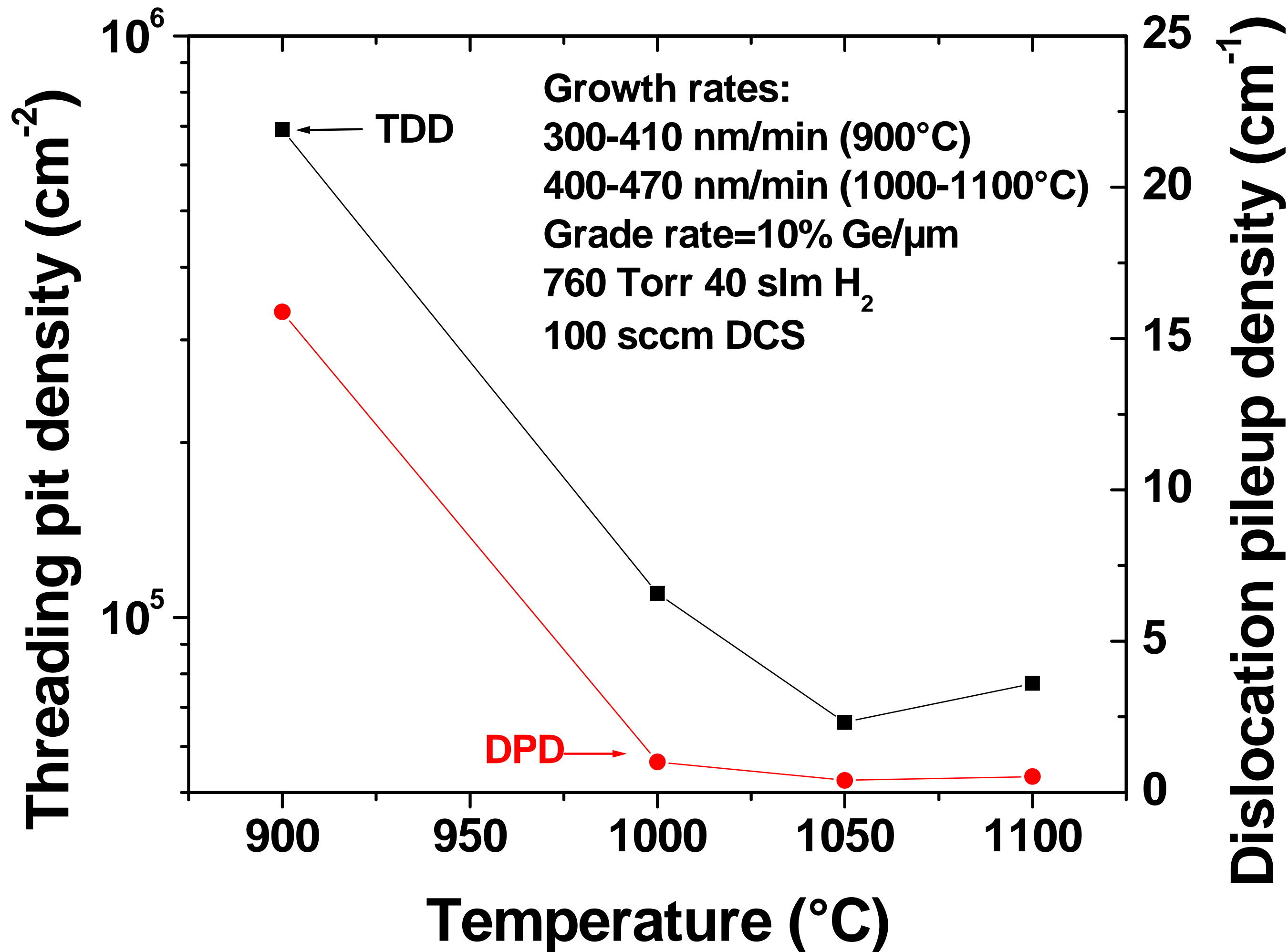
Effect of Temperature on TDD and DPD

- Increased temperature (>900°C) reduces both TDD and DPD



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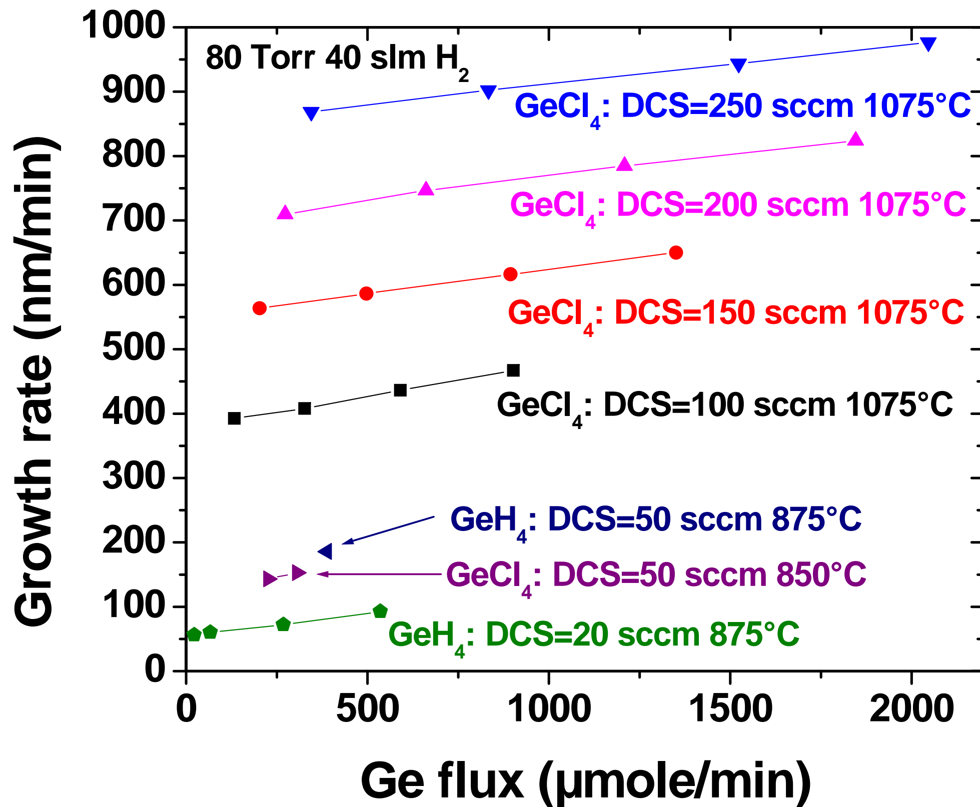
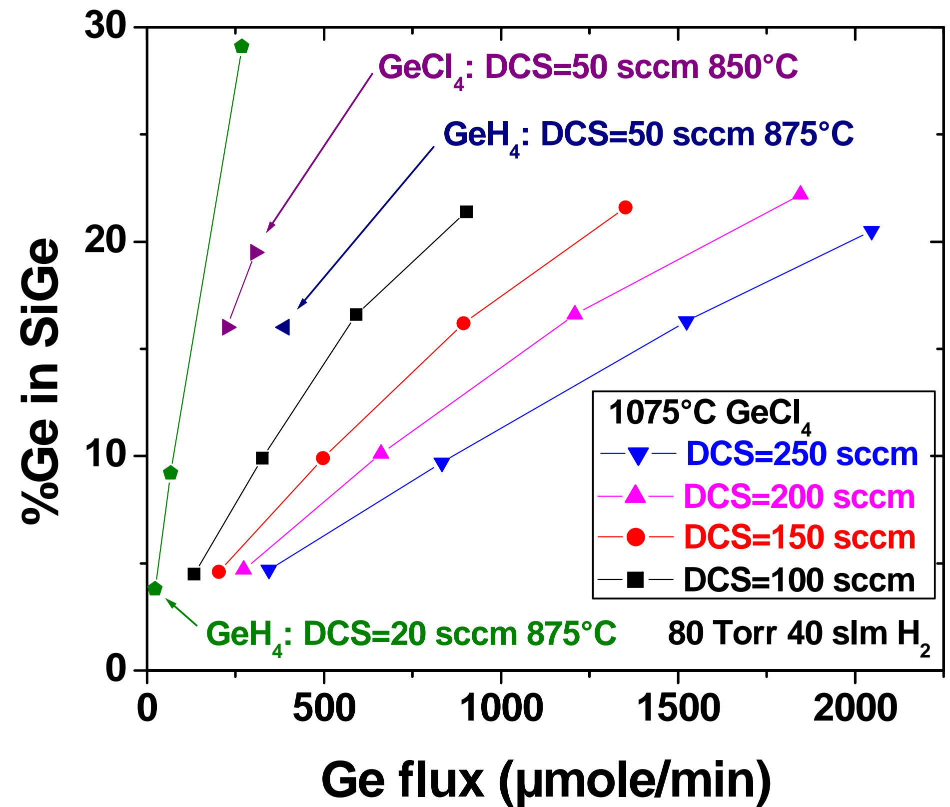
DCS and $GeCl_4$ Process Space

- Measured Ge incorporation and growth rate for reduced pressure conditions: Used for process design purposes





Conclusions

- Use of $GeCl_4$ opens window for high temperature relaxed SiGe
- Qualified fast, clean process for growing high quality SiGe graded buffers
- SiGe GB growth up to 1100°C
- Growth time for 4.5 µm, 20% SiGe graded buffer:
  5 minutes
- Path to cost-effective, high quality SiGe graded buffer wafers

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