Integrated Silicon Carbide Photonics for Color Center-based quantum technology and classical applications

Martin Hofmann[1], Patrick Berwian[1], Toby Bi[2], Fabian Magerl[3], Julietta Förthner[1,3], Marina Scharin-Mehlmann[1], Christian Gobert[1], Michael Seidel[1], Christophe Pixius[1], Eberhard Bär[1], Pascal Del'Haye[2], Jörg Schulze[1,3]

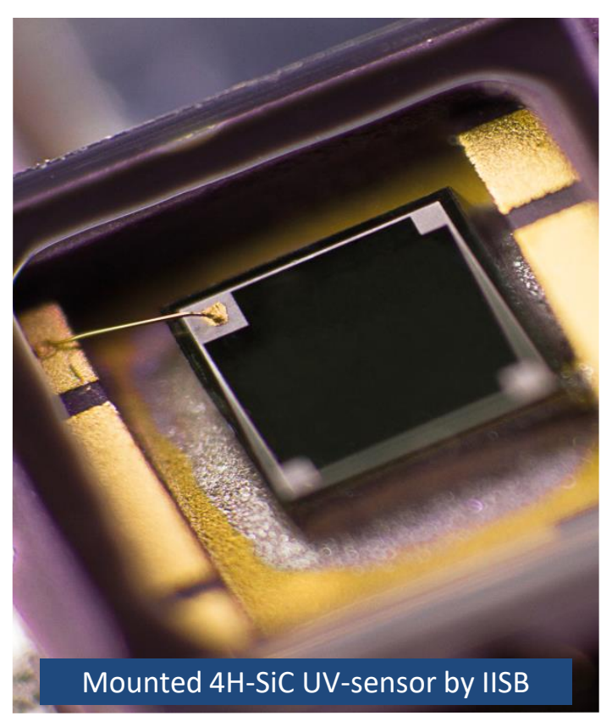
[1] Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Erlangen, Germany
[2] Max-Planck-Institute for the Science of Light (MPL), Erlangen, Germany
[3] Chair of Electron Devices, Friedrich-Alexander-University, Erlangen, Germany

Mature semiconductor technology

Huge demand in SiC power electronics, due to electrification of industry and consumer market

SiC offers high quality substrates and device technology with:

- Large bandgap (2.4 eV – 3.2 eV)
- 8“ wafer availability
- CMOS compatibility
- Customizable material properties by means of epitaxy



QT with Color Center Spin Qubits

Color centers are point defects in semiconductors

Provide a spin system that can be…

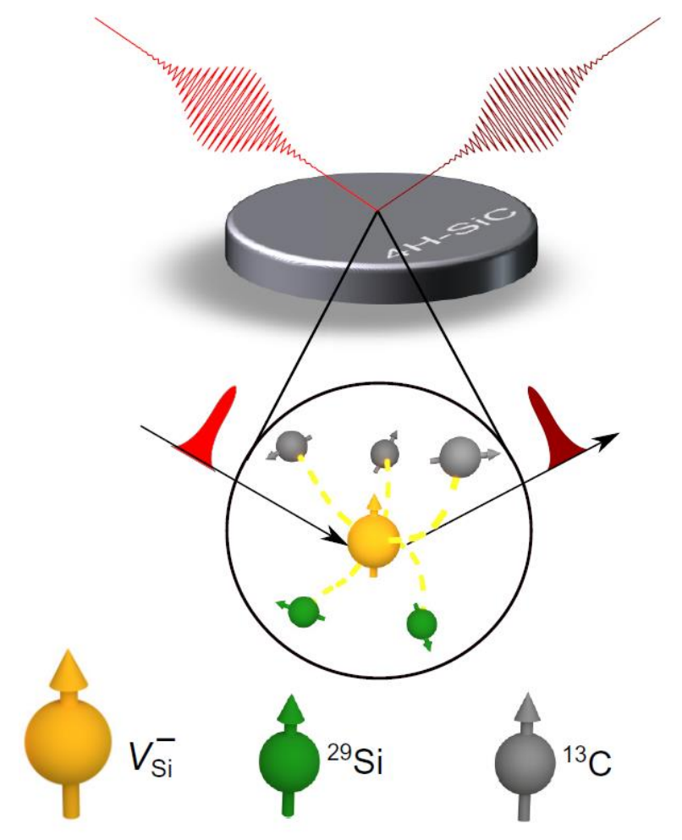
- initialized
- manipulated
- read out via PL

… using a spin-optical interface

SiC QT operation temperature above 4K (even RT)

-> Other platforms operate often in range of few mK

-> Different use cases possible



[1]

Photonics capability

Low waveguide losses possible (compareable to Si)

Nonlinear optics

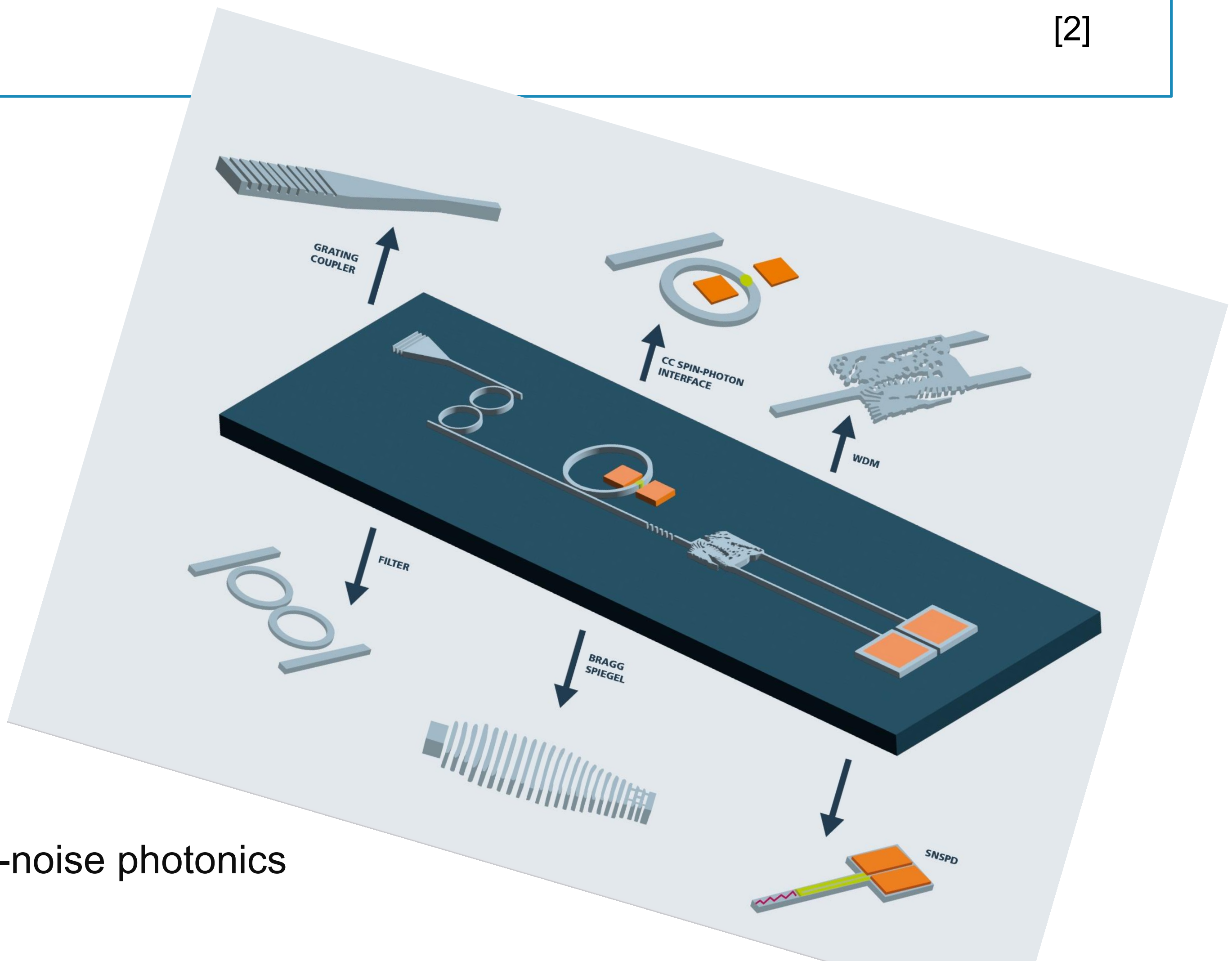
Integration of electronics into photonics possible

	Si	LN	SiC	SiN
Transparent window (µm)	1,1-5,5	0,35-5,5	0,37-5,6	0,4-6,7
Refractive index	3,5	2,2	2,5-2,7	2
Second-order nonlinearities (pm/V)	-	27	12	-
Electro-optic coefficient (pm/V)	Carrier plasma effect	30,8	1,8	Close to 0
Third-order nonlinearities (x10^{-20} m^2/W)	400	18	23-91	25
Waveguide losses (dB/cm)	0,3	0,027	0,38	0,01

[2]

Silicon Carbide is an excellent platform for (Quantum) Photonics Technology

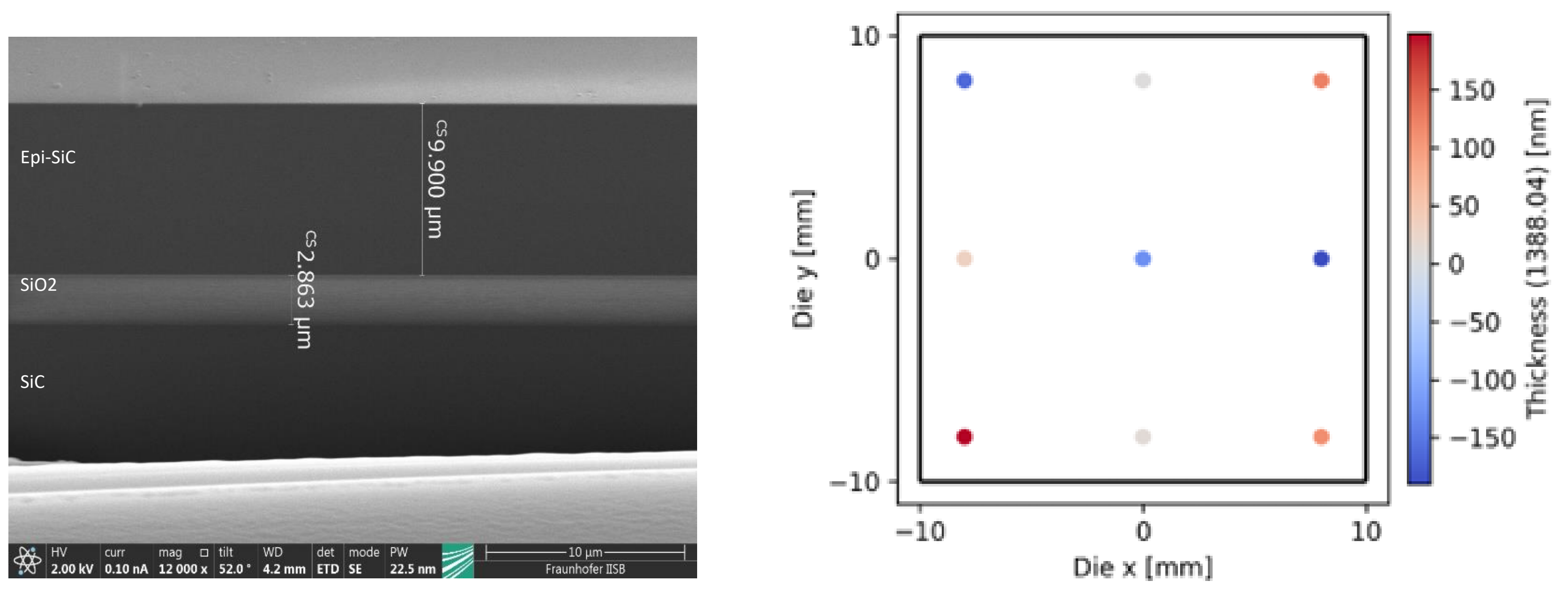
Integrated Photonics and **Color Centers** allow
basic devices such as switches, waveguides, filters and diodes
up to complex quantum photonic integrated circuits (QPIC)
on the same chip



Three substantial challenges must be addressed:

a) Fabrication of SiC-on-Insulator (SiCOI) stacks, for light confinement
b) Optimization of material interfaces and suppression of surface-related optical background for low-loss and low-noise photonics
c) Demonstration of integrated photonics for e.g., color center tuning by Stark shift or electro-optic modulators

SiCOI substrate fabrication



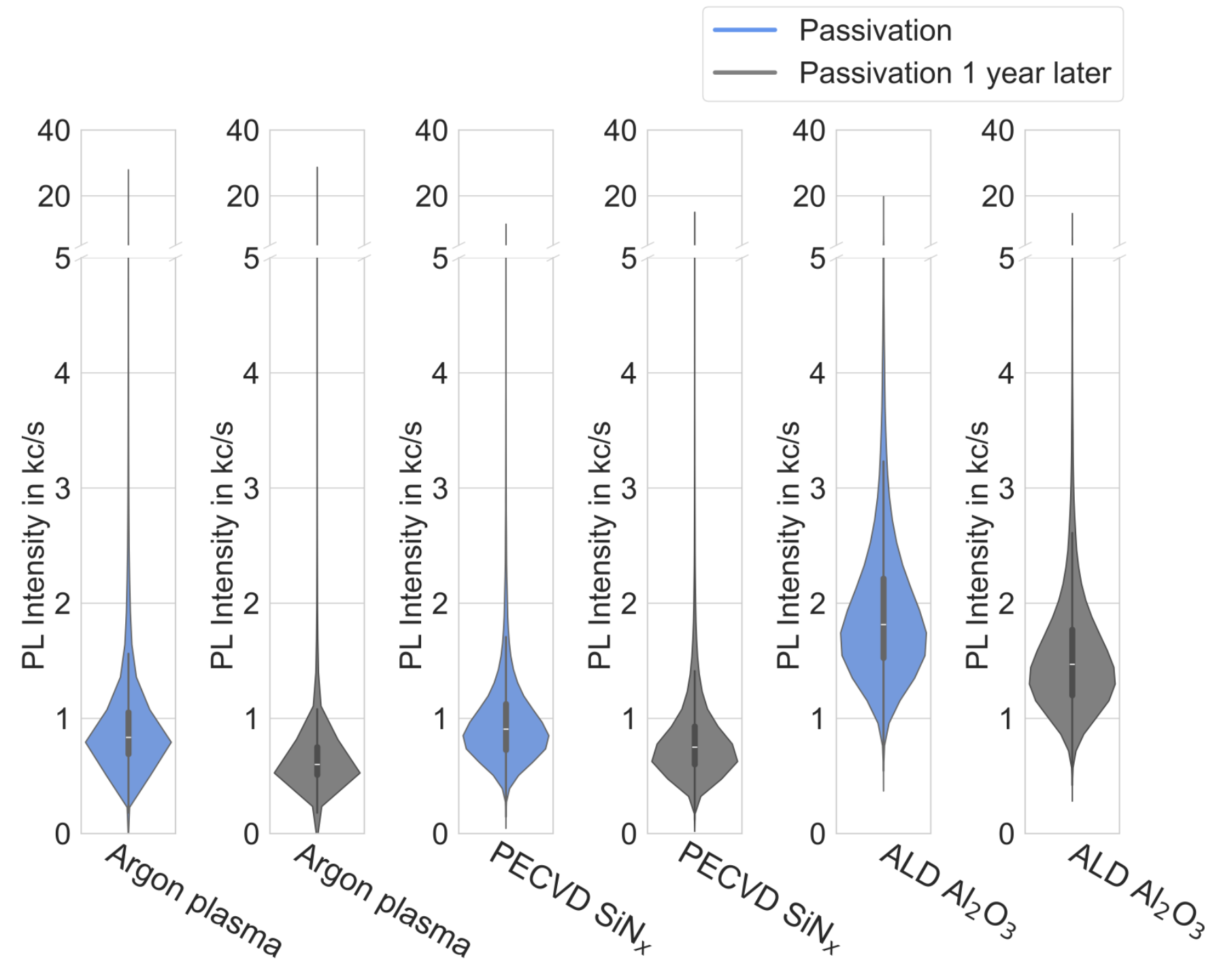
Thin-film **SiCOI substrates** for quantum photonic device production **are available**.
Fabrication scheme contains wafer bonding, grinding, CMP and RIE thinning

SiC surface modification

Comparative study of Al_2O_3, SiN_x and SiO_2 dielectric passivation layers on SiC, including plasma-modified surfaces.

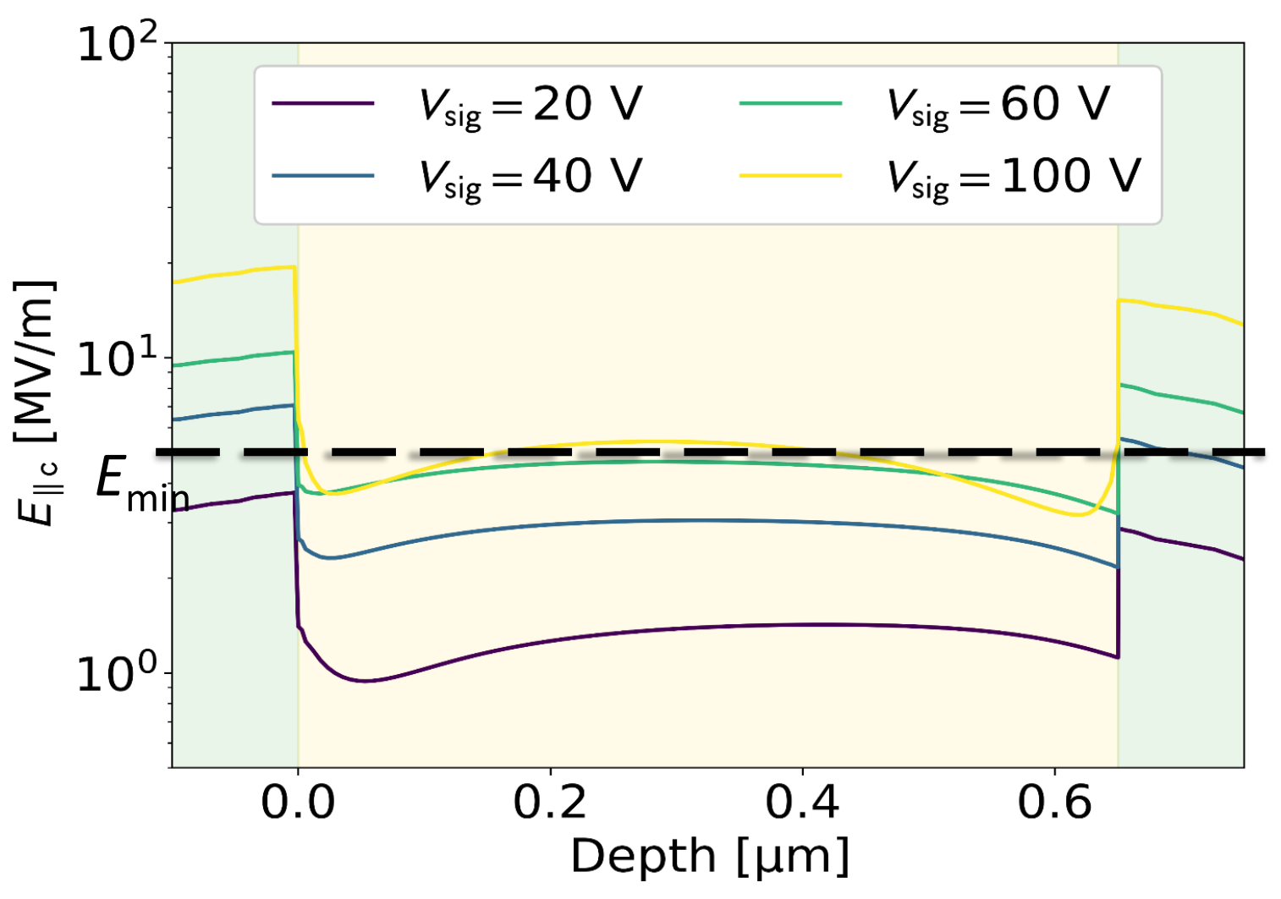
Proper **passivation enables chemically stable SiC surfaces** with **reduced optical background**.

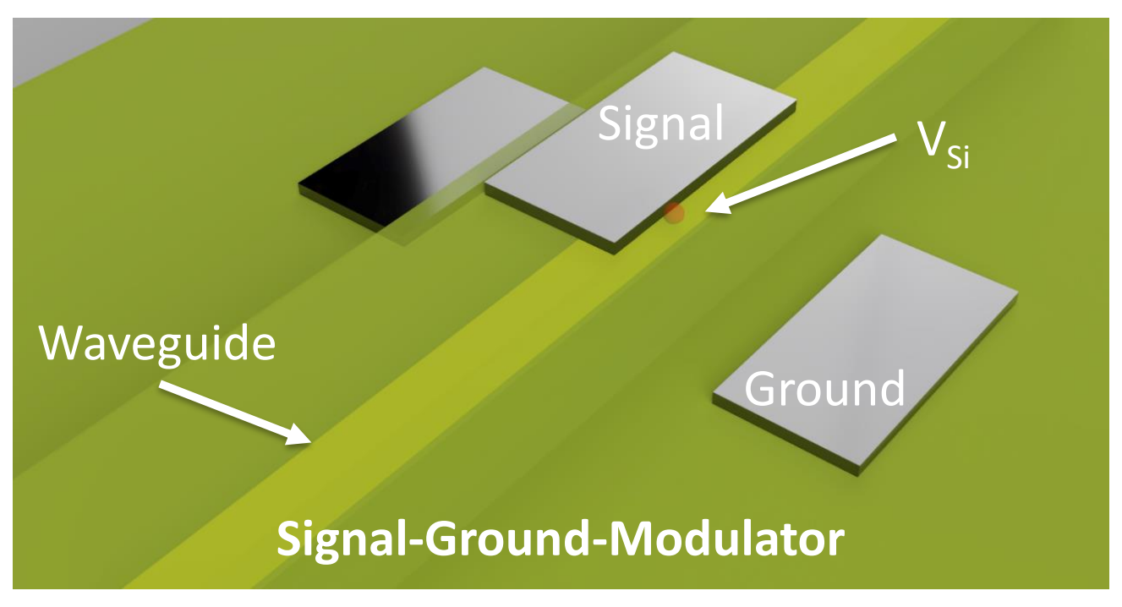
Atomic layer etching (**ALE**) of SiC **for waveguide smoothing** → Poster number 14100-79



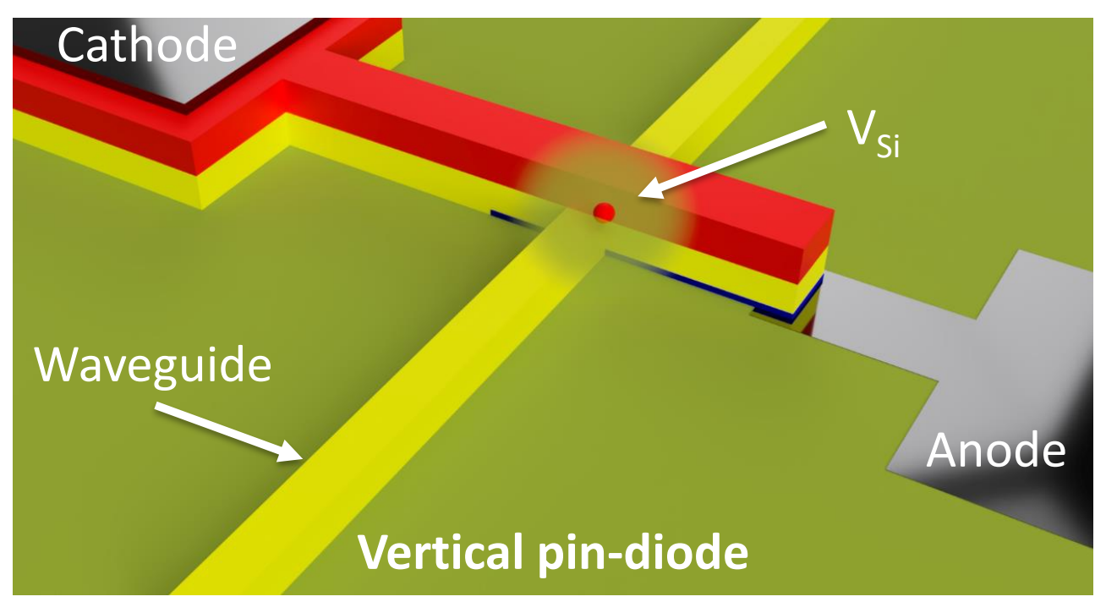
Novel device design for (quantum) integrated photonics

In **Signal-Ground-Modulators**, most of the electric field is concentrated across oxide cladding (green region in figure below)

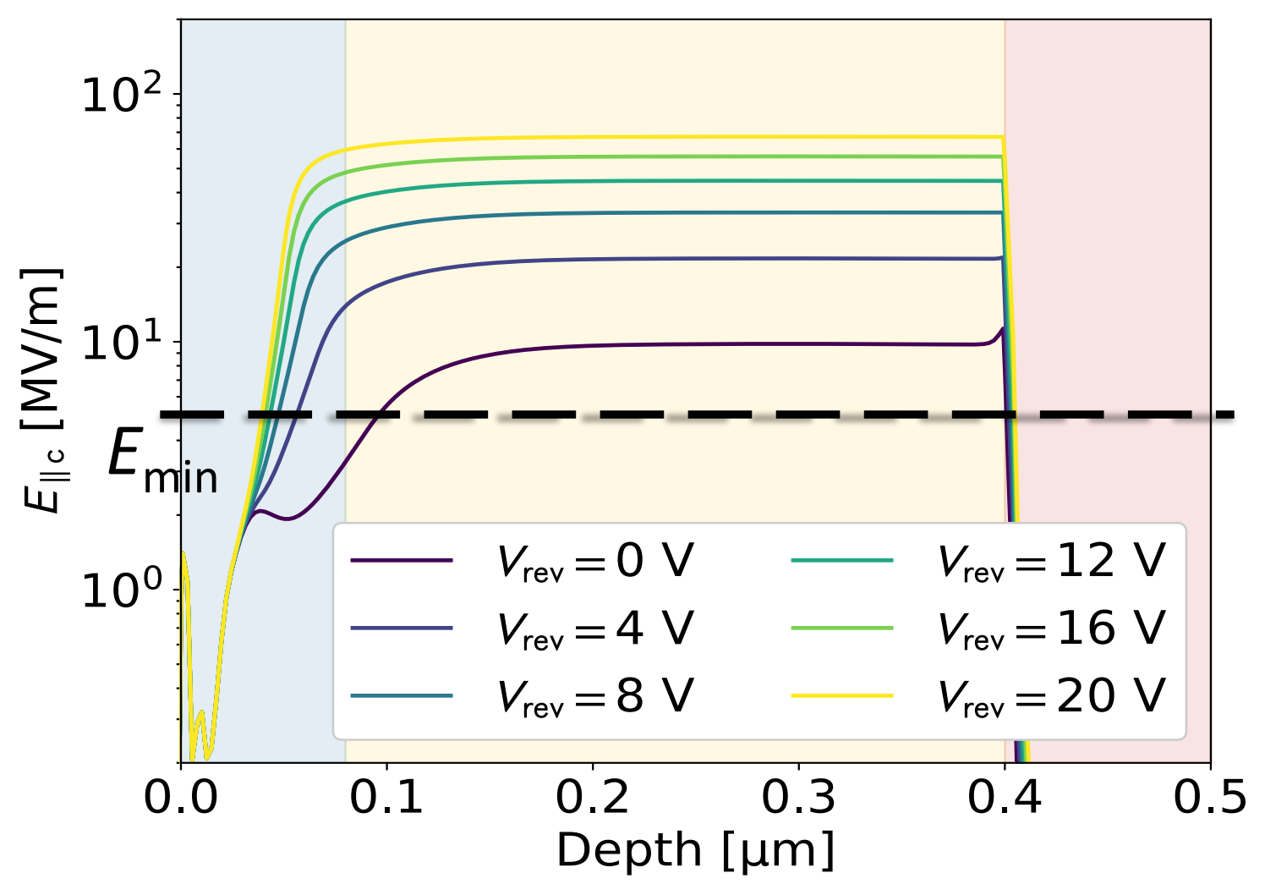




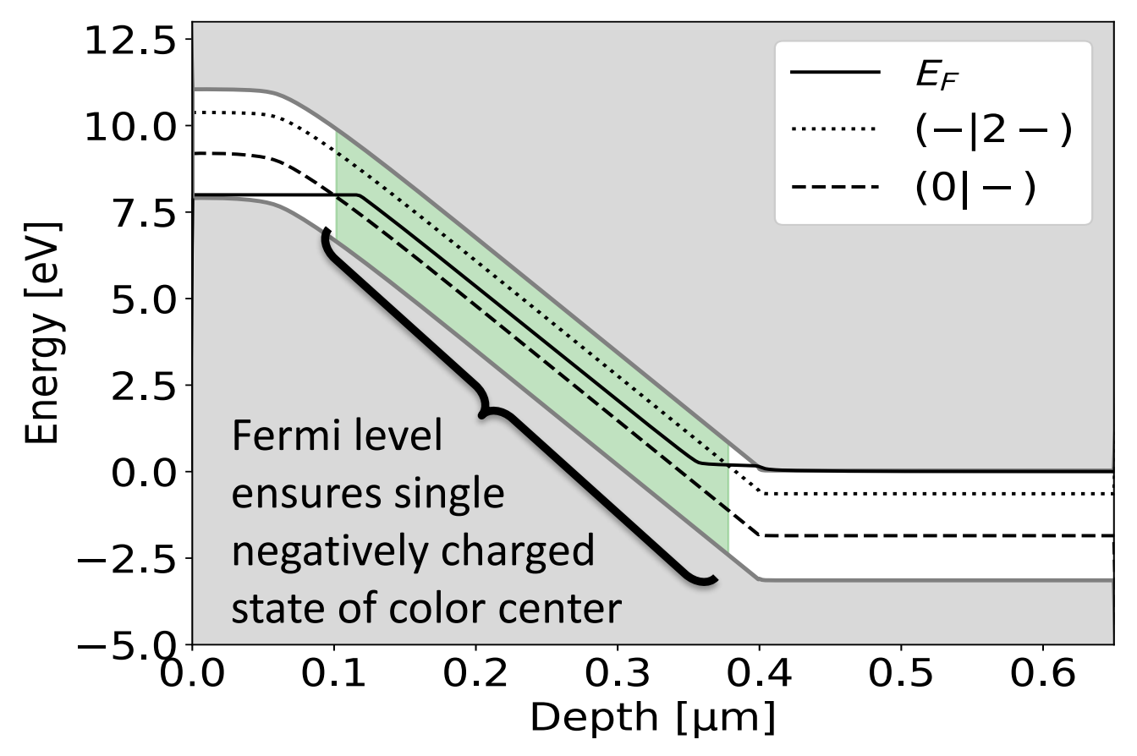
Maximum achievable electric field strength scales with waveguide height H and bandgap E_g due to **Fermi level pinning** at the interfaces



PIN-diodes have already shown promising results regarding V_{Si} Stark shift, charge state control and linewidth stabilization



In thermal equilibrium the intrinsic layer of the pin-diode offers a wide region to host V_{Si} in optically active charge state (see green region below)



Shown above, the pin-diode **reaches the required field strength** in the intrinsic region (yellow) at **substantially lower voltages** than the signal-ground-modulator, making it more suitable for quantum photonic integrated circuits

Acknowledgements

One project is part of the Munich Quantum Valley, supported by the Government of Middle Franconia (Bavaria), project number RMF-SG20-3410-7-3-3

One project is funded by the Deutsche Forschungsgesellschaft DFG as part of QuantERA project number FO1604/1-1

References

[1] Parthasarathy et al., „Scalable Quantum Memory Nodes Using Nuclear Spins in Silicon Carbide“, Phys. Rev. Applied 19, 034026 (2023). DOI: https://doi.org/10.1103/PhysRevApplied.19.034026

[2] Boretti et al., „Pioneering the future with silicon carbide integrated photonics“ Optics & Laser Technology 181 111910 (2025). DOI: https://doi.org/10.1016/j.optlastec.2024.111910