Fabrication of SiGe Heterojunction Bipolar Transistors

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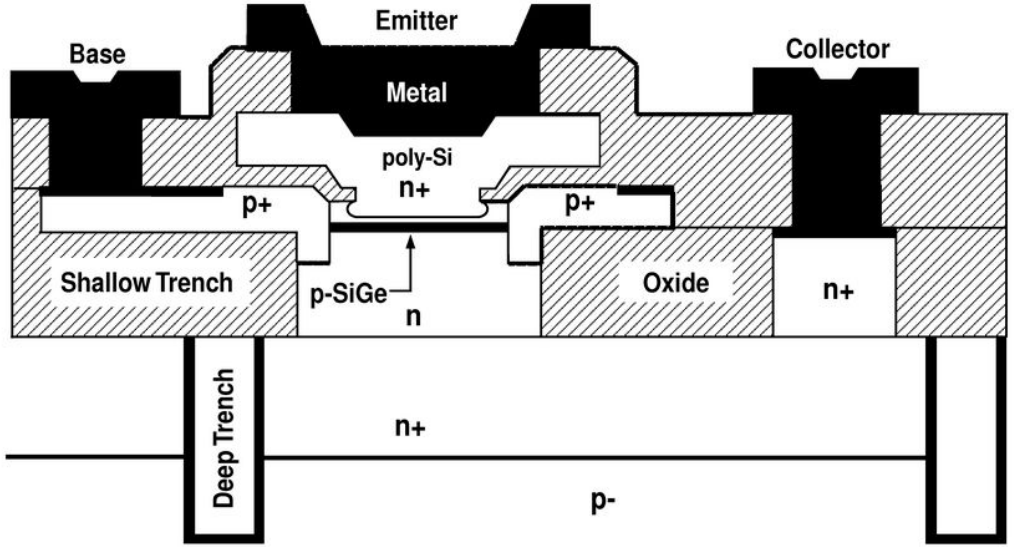
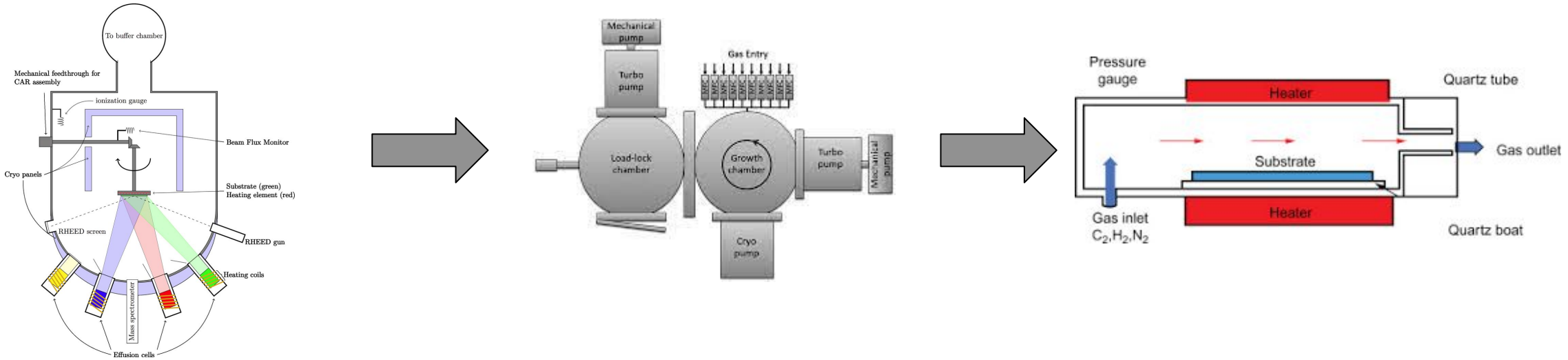
Introduction - What is an HBT?

- Si (N) - SiGe:C (P) - Si (N) bipolar transistor.
  - Allows one to carry out bandgap engineering in Silicon.
- Ge grading allows for variations in bandgap. (III-V like behavior in Si)
- Can integrate with CMOS.
- No more since this is a fab class.



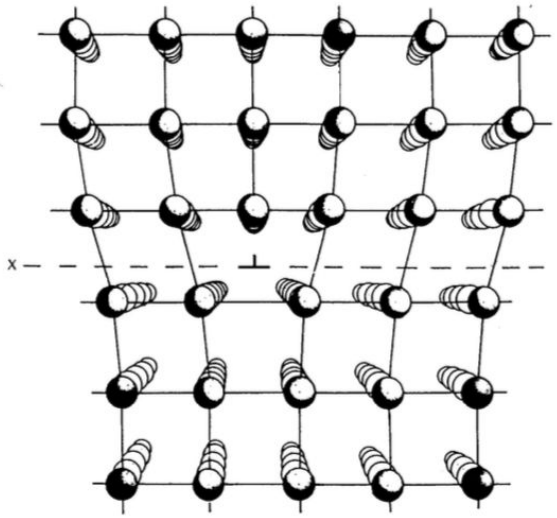
Introduction - History of SiGe Growth

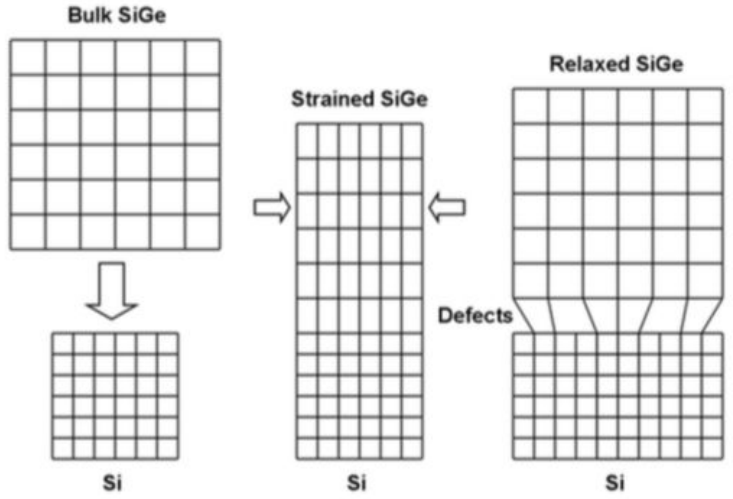
- 1985 - First molecular beam epitaxy grown device (IBM).
- 1987 - First UHV CVD grown device.
- 1990 - First APCVD grown device.
- Noteworthy trend here is epitaxial growth.



Challenges with SiGe Growth

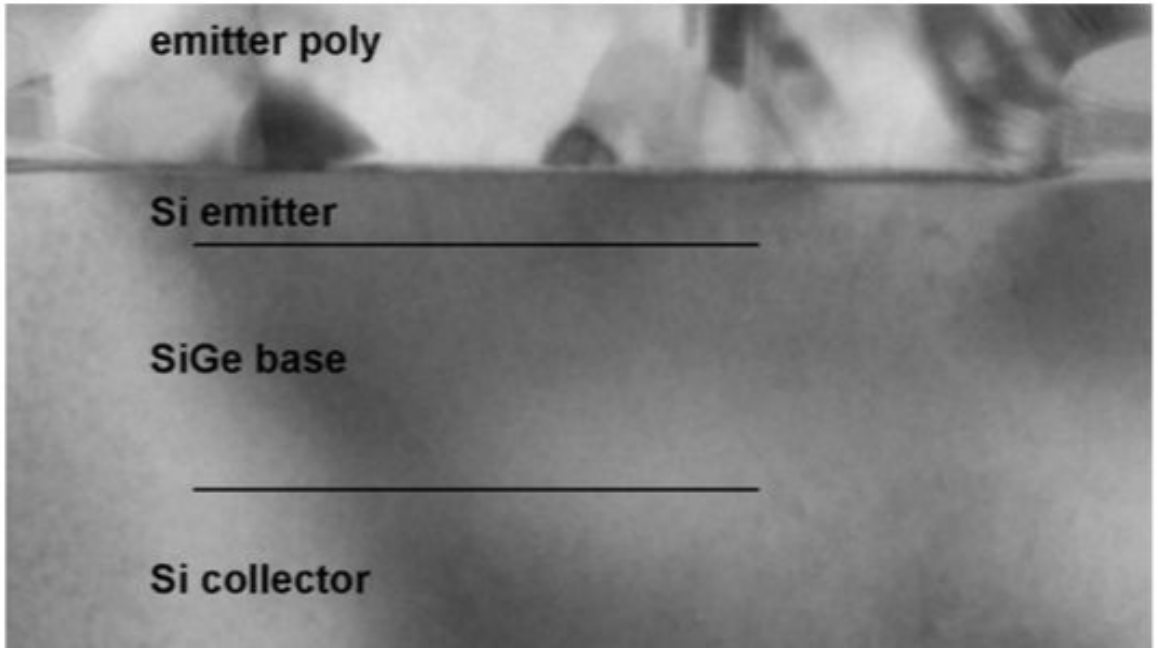
- Different sized crystals, mismatch in lattice constant.
  - Results in strain being put on interface (hence strained layer epitaxy).
  - Too much strain results in defects.
- Can't use high temperatures (>600C) during SiGe epitaxy.
  - Causes unwanted diffusion or relaxation of strained layer (bad).
  - Polysilicon emitter is on purpose (Increased current gain).





Modern Growth

- Utilizes CVD growth for SiGe base layer.
  - Ion implantation for collector (As or P but probably As).
  - In situ doping for the emitter.
  - 4-40 Angstrom/Minute. Control of 1-2 atomic layers across wafer.
- Emitter on top to minimize series resistance/shunt capacitance to the substrate.



General Growth Process - Wafer Cleansing

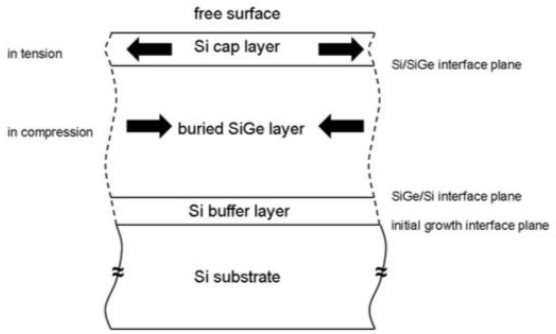
- Need pure wafer for the growth process.
- Can purify in two ways:
  - High heat
  - H20/HF cleansing.
- H20/HF far better if vacuum is available.
  - Only need about 10 seconds in 10:1 H20/HF mixture (compared to minutes at temperature) for low oxide result.
- APCVD uses prebake (10 minutes) and gasous HCL etch.
- Clean wafer important for epitaxy as well as subsequent doping.

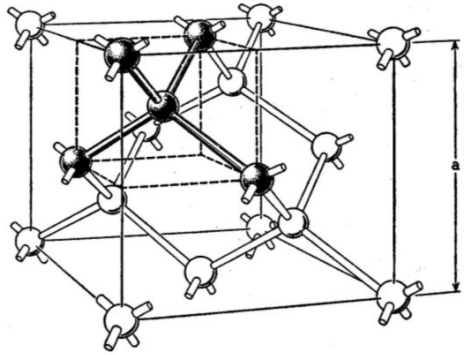
General Growth Process - UHVCVD

- SiGe layer deposited over clean silicon buffer layer.
  - Performed at 400-500 C, 10^-6 torr.
  - Utilize GeH4 in H2 carrier for Ge.
  - Use SiH4 for Si. In APCVD, use SiH2Cl2.
- Some chemistry happens. SiGe pops up.
- Modern process' most likely use RPCVD (reduced pressure) in order to experiment with pressure profile.

Final Result

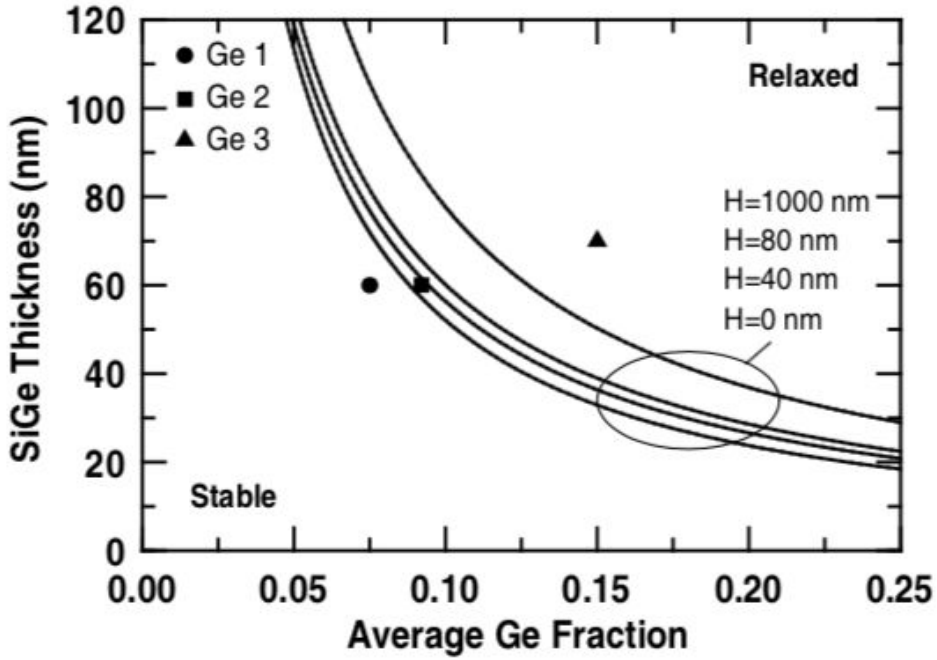
- Si Cap over SiGe base
  - Allows growth of oxide over SiGe (SiGe poor oxidizer).
  - Allows room for base out diffusion, and emitter out diffusion.
  - Provides added stability.
- SiGe Layer
  - Can use Carbon (10^20/cm^3) to reduce out diffusion of Boron.
- Buffer Layer
  - Used to ensure good growth interface.
- Substrate (Si).





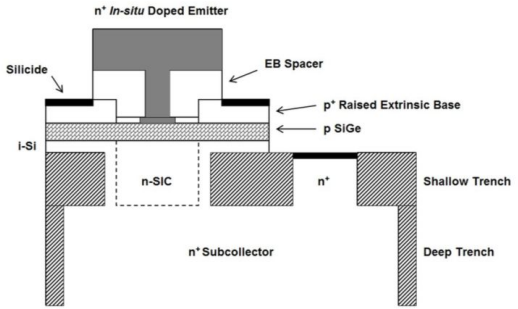
Stability Limits

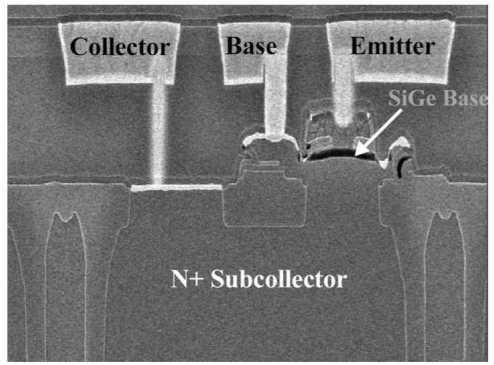
- Some critical SiGe thickness where device fails.
  - Can get very complex very quickly (force vs. energy balance at interface)
  - Practically stability can easily be determined from SiGe layer thickness vs. Ge fraction (more Ge = less stable).



Fun Facts

- Hard to build high Q passives in SiGe.
  - Not so good substrate/dielectric coupling.
  - Can't use gold as a conductor (forms deep traps in Si).
  - Advantage in SiGe over III-V is passives are quite far from substrate.
  - Use Cu instead of Al, lower sheet resistance. (Cu deep trap formation solved)
- When integrating with CMOS use BAG method.
  - Base after Gate.
  - Saves HBT from pain of high temperatures.
- Raising the base physically is favorable (reduces resistance).





Summary

- SiGe HBT is a useful device.
  - Very fast, still get more power output from III-V.
- Various epetaxial fabrication methods.
  - MBE
  - UHVCVD
  - APCVD
- General process is to clean the wafer, then deposit material.
  - How this is done is dependent on pressure/temperature.
- Can get very accurate profiles
- SiGe layer can become unstable quickly. Must consider Ge fraction and layer thickness.

Thank you

Citations:

1. J.D. Cressler and G.Niu, Silicon-Germanium Heterojunction Bipolar Transistors, Artech House, Boston, MA, 2003, 584 pages (ISBN 1-58053-361-2).
2. John D. Cressler, The Silicon Heterostructure Handbook: Materials, Fabrication, Devices, Circuits, and Applications of SiGe and Si Strained-Layer Epitaxy , CRC Press, New York, NY, 2005, 1210 pages (ISBN 0-8493-3559-0).
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