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# A Simulation Study of Electronic Device Designs for the Control of SiC Color Centers as Spin Qubits

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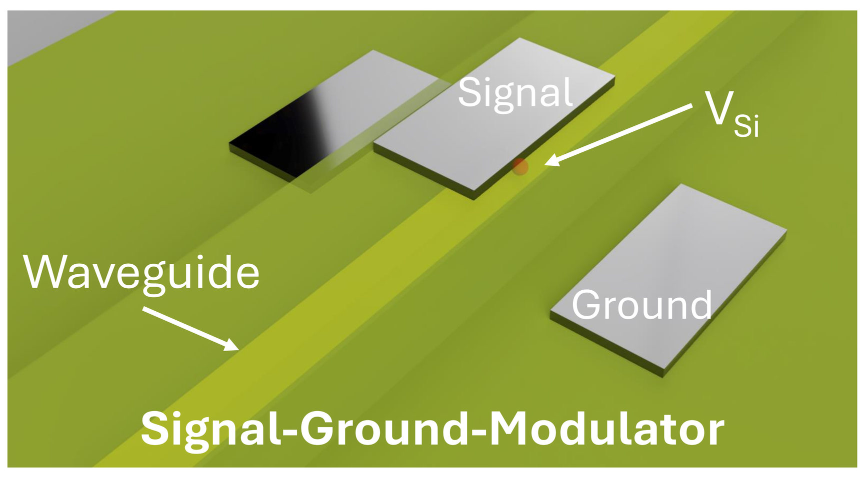
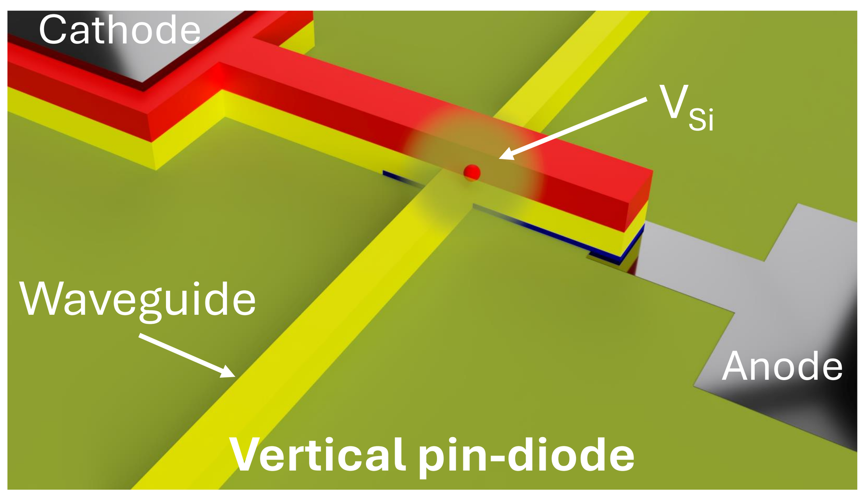
## Motivation & Toolbox

- The negatively charged silicon vacancy ($V_{Si}$) in 4H-SiC is a promising spin-qubit for quantum technologies [1]
- Entanglement requires indistinguishable photons, but typically V1's show a spectral distribution of ca. ±10 GHz [2]

→ Minimum field strength required to shift two V1 centers via Stark tuning between 5 and 20 MV/m [3,4]

→ **Which device structures are most suitable to achieve electric field control and $V_{Si}$ charge stabilization inside a single-mode waveguide?**

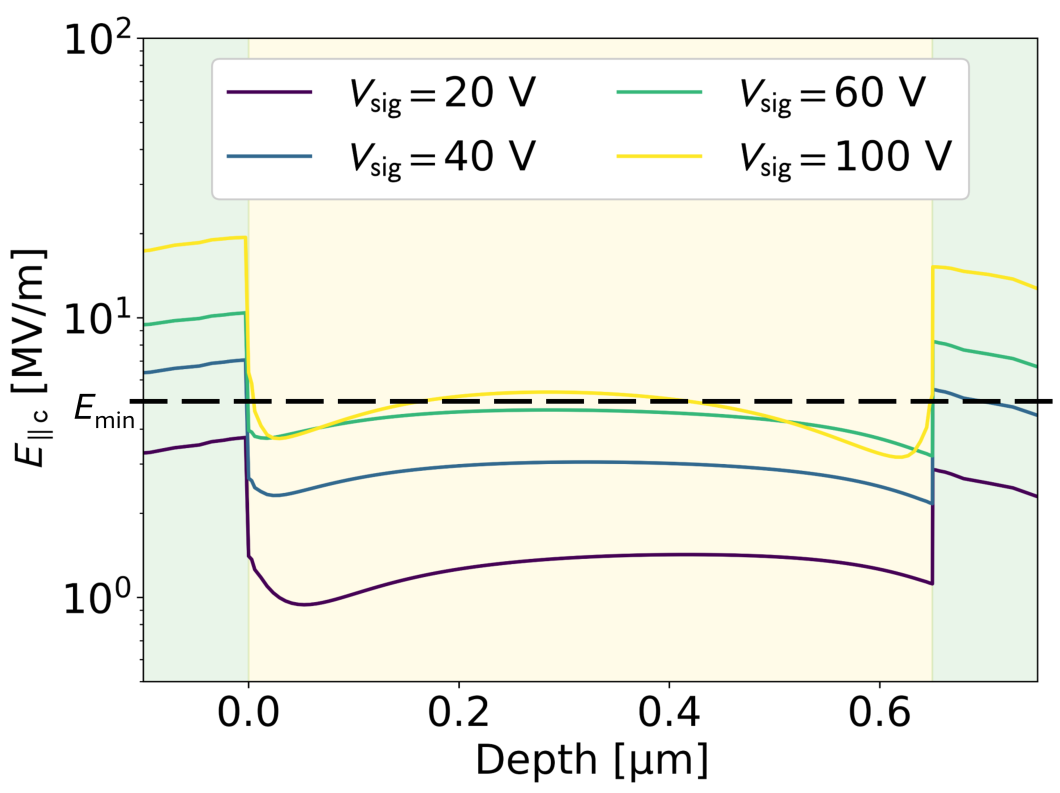



- We investigated a signal-ground-modulator and a vertical pin-diode in 4H-Silicon Carbide on Insulator in combination with an on-chip single-mode waveguide (see left)
- 2D and 3D electronic and optical device simulations were performed using Synopsis Sentaurus and Ansys Lumerical Mode FDE

## Signal-Ground-Modulator

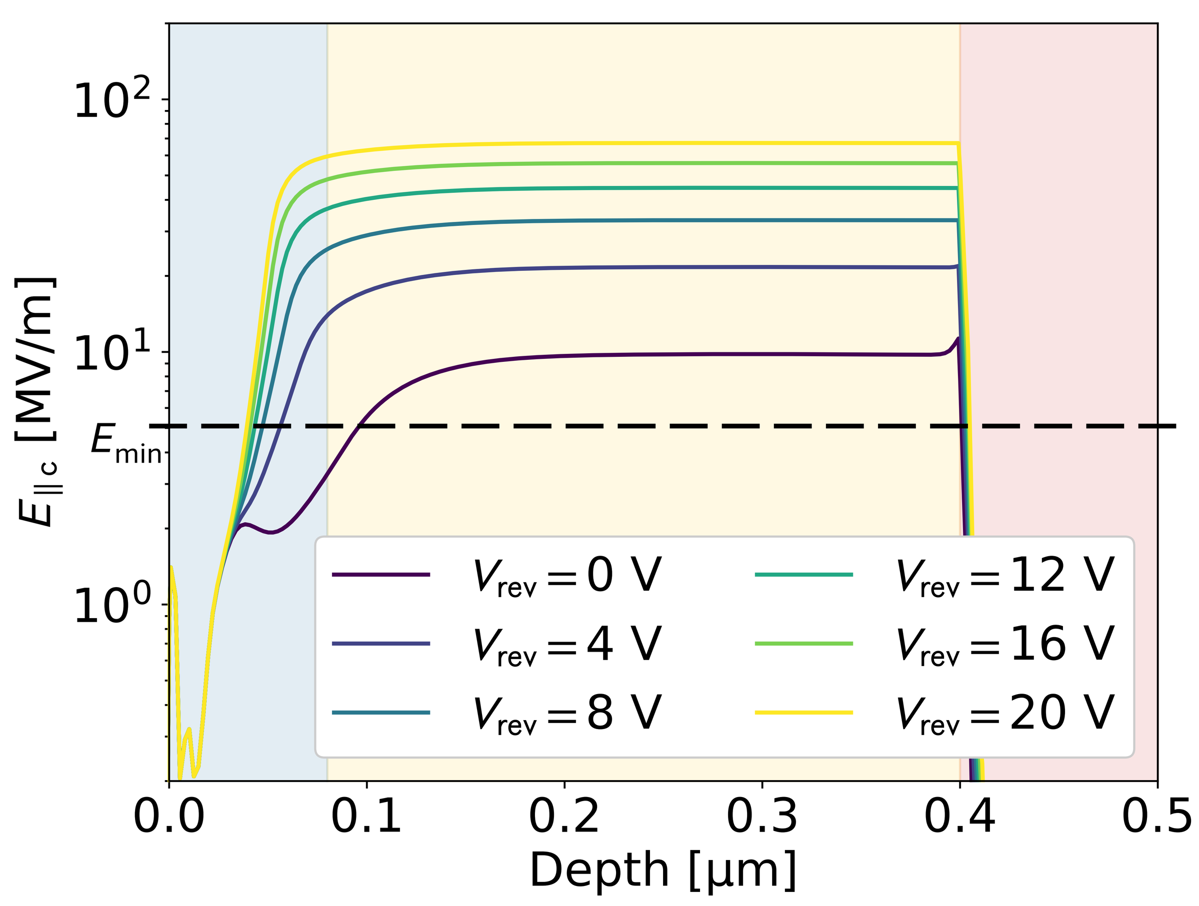
- Most of the electric field is concentrated across oxide cladding (green region in figure below)



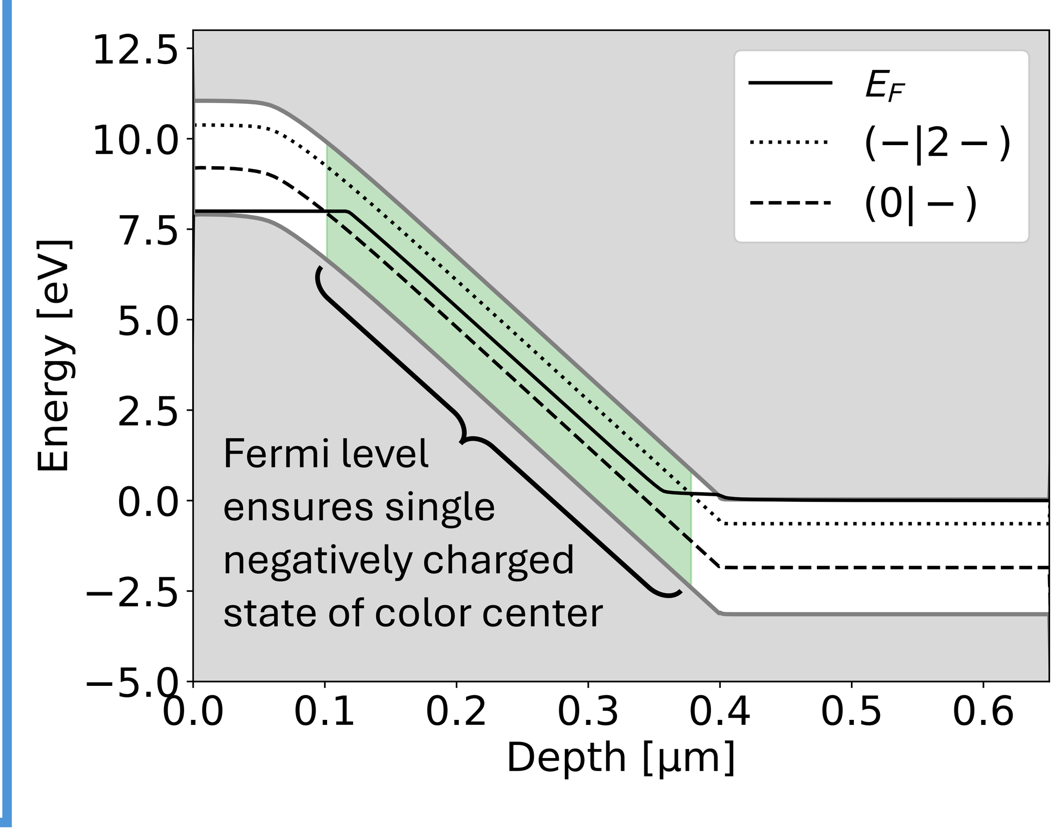

- Maximum achievable electric field strength scales with waveguide height *H* and bandgap $E_g$ due to **Fermi level pinning** at the interfaces

## Vertical pin-Diode

- $V_{Si}$ in pin-diode has already shown promising results regarding Stark shift, charge state control and linewidth stabilization [3,5]




- 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

**→ Signal-Ground-Modulator barely attains the lower limit of the required electric field strength within the waveguide**

**→ Vertical pin-diode offers both high electric field for Stark tuning and a wide region for single negatively charged $V_{Si}$**

[1] Fang, R.-Z. et al., Physical Review Letters, 132(16), p. 160801, (2024)
[2] Nagy, R. et al., Applied Physics Letters, 118(14), p. 144003, (2021).
[3] Rühl, M. et al., Nano Letters, 20(1), pp. 658–663, (2020).
[4] Bathen, M.E., et al., Journal of Physics: Condensed Matter, 33(7), p. 075502, (2020).
[5] Widmann, M. et al., Nano Letters, 19(10), pp. 7173–7180, (2019).

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