Superconducting layers in silicon

- Get ready for the quantum interference -

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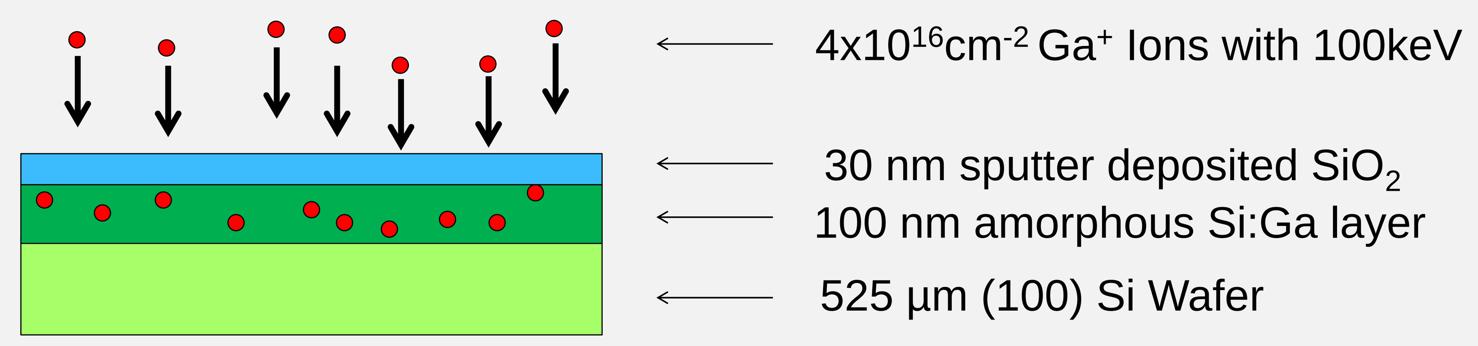
Introduction

- 2004 the superconductivity of doped group-IV semiconductors was discovered [1]
- our group investigated the superconducting state of Ga implanted and short term annealed Ge in 2009 [2]
- for applications in superconducting microelectronics Josephson-Junctions have to be implemented [3]
- superconducting properties have been improved by using Ga precipitation in Si [4][5]
- now we are able to manufacture superconducting circuits with technology compatible to standard microelectronics
- within 3 years we went from fundamental research to a full integrated application

1. Sample processing

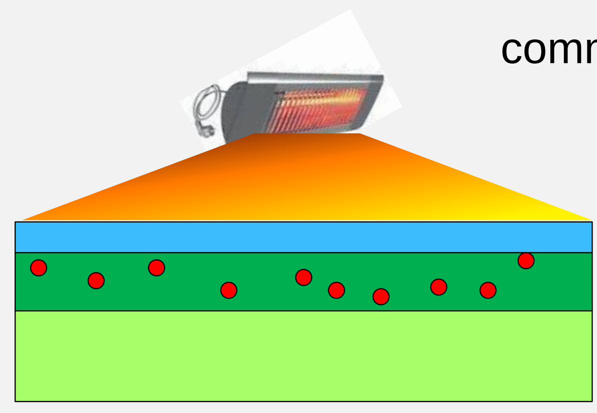
Ion implantation

- is used to integrate a Ga peak concentration of 13 at.% (Gauß-profile).
- during implantation the crystal structure of the substrate is destroyed.



Rapid thermal annealing

- Ga redistribution and layer recrystallization is initiated



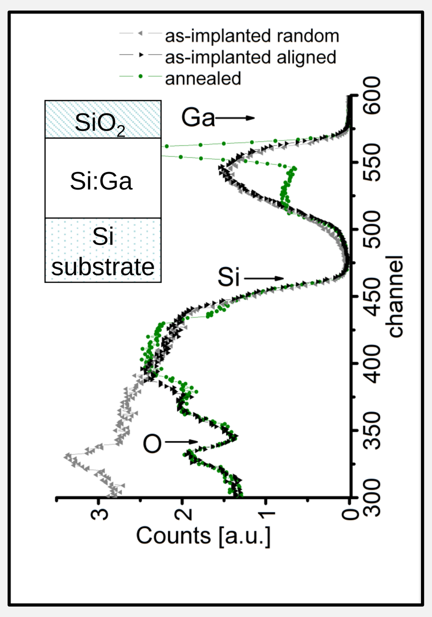
commercial RTA equipment:

temperature: 600 - 700°C
annealing time: 60 sec
atmosphere: Ar

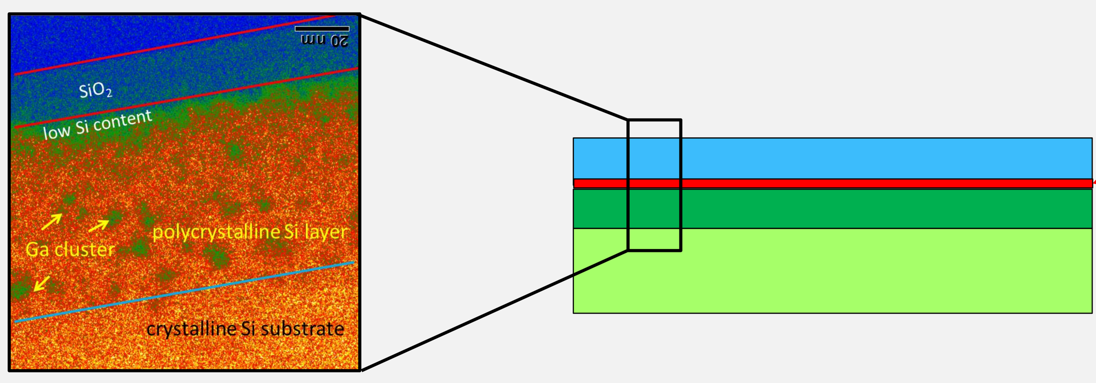
Sample size: 1x1 cm²

2. Layer properties

Microstructure

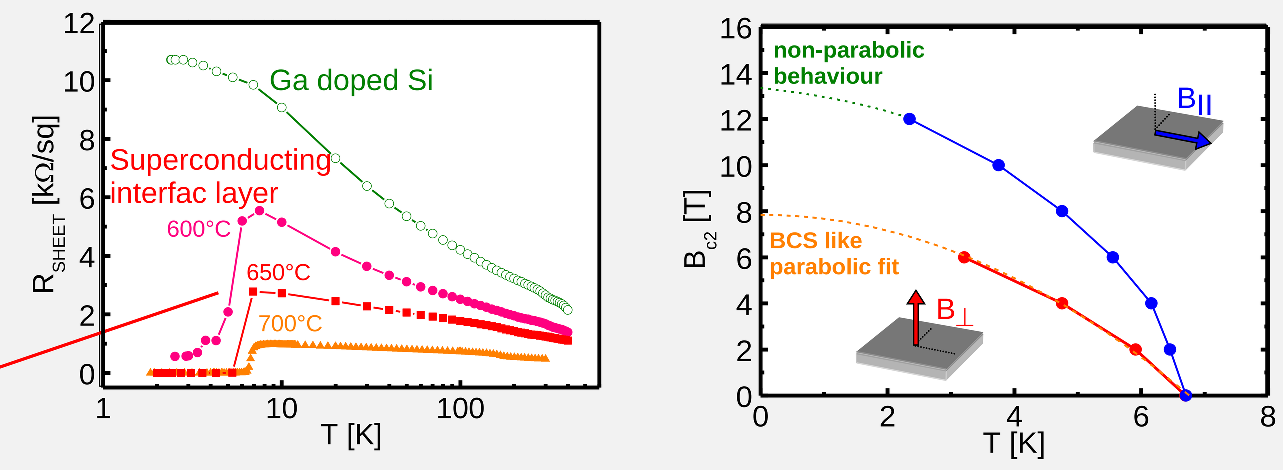


- Rutherford Backscattering Spectroscopy reveals a Ga concentration of 21 at.% at the interface
- Energy filtered TEM indicates Ga-rich precipitates



- the former amorphous layer is polycrystalline after annealing
- amorphous Ga rich layers are stabilized at SiO_2 / Si interfaces
- superconducting properties are comparable to amorphous Ga
- these layers resist environmental influences

Superconductivity

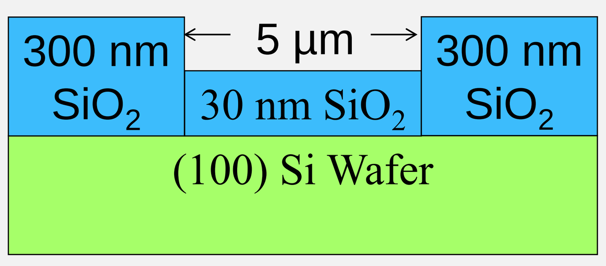


- Ga rich interface layer is responsible for robust superconducting state
- superconductivity occurs below 7 K
- perpendicular critical field: ~ 8 T; parallel critical field: ~ 14 T
- critical current density of 50 kA/cm²
- RTA temperature triggers the superconducting properties

3. Application

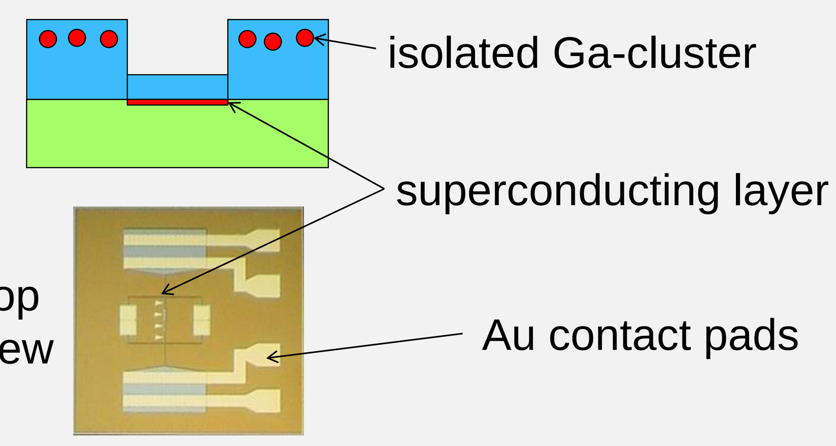
Microelectronic patterning

- 300 nm thermally grown SiO_2
- structured with lithography



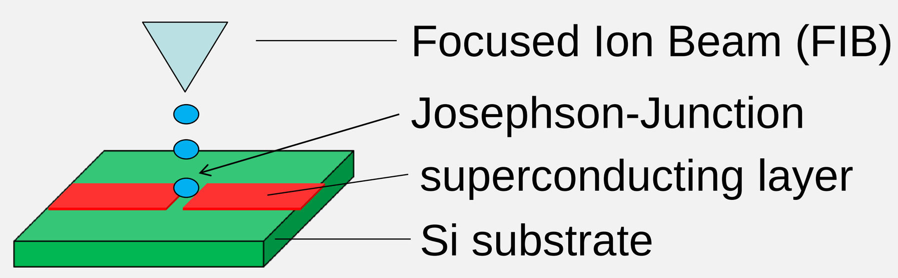
Superconducting circuits

- optimized annealing
- superconducting microstructures



Josephson-Junctions

- next step: implementation of Josephson-Junctions, i.e. superconducting tunnel junctions
- focused ion beam technique is used
- basis for applications as **S**uperconducting **Qu**antum **I**nterference **D**evice (SQUID).



Conclusion

- high fluence ion implantation and annealing is used to produce Ga layers in Si
- the Ga rich interface layers show a robust superconducting state
- microelectronic processing is used to fabricate superconducting circuits
- this approach opens the way to fabricate superconducting and classical microelectronic devices on Si with one well developed technology

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