Chemical Vapour Deposition of 3C-SiC

RakeshSohal

Under the Supervision
of
Prof. Dieter Schmeißer

Lehrstuhl für Angewandte Physik - Sensorik
Brandenburgische Technische Universität Cottbus, Germany

Outline

- **Introduction**
  - Motivation: Why SiC /3C-SiC?
  - Chemical Vapour Deposition
  - CVD of 3C-SiC
- **Experimental**

  Substrate Cleaning

  Carbonization & Growth
- **Results**

  XPS FTIR XRD
- **Conclusions**
- **Future Directions**

Introduction - Semiconductors

- First Germanium then Silicon
- Bang gap larger than Ge
- Stable & high quality SiO_2 can be grown
- Larger intrinsic resistivity
- Economically cheap

Silicon is so great, why do we need anything else ?

SiC have Distinguished properties

- Good Mechanical Properties
- Wide Band Gap (2.2 - 3.3 eV)
- High Thermal Conductivity
  3.2 W $cm^{-1}K^{-1}$ for 3C-SiC
- High Breakdown electric field
- High Saturation electron drift velocity
- High forward current density

Silicon Carbide - An Introduction

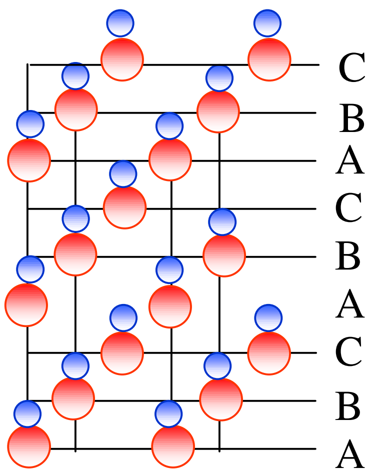
- IV-IV Compound
- Discovered in 1824 by Berzelius
- Initially used for Grinding and Cutting
- SiC realized to be high (temperature/power/frequency) semiconductor at early stage of Si development
- Problem of Single Crystal Growth
- 1955-Lely Solved the problem - Modified Lely Process
- Heteroepitaxial Growth on Silicon Wafers

POLYTYPISM

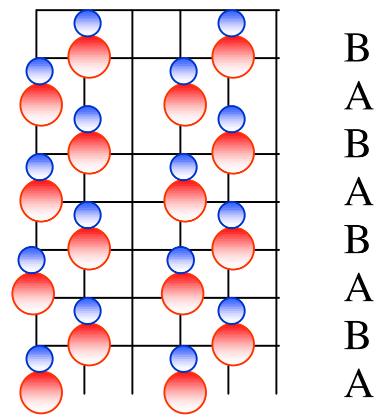
Polytypism in SiC

- Polymorphism- Same compound & different Crystal structure
- One dimensional polymorphism is termed POLYTYPISM

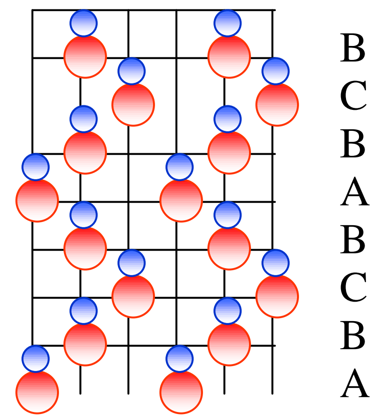
Stacking Order in SiC Polytypes



3C-SiC



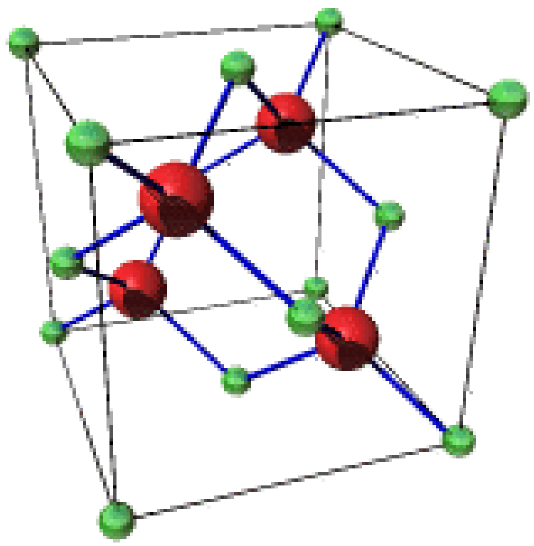
2H-SiC

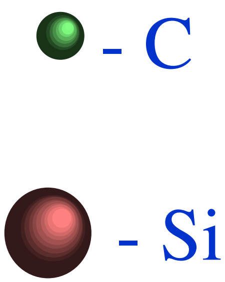


4H-SiC

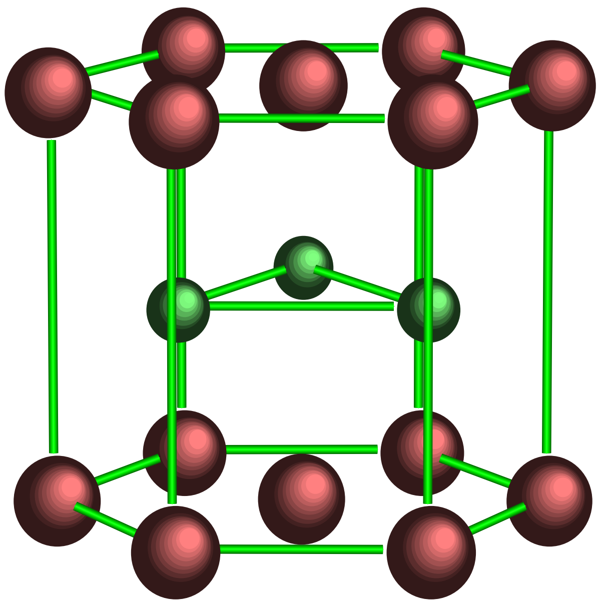
SiC - Crystal Structures

3C-SiC





4H SiC



Zinc Blend

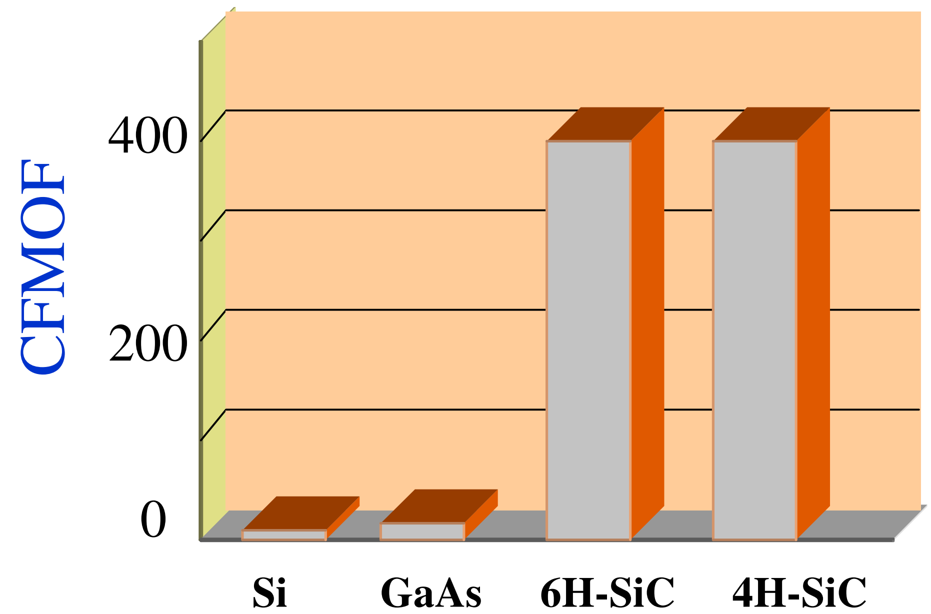
Hexagonal Close Packed

SiC Comparison with others

Semiconductor	Si	GaAs	3C-SiC	4H-SiC	6H-SiC	GaN	Diamond
Specific density [$g \cdot cm^{-3}$]	2.33	5.32	3.21	-	3.21	6.1	3.51
Lattice constant [Å]	5.43	5.65	4.36	3.07	3.08	3.19	3.57
Vickers hardness [$kg \cdot mm^{-2}$]	1000	600	2600	2600	2600	-	10000
Band gap (Eg) [eV] 300 K	1.12	1.43	2.23	3.26	3.02	3.39	5.45
v_{sat} [$10^7 cm.s^{-1}$]	1.0	2.0	2.5	2.0	2.0		2.7.
T_{max} [K]	600	760	1200	-	1580	1100	1400
Melting point [K]	1690	1510	3000	3000	3000	1123	3820
Mechanical stability	High	Medium	High	High	High	High	High
n-mobility [$cm^2(Vs)^{-1}$]	1400	8500	1000	460	600	900	2200
p-mobility [$cm^2(Vs)^{-1}$]	600	400	40	115	50	150	1600
Breakdown electric field (E_b) [10^6 $V \cdot cm^{-1}$]	0.3	0.4	2.2	4	2.4	5	10
Thermal Conductivity [$W \cdot (cmK)^{-1}$]	1.45	0.46	4.9	3.7	4.9	1.3	20
Dielectric constant	11.8	12.8	9.7	-	9.66	9	5.5

(T_{max} = Maximum work temperature)

Combined Figure of Merit (CFOM)



- Johnson's figure of merit
- Keyes's figure of merit
- Baliga's figure of merit

$$CFOM = \frac{\chi \varepsilon_0 \mu v_S E_B^2}{\left(\chi \varepsilon_0 \mu E_B^2\right)_{Si}}$$

SiC Materials Technology

Material functions well beyond the limits

- high temperature
- high power
- high radiation conditions
- Chemically harsh environments

Applications

- high voltage switching for energy saving in electric power distribution
- sensors and controls for cleaner burning
- components for more fuel efficient jet aircraft and car engines
- more powerful microwave electronics for radar and
- communications higher operating voltages and wide operating temperature ranges.

Motivation

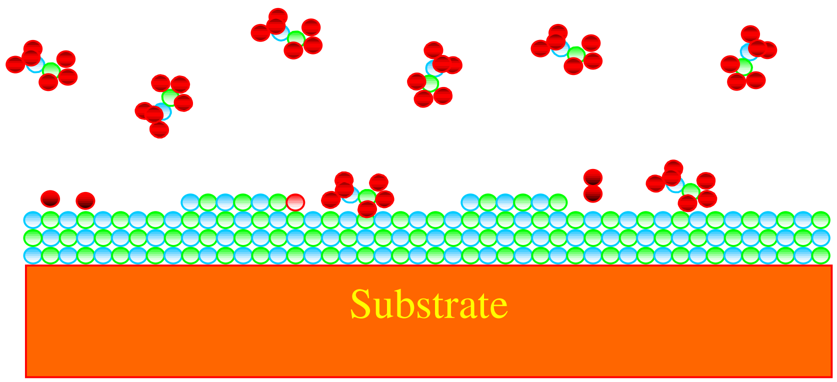
- Wide band gap semiconductor
- Excellent mechanical, chemical, and physical properties
- SiC is a good candidate for high power electronic devices and MEMS/NEMS.
- Gas sensors in high temperature environment

SiC Production

- Acheson Process - reduction of quartz sand, pure C in electric discharge oven
- Van-Arkel Process - thermal decomposition of precursors on hot graphite
- Lely Process
- LPE
- MBE
- Chemical Vapour Deposition

Chemical Vapour Deposition

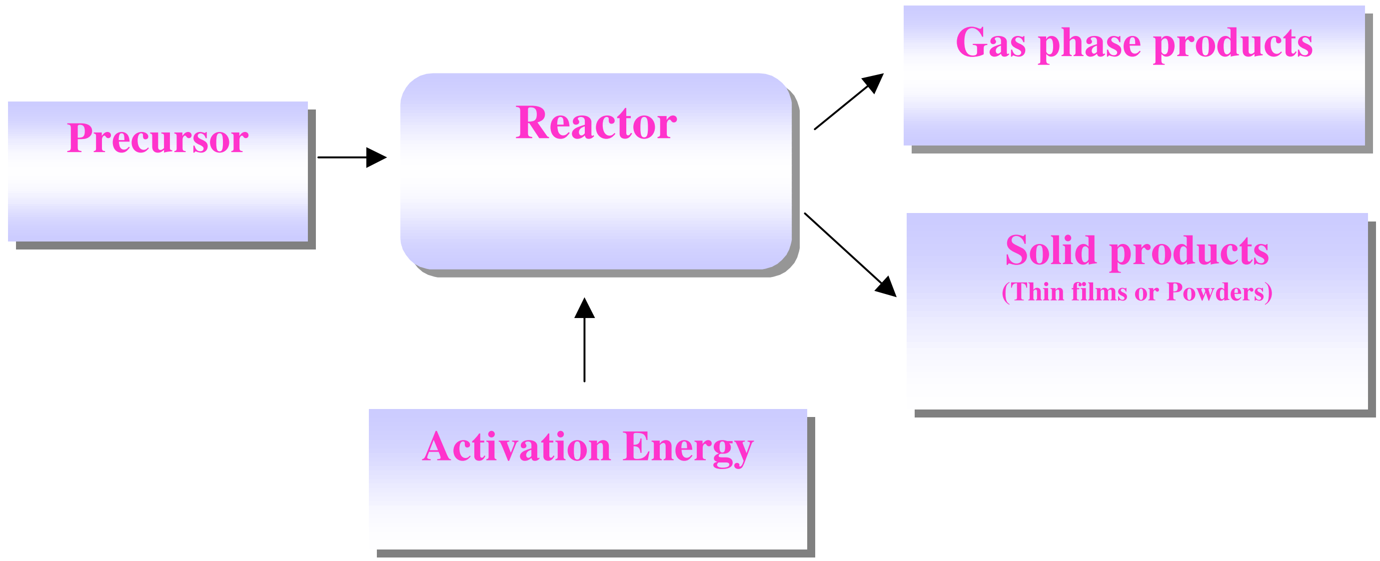
Chemical Constituents react in vapour phase near or on heated substrate to form thin films or powder



Widely used to fabricate Semiconductor Devices

CVD Types - APCVD, LPCVD, PECVD and MOCVD

CVD Essentials



Fundamental CVD Steps

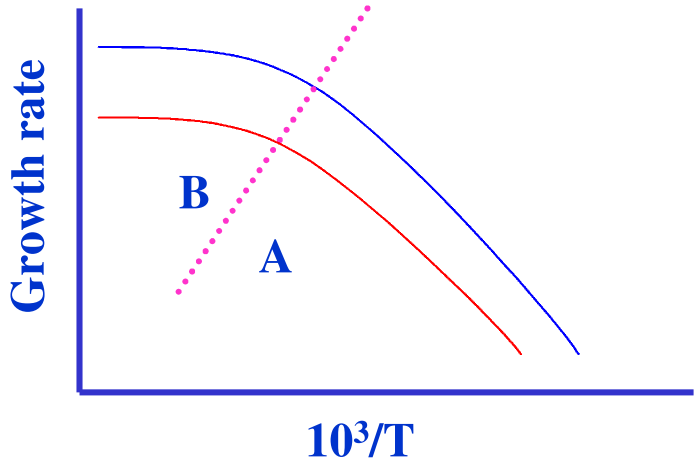
- Precursor vapourization and transport to reactor
- Diffusion of precursor molecules across boundary layer
- Decomposition of precursor molecules and incorporation into solid film
- Recombination of molecular byproducts and desorption in Gas phase

Film - Quality Control

- Reactor geometry
- Process parameters
  Flow rates, temperature, pressure and time
- Chemical reactions
- Transport phenomena - mass/heat transport
- Kinetics & Thermodynamics

So, CVD technique combines several scientific and engineering disciplines

Temperature role in CVD



A. Mass transport or diffusion limited

B. Reaction rate limited

3C-SiC epitaxial growth by CVD

- Epitaxial growth ?
- Considerable factors for epitaxial growth

  (i) thermal & lattice mismatch
  (ii) deposition temperature
  (iii) rate of deposition
  (iv) surface contamination and defects

20% lattice and 8% thermal expansion coefficient mismatch between Si and 3C-SiC

SiC CVD working Groups

Japan

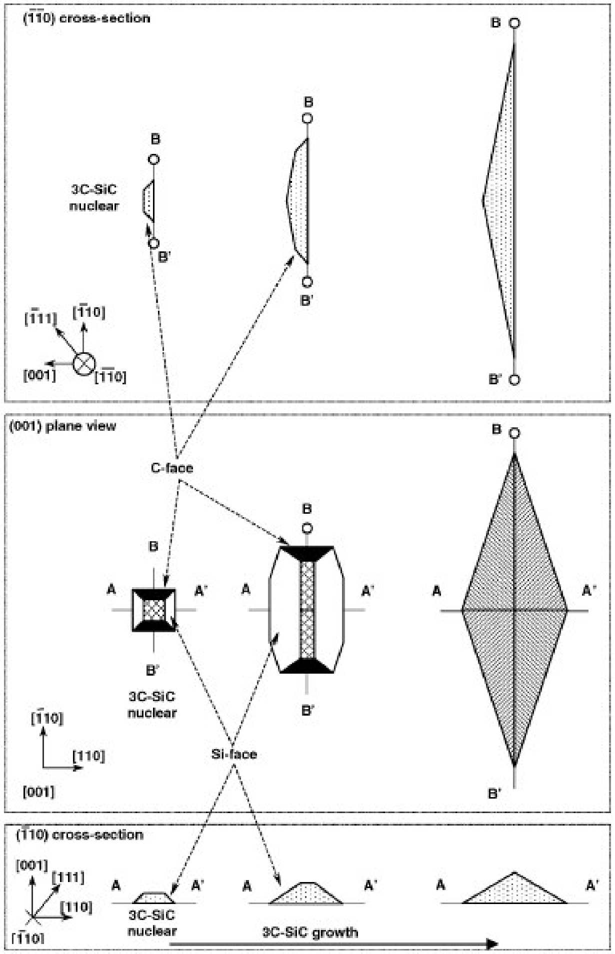
Nagaoka University of Technology

Triod Plasma CVD using dimethylsilane, substrate heating by same method, in-situ RHEED analysis, observed the temperature when growth starts

Hoya Corporation

Studied the effect of alternate supply of gases, growth on undulated substrates, could deposite 200µm thick layer in 5hrs.

Effect of Undulated surface



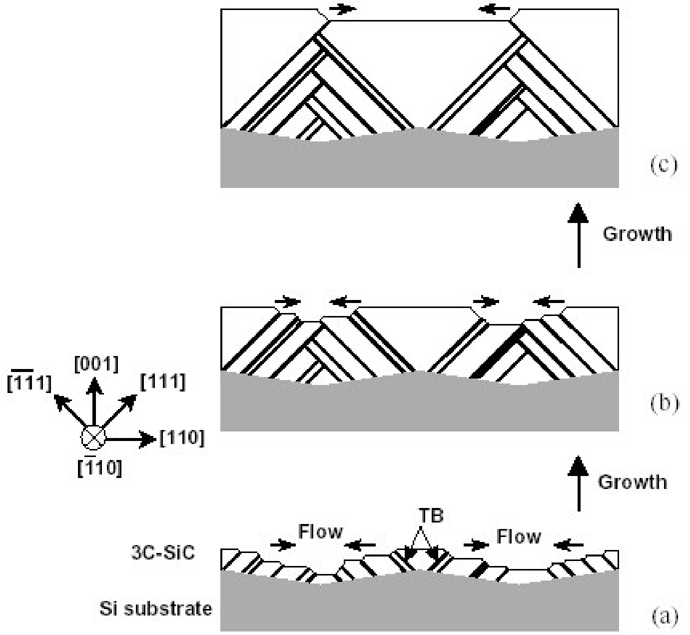


Fig. 5. Model of the elimination of TBs in the 3C-SiC layer on "Undulant-Si" with 3C-SiC growth. The (1̄ 1 1) cross-sectional structure of 3C-SiC changes from (a) to (c) as growth progresses.

SiC CVD working Groups (contd.)

Korea

Korea Research Institute of Chemical Technology

LP-MOCVD using single precursor, 750-970°C, deposited polycrystalline layers, Also studied the effect of different heating ramp rate > 1.5°C/s gives polycrystalline, <1.5°C/s gives single crystalline layers.

SiC CVD working Groups (contd.)

USA

Nishino @ Lewis Research Centre

APCVD using silane+propane or HMDS, Studied the effect of H_2 poor ambient using Ar, Studied the effect of using Coated & uncoated graphite susceptor, **Introduced buffer layer to minimize effect of lattice mismatch,** Deposited of full wafer and studied the uniformity on different positions

Y. Gao @ Kansas State University

Studied the effect of adding HCL Gas - Improved crystallinity and stoichiometry, and eliminates Oxygen content.

HCL eliminates Si nucleation, HCL allows the adsorbed species more time

SiC CVD working Groups (contd.)

Germany

TU - Braunschweig

CVD with UV stimulation alongwith heating, Also done some patterning of grown layers

Angewandte Physik - Sensorik @ BTU Cottbus

Studied Buffer layer formation with LPCVD using acetelene & Trichlorosilane

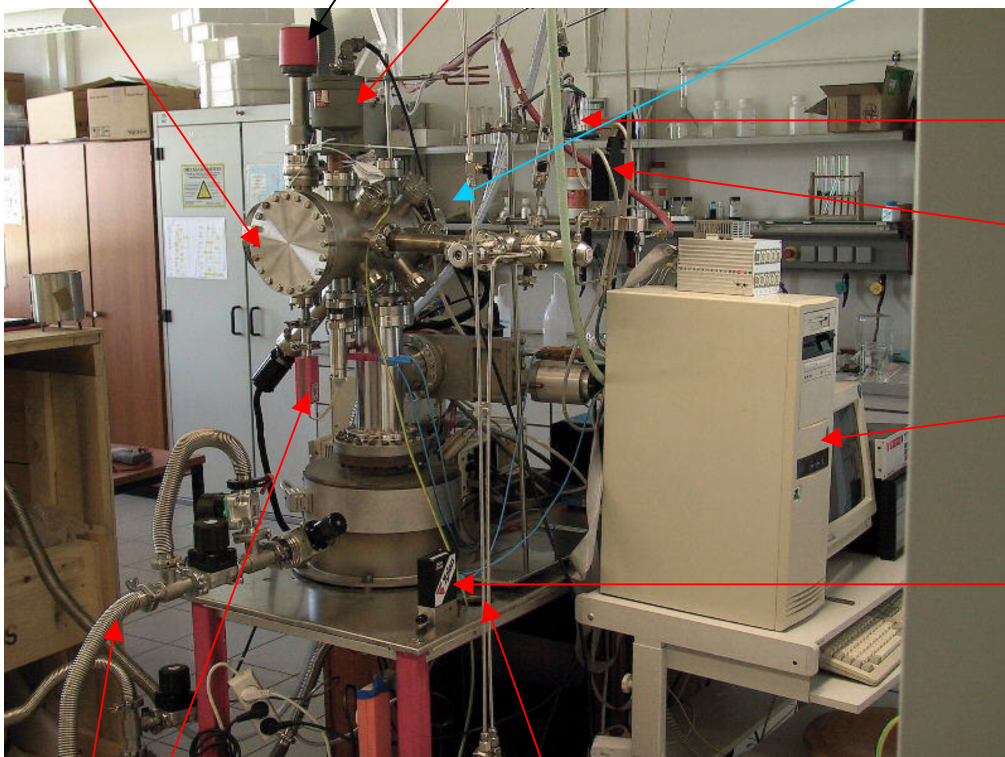
CVD of 3C-SiC

@

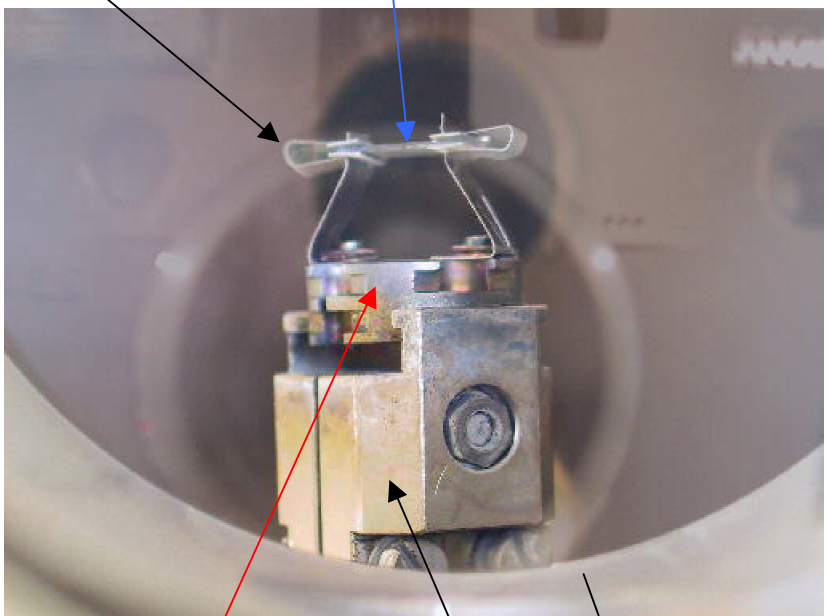
Angewandte Physik - Sensorik

BTU Cottbus

CVD System


High pressure guage
Reaction chamber
Pyrometer
Turbo Pump
MFC for Hydrogen
MFC for Acetelene
PC for MFCs control during carbonization and growth
MFC for TCS
Low pressure guage head
Tubing to TCSilane cylinder
To Rotary pump

Substrate Holder



Temperature range

400°C to 1200°C

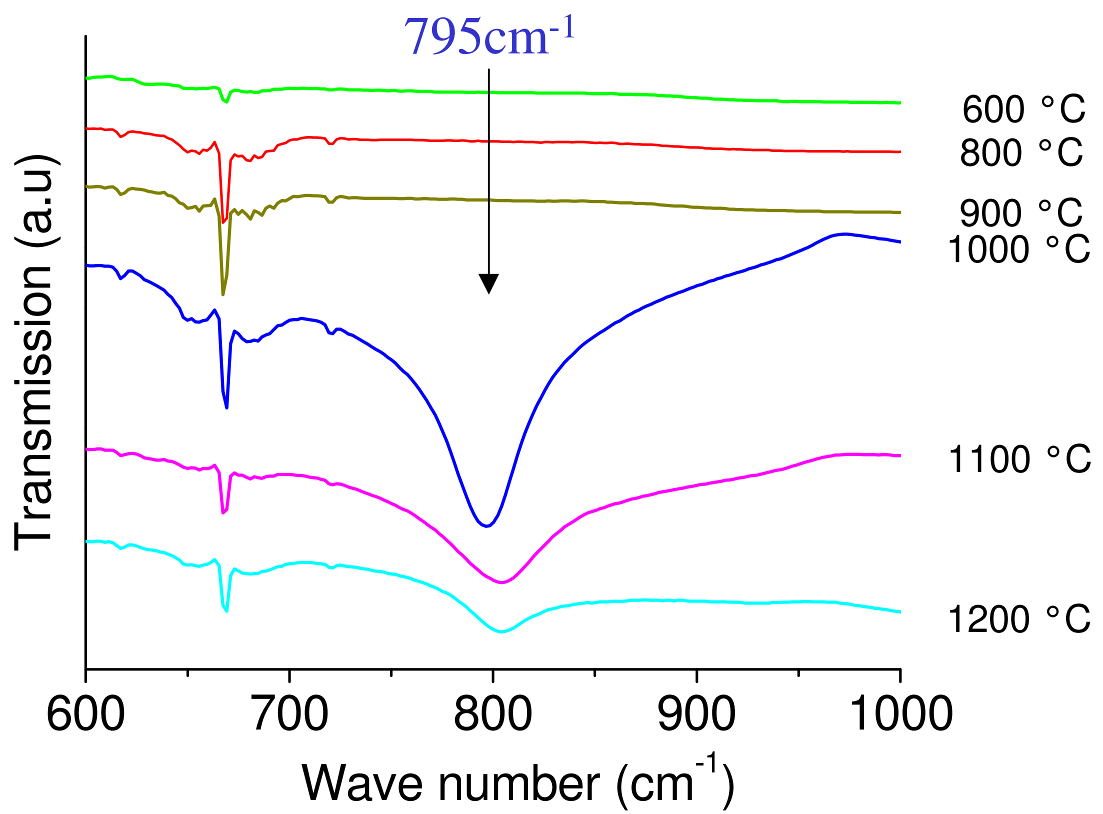
Experimental

- Substrate Cleaning
  - cleaned in HF for 2min then rinsed in DI water
- Carbonization & Growth

CVD Process Parameters

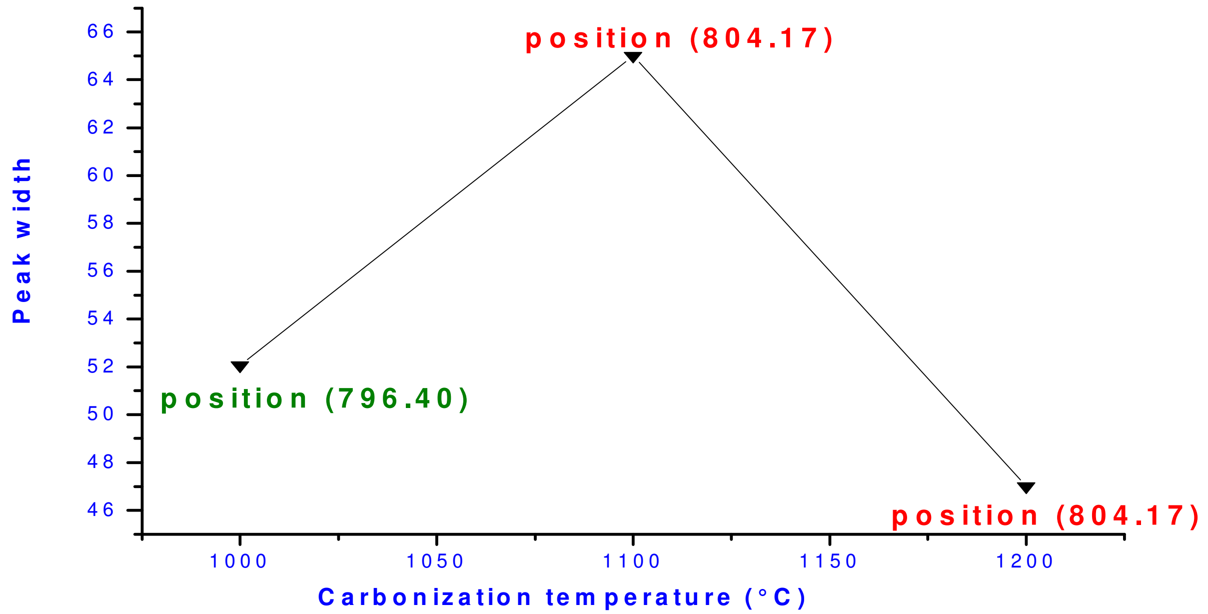
	Gas flow rate (sccm) TCS	Ac.	H_2	Pressure (mbar)	Temperature (°C)	Time (min.)
Carbonization	0	5	50	8×10^{-1}	1000 - 1200	3
GROWTH	25	5	50	1.4	1000 - 1200	10 - 30

Results - FTIR Spectra after Carbonization



Optimum temperature: 1200>T_c >1000

Results - FTIR peak width after Carbonization

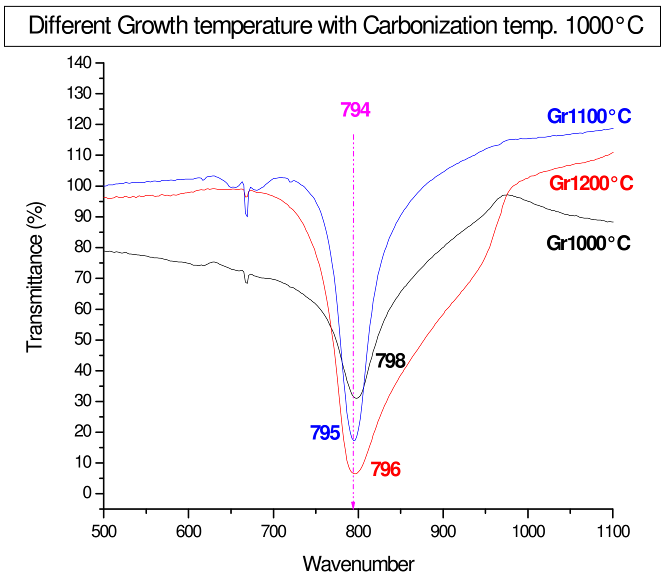


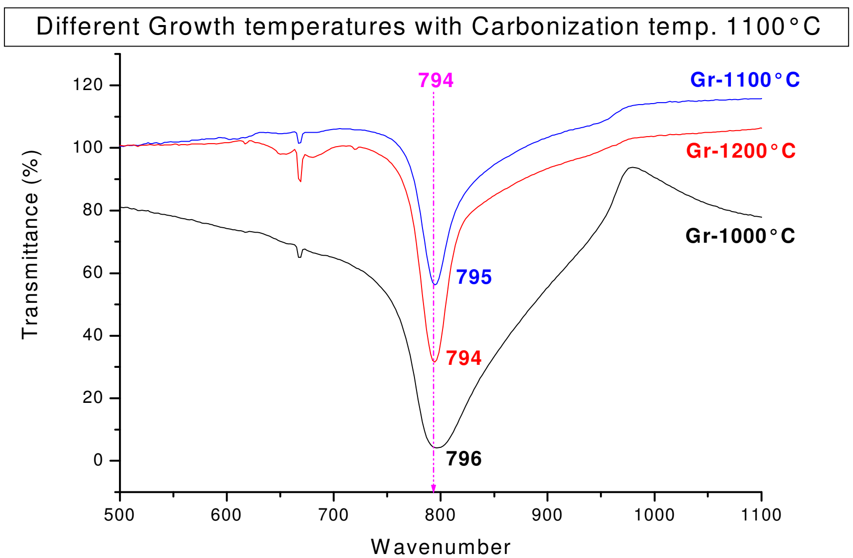
Peak width vs Carbonization Temperature

Note: Carbonization at higher temperature results peaks at higher values

Results - FTIR Spectra after 10 min. Growth

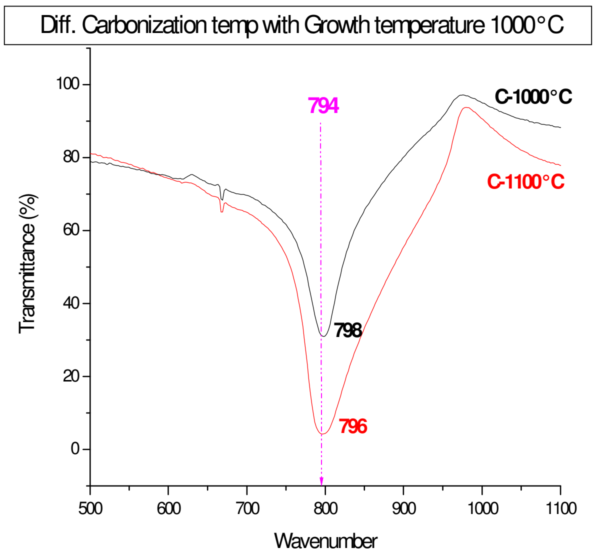
Effect of Substrate Temperature

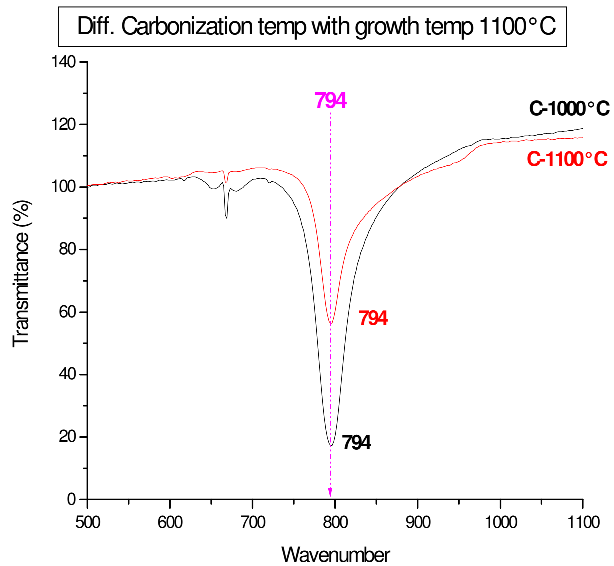


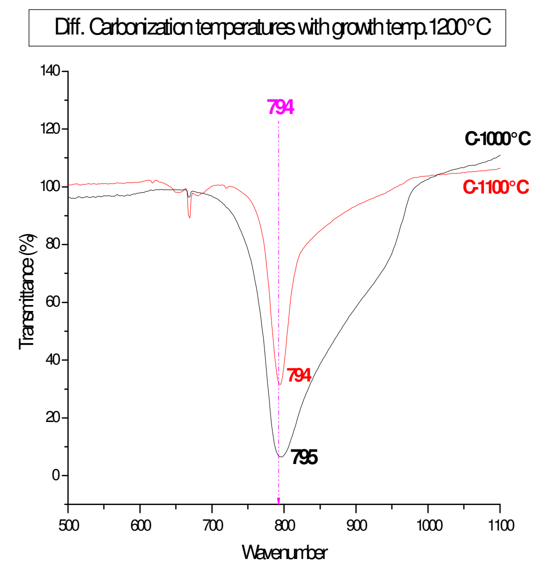


Note: All peaks position is around 795cm^{-1} which corresponds to SiC. Growth at lower temperature shifts the peak position to higher value.

Results - FTIR Spectra after 10 min. Growth







Results - FTIR peak width & Area

WIDTH

Carbonization / Growth	1000°C	1100°C
1000°C	88	123
1100°C	42	38
1200°C	129	32

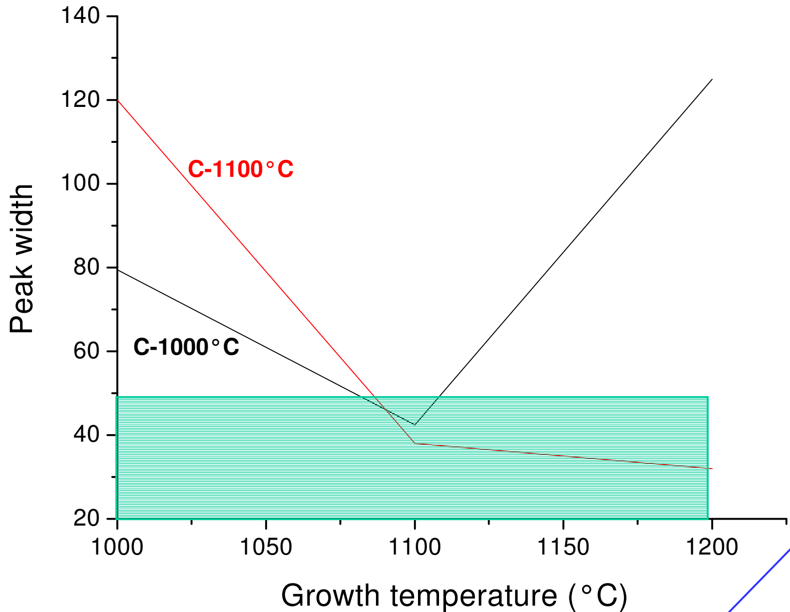
AREA

Carbonization / Growth	1000°C	1100°C
1000°C	9693	15287
1100°C	5450	3462
1200°C	13638	4367

Notes:

1. Both width and area are very large
2. Suitable for our CVD System

Results - FTIR peak width Vs. Growth temperature



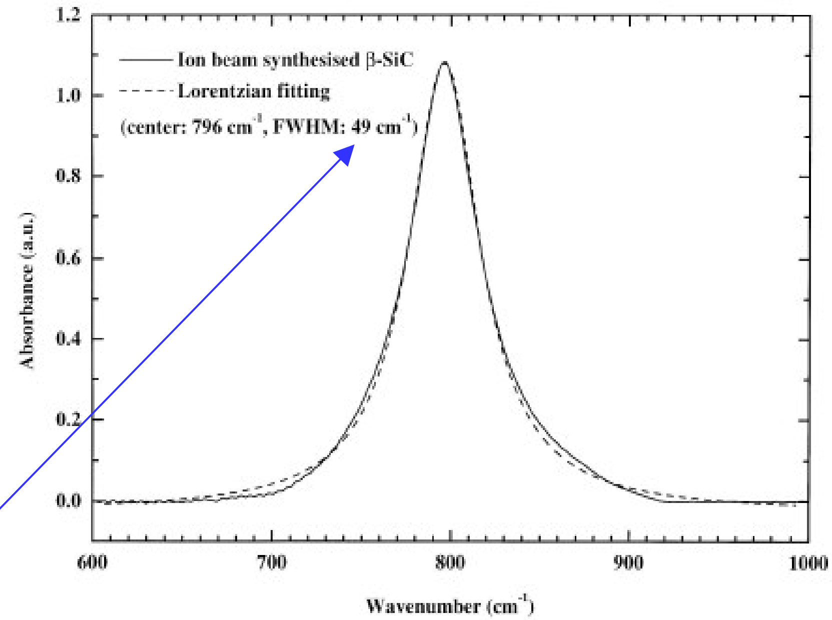
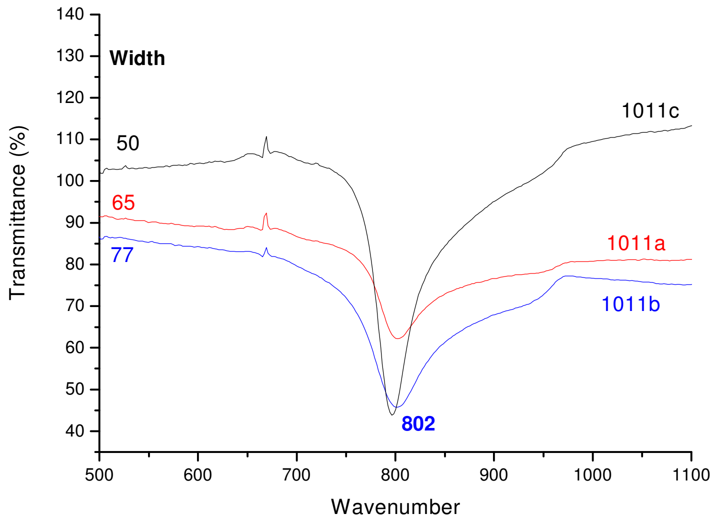
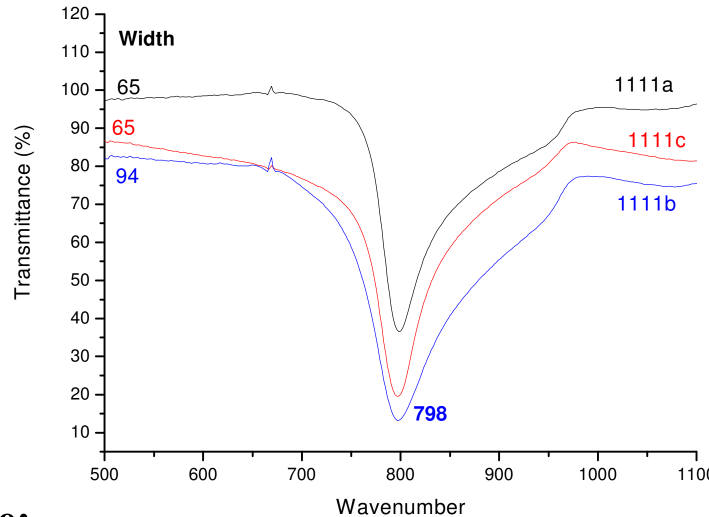


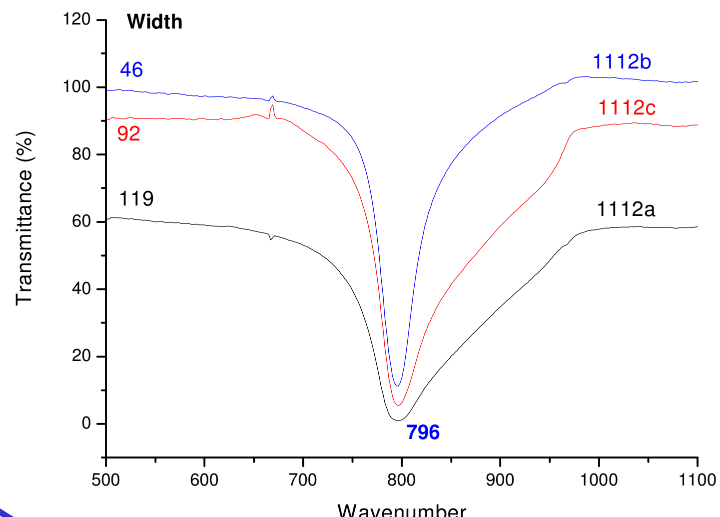
Fig. 1. FTIR absorption spectrum of a crystalline β-SiC buried layer synthesised by multiple C ion implantation at 500°C and annealing (1150°C, 6 h).

Note: Obtained FWHM is below 42 cm^{-1} C. Serre et al Sensors and Actuators 169-173, 74(1999)

Results - FTIR Spectra after 30 min. Growth



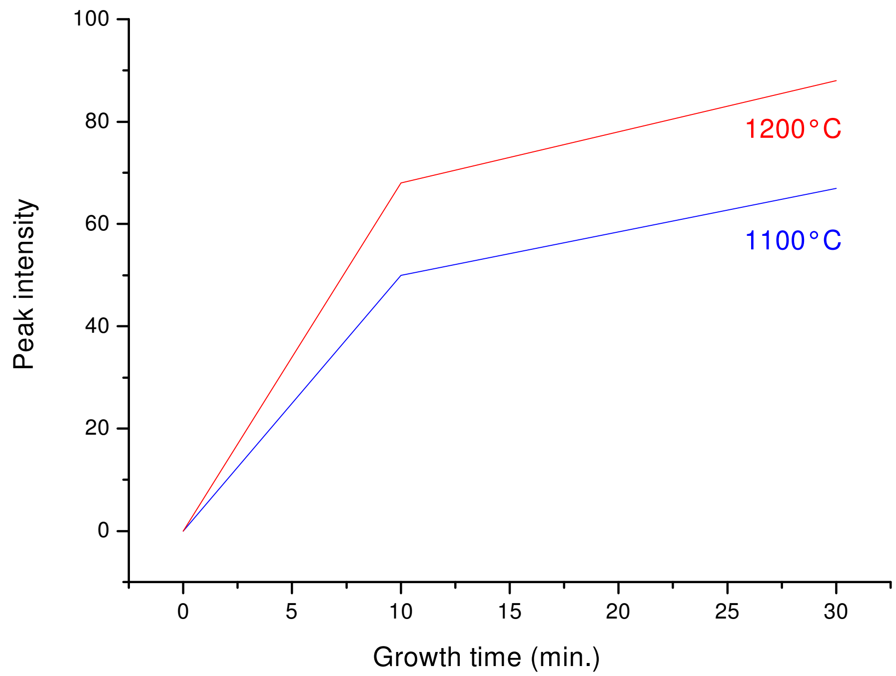




Note:

- Peak positions are consistent for same growth parameters
- Carbonization at 1000°C results higher peak position.
- Carbonization at 1100°C and growth at 1200°C results less strained layers
- Peak intensities are higher as compared to that of layers grown for 10 minutes
- **Sample 1112b was the uniform layer and its ftir peak is also very intence and symmetric.**

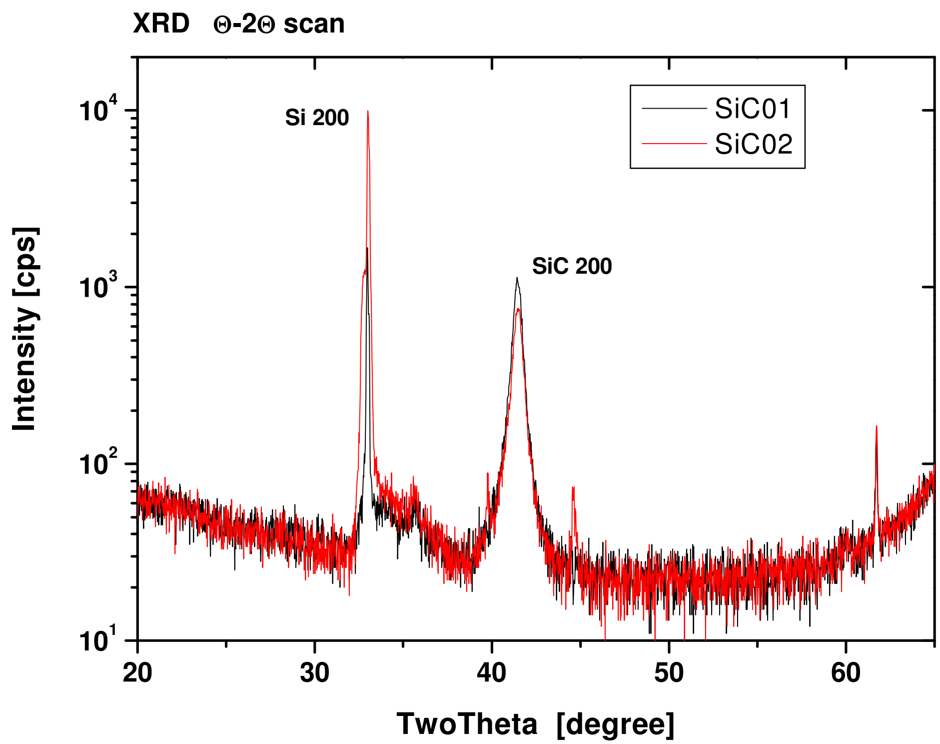
Results - FTIR peak intensity Vs. Growth time



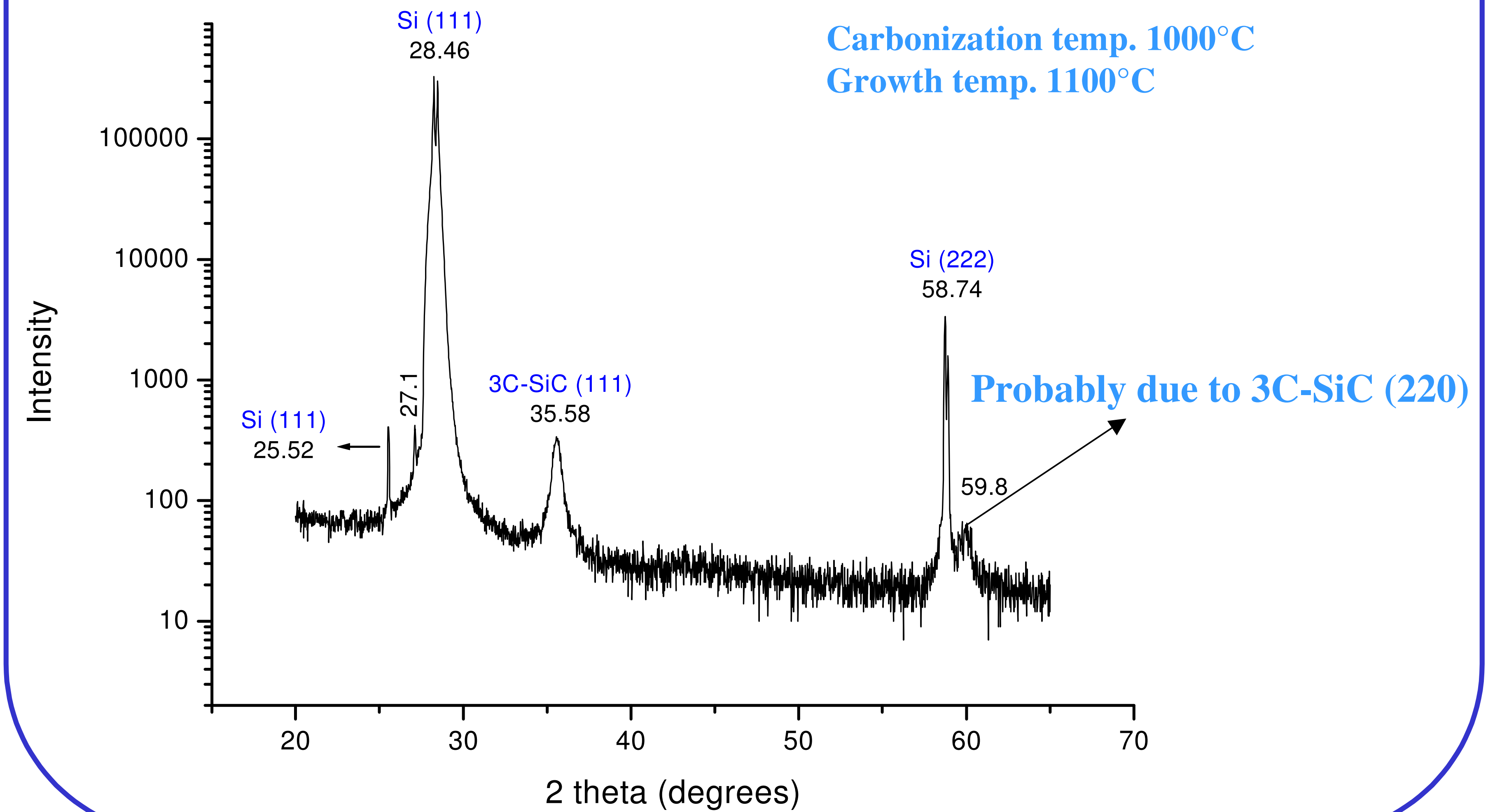
Peak intensity is higher by 25% for 30min. Grown layer

⇒ Thicker layer

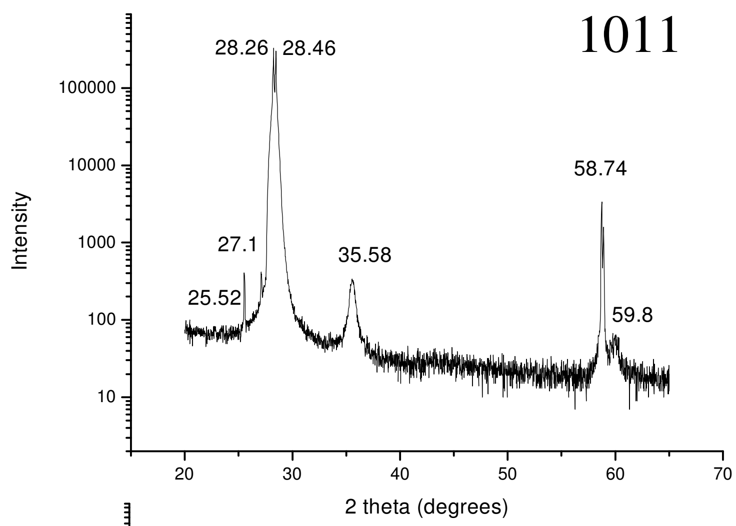
Results - XRD pattern after Carbonization

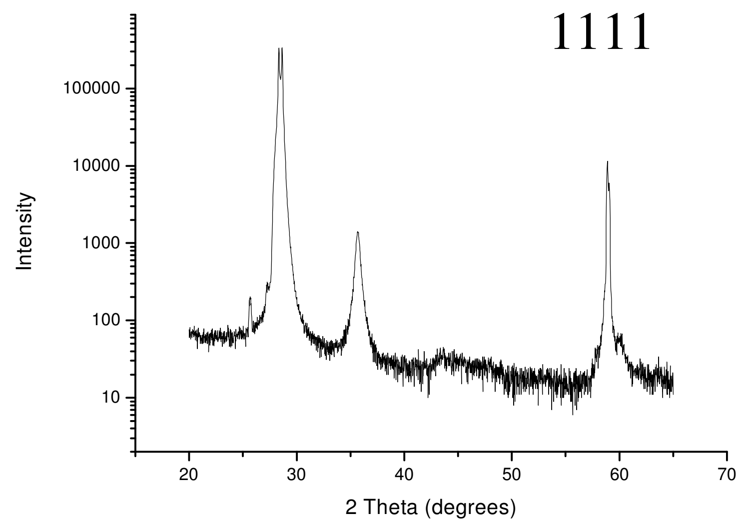


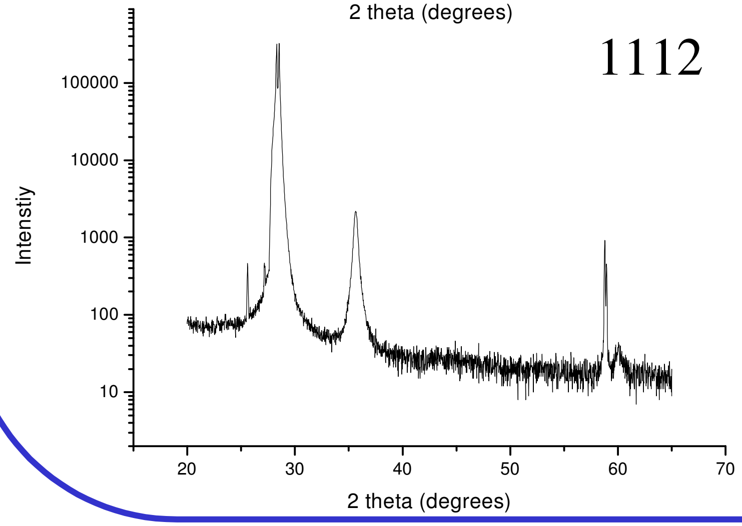
Results - XRD pattern after 30 min. Growth



Results - XRD pattern after 30 min. Growth







Note:

- Layers are probably polycrystalline 3C-SiC
- Peak intensity increases with Carb. temp.
- Peak intensiy/crystallinity increases with Growth temp.

Conclusions

- Films were analysed by XPS, FTIR and XRD
- Substrate temperature was optimized for carbonization and growth
- Epitaxial less strained film was grown on Si(111) substrates

Future Directions .. ..

- Growth on Si (100) substrates for longer time
- Growth on undulated Si substrates
- SiO_2 growth on SiC surface by heating in ambient air
- Electrical contacts (Schottky or Ohmic) suitable for gas sensors

Dankeschön !