An open-source stack for integrated photonic circuits design and simulation?

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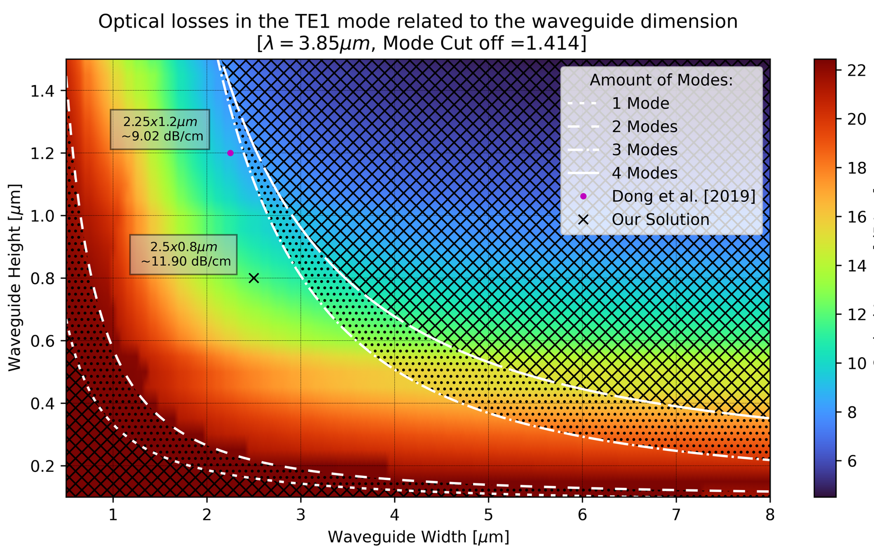
1. INTRODUCTION

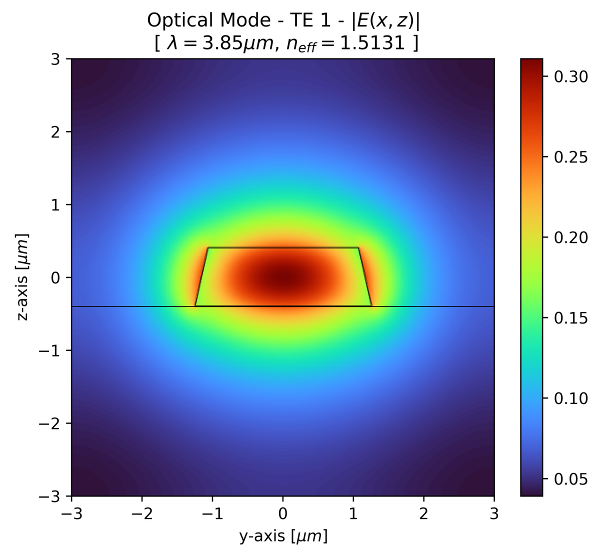
CONTEXT: Silicon-photonic market **explosive growth** will bring new players looking for affordable design tools. Free and Open-Source Software (**FOSS**) offer **a viable alternative** to standard proprietary solution.

PROJECT: Using those FOSS tools we implemented **an Aluminium Nitride (AlN) process design kit (PDK) for mid-infrared application**. The goal is to create a **complete & efficient design workflow**.

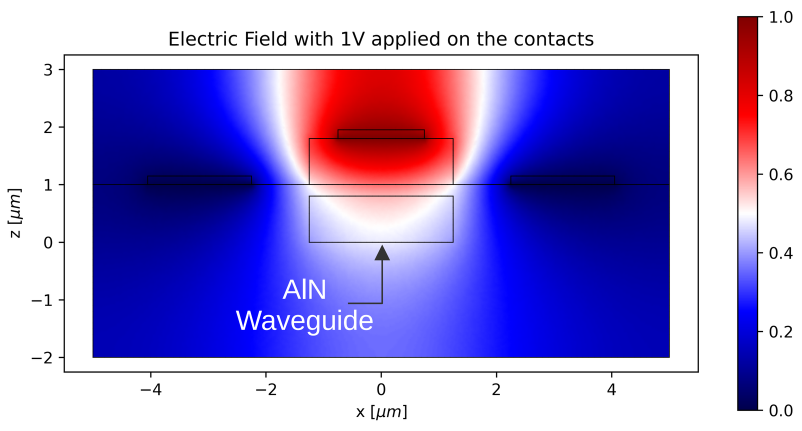
2. WAVEGUIDE DESIGN

STEP 1: Using **Tidy3d** mode solver we define our passive waveguide dimension by **considering simulated polarization and optical losses**:



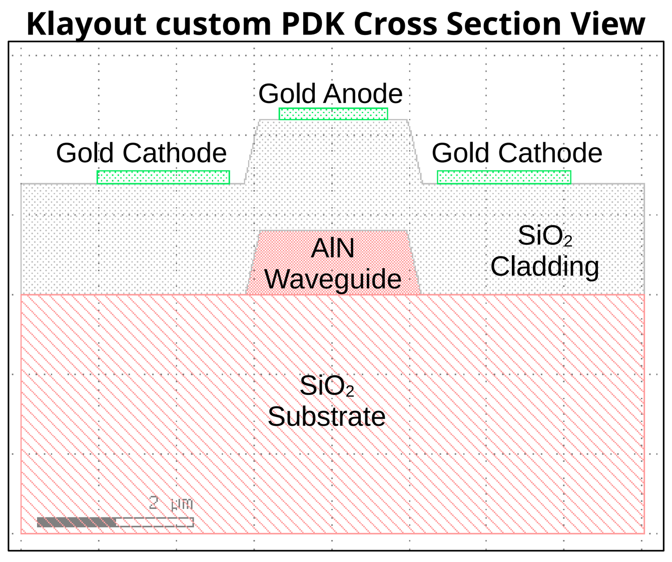


STEP 2: We simulate the AlN electro-optic effect with **FEMWELL** coulomb solver. A **swarm optimization** found the **optimal gold contacts dimensions and placement** to maximize the Δn_{eff} modulation:



STEP 3: Results are implemented in a custom **GDSFactory** Layer Stack:

Klayout custom PDK Cross Section View

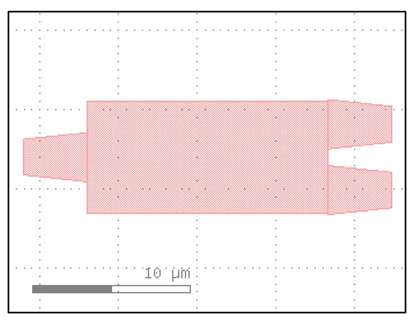


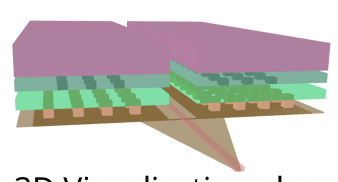
3. DEVICE DESIGN

STEP 1: Using **GDSFactory** we can programmaticaly define components. GDSFactory already comes with generic component shapes from the SiEPIC PDK that we can adapt for our application:

```
#To generate and show a component:
mmi = gf.components.mmi1x2(
        length_mmi   = 15.3,
        width_mmi    = 7.09,
        gap_mmi      = 1.06,
        length_taper = 4.03,
        width_taper  = 3.09,
)
mmi.plot()
```

Output can be seen in Klayout





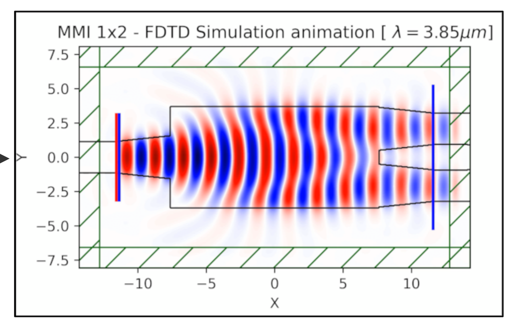
3D Visualization also available

STEP 2: Simulation of components is done with **MEEP FDTD solver**. The solver will automatically use the cross-section defined in the waveguide design:

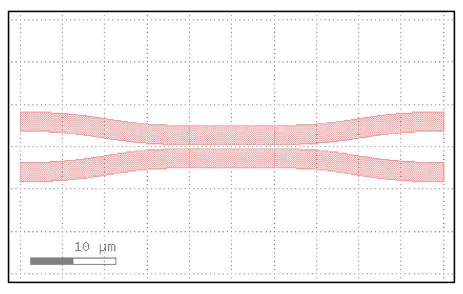
```
#To run a FDTD Simulation on a Component:
s_params = gm.write_sparameters_meep(
    component          = mmi,
    wavelength_start   = 3.0,
    wavelength_stop    = 4.0,
    wavelength_points  = 20,
    resolution         = 20,
    run                = True,
)
```

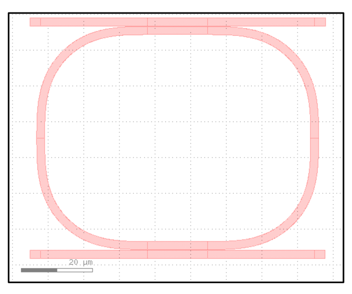
Many ways to visualize simulation results

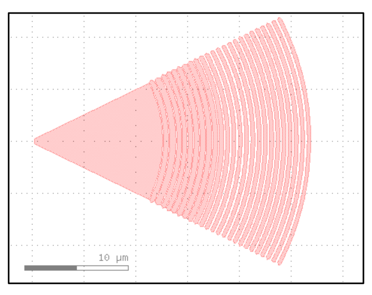
(animation, s-parameters, etc...)

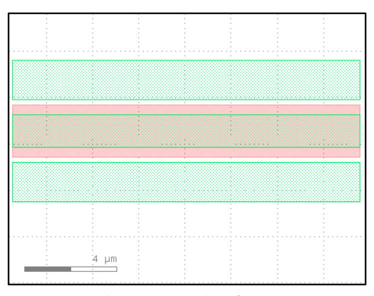


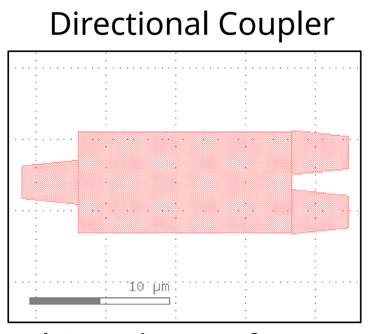
STEP 3: A library of useful components is created by repeating those steps:

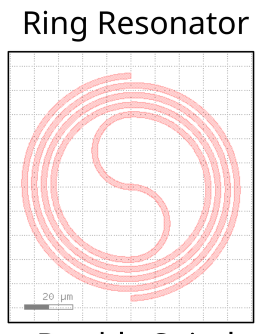

Directional Coupler

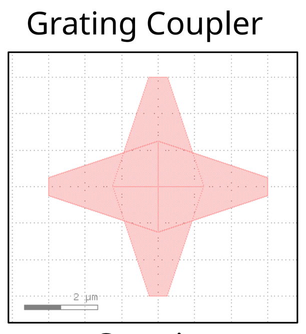

Ring Resonator

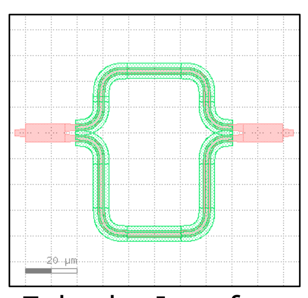

Grating Coupler


Phase-Shifter


Multi-Mode Interferometer

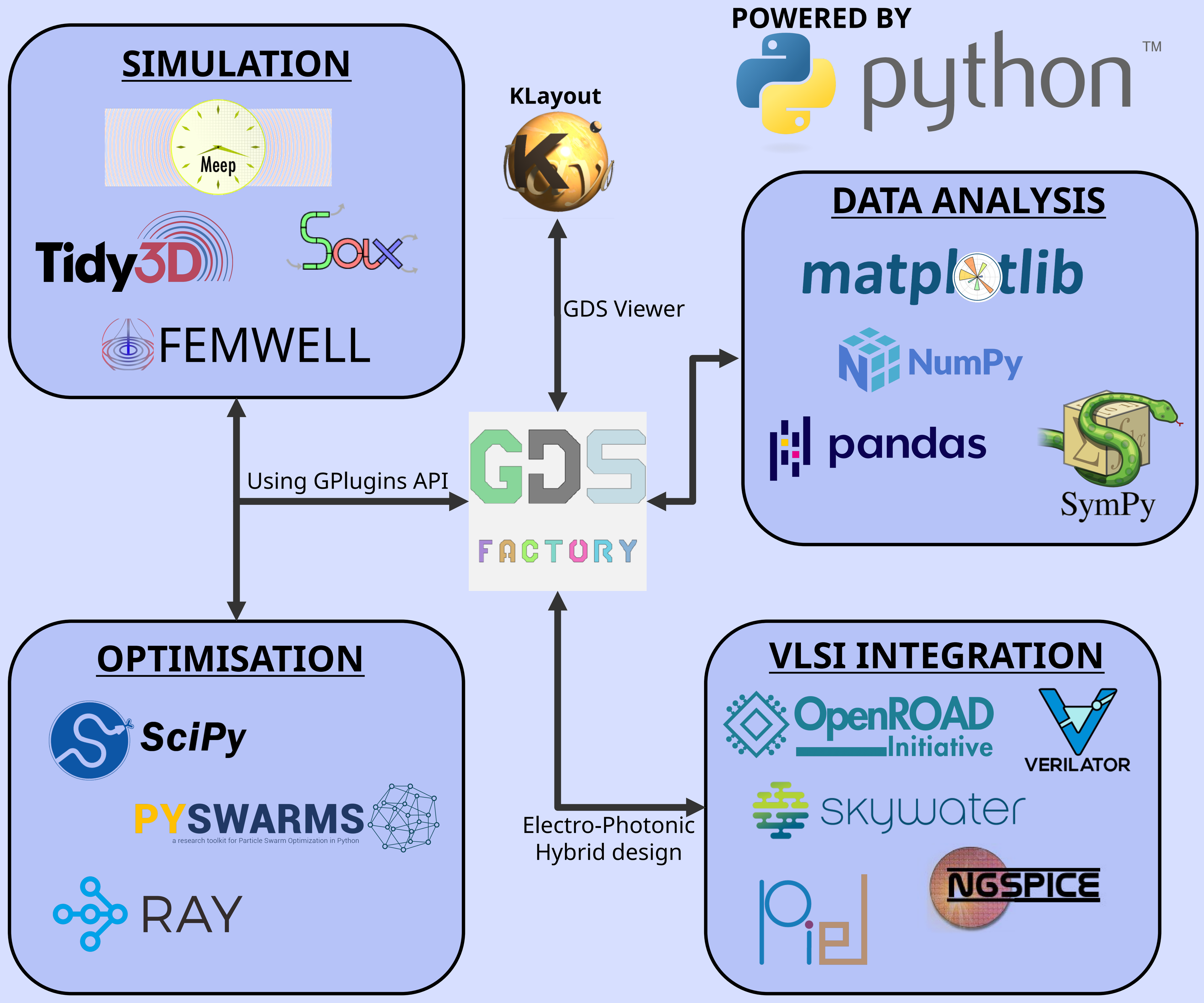

Double Spiral


Crossing


Mach-Zehnder Interferometer

HIGHLIGHTS:

- Open-Source tools can be used **at every steps** of silicon-photonic circuit design process. Main feature include:
  - **Custom** Process Design Kit (PDK) implementation.
  - Components and photonic circuit layout
  - Many **simulation** type (FDE, FDTD, electrostatic, thermal, etc...)
  - Automatic Design Rule Check (DRC)
  - And much more...



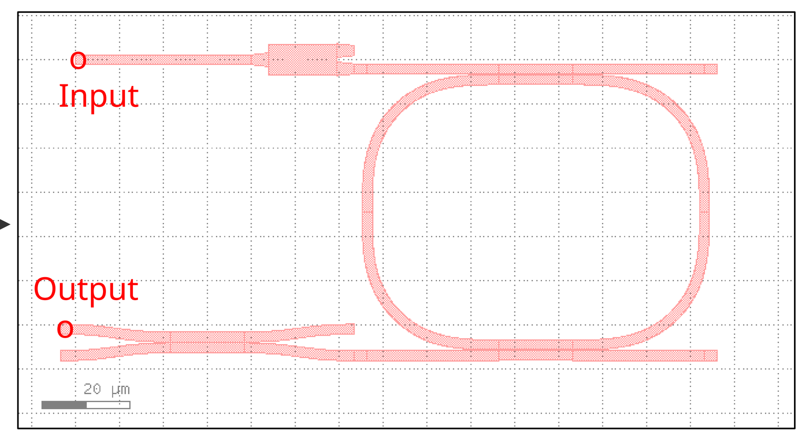
4. CIRCUIT DESIGN

STEP 1: Using **GDSFactory** we can programmaticaly create a circuit layout using components from our library.

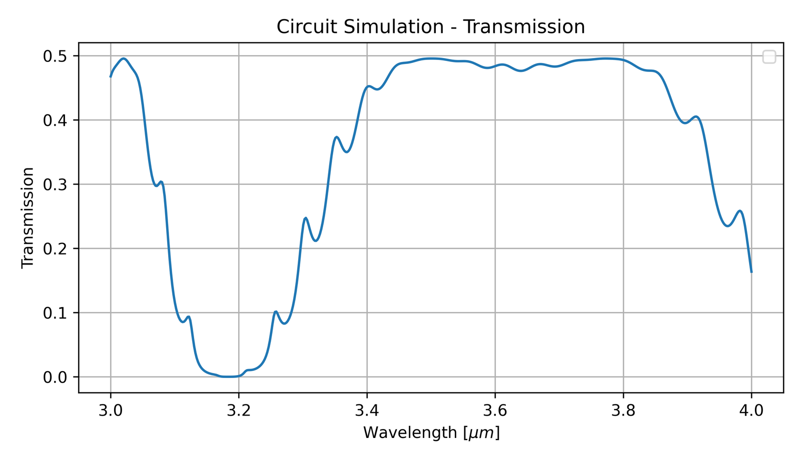
```
@gf.cell
def demo_circuit() -> gf.Component:
    c = gf.Component()
    #Create Components
    strip_input   = c << component_strip()
    mmi           = c << component_mmi()
    ring          = c << component_ring()
    coupler       = c << component_coupler()
    #Connect Components together
    mmi.connect("o1", strip_input.ports["o2"])
    ring.connect("o2", mmi.ports["o3"])
    coupler.connect("o2", ring.ports["o4"])
    return c

c = demo_circuit()
c.show()
```

Klayout Output



STEP 2: Using FDTD Simulation results, we can create a model of our components using **SAX**. These models can be combined to simulate the circuit response:



Simulation

5. CONCLUSION

We have demonstrated that **Open-Source tools are now sufficiently mature** to compete against mainstream proprietary software, by implementing a **non-standard** process design kit in the mid infrared region.

In the future, we hope to validate the PDK by **comparing** simulation results with real optical mesurement of those devices and circuit.

REFERENCES

1. Joaquin Matres – GDSFactory v8.3.0, 2024

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