IceLab: A Python-based framework for semiconductor device measurement and analysis

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Abstract

Icelab provides designers of semiconductor components or devices with Python tools that help them define and carry out highly-automated device measurements and data analysis.
It supports local and remote operation of semiconductor wafer probe-stations and measurement equipment.
Data is stored in a **MongoDB** database for subsequent analysis, including interactive visualization with **Bokeh** or **Matplotlib**.

Features

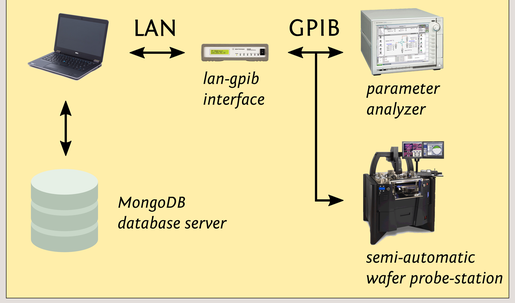
- Replaces labor-intensive manual measurements, thereby saving valuable time.
- Is flexible in type of measurements and instruments and ability to define measurement sequences.
- Uses structured storage of measured data in database for later (statistical) analysis.
- Powerful query and plotting methods enable visualization of almost any combination of parameters.

Rationale

- Commercial alternatives do not always offer the required measurement flexibility.
- Licenses can be too expensive to justify.

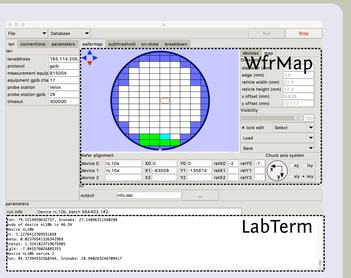
Infrastructure

- Multiple network options: LAN-GPIB, USB-GPIB, or fixed GPIB network card.
- Network communication with **pyVisa** in combination with **VISA** library (from **Keysight** or **National Instruments**), or **SICL** library (**Agilent/Keysight**).

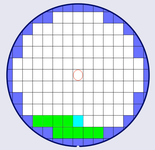


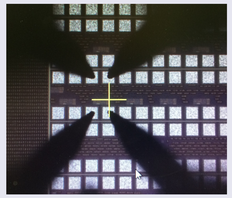
Measurement

- User builds own GUI-based measurement application.
- **Icelab** provides specialized super-widgets and simplified placement scheme.
- **Icelab** also provides drivers for communication with measurement instruments and probe-stations.




```python
from icelab.core import labui as ui
from icelab.langpib import connect
from icelab.drivers import B1500A, Nucleus
from icelab.db.mongolib import ConnectDB
from icelab.measurements import bvds

def setup(g, wnd):
    # place widgets on grid
    nb = ui.LabNotebook(wnd, row=0, column=1, ...)
    g.wfr = ui.WfrMap(nb, toplabel='wafermap', ...)
    g.pl = ui.LabPlot2D(nb, toplabel='breakdown')
    ...
    g.term = ui.LabTerm(wnd, row=3, column=0, columnspan=2, ...)

def enable(g):
    # open instrument connections
    g.par = connect(driver=B1500, gpib=17, url='apc1221').open(timeout=10000)
    g.probe = connect(driver=Nucleus, gpib=28, url='apc1221').open(timeout=10000)
    ...
    # open database connection
    g.db = ConnectDB(**ui.menu.database)


def execute(g):
    gate = g.par.module(slot=1)
    drain = g.par.module(slot=2)
    source = g.par.module(slot=3)

    for device in g.wfr.get_devices(db=g.db):
        # move probe to position and contact
        xpos, ypos = device.position()
        g.probe.move(xpos, ypos)
        g.probe.contact()

        # do breakdown measurement
        data = bvds(g.par, source=source, drain=drain, gate=gate)
        g.term.write('measured breakdown {}\n'.format(data.bvds))

        # store result in MongoDB database
        g.db.insert_db(device=device, data=data, ...)

        # plot leakage current
        g.pl.plot('idvd', data.vd, abs(data.idrain), color='red',
        g.pl.draw()

def close(g):
    # close resources
    g.par.close()
    g.probe.separate()
    g.probe.close()
    g.db.close()

main = ui.main(setup=setup, enable=enable, execute=execute,
               close=close)
# start event loop
main.start()
```



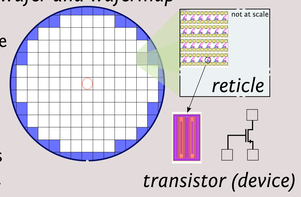


```
DV 1,0,0.0,2.0E-7
DV 3,0,0.0,2.0E-7
WV 2,0,0.0,100,201,1E-7
MM 2,1,2,3
XE
```

```
{ 'run_id':<sequence number>,
  'device_id':<ObjectId>,
  'batch_id':<ObjectId>,
  'abc':'nL22b','bvds':45,
  'idrain':{'type':'ndarray',
            'data': <numpy.array>}
  ...}
```

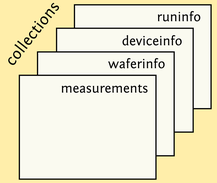
MongoDB

Silicon wafers are processed in batches. Patterning of structures is done through a photo-lithographic process, using multiple masks. A set of masks needed for a fully processed wafer is called a *maskset*. A maskset represents the design of a *reticle* that consists of many components and/or electronic circuits. A reticle design is repeated multiple times on a wafer surface.

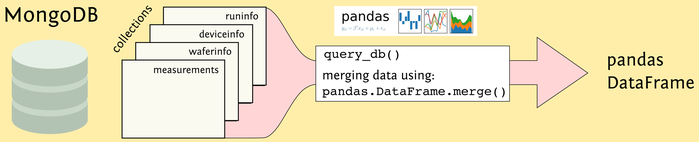


Database

- **MongoDB** used as default database with easy key/value datastore
- Flexible schema for handling variety of measurement data
- Collection *runinfo* keeps information of each measurement session.
- Device names, types, reticle positions, and geometry stored in *deviceinfo* collection.
- Wafer number, maskset name and processing conditions stored in *waferinfo* collection.
- All measurement data together with position on wafer, wafer reference, and device reference are stored in one *measurements* collection.



Querying the database

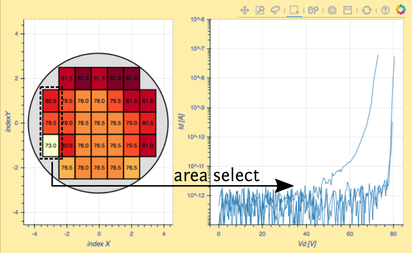


Visualization

- **Bokeh** for interactive plots in **Jupyter** notebook.
- **Matplotlib** for high-quality plots. Ideal for use in reports and for batch plotting.
- **Icelab** provides special plotting functions for plotting in **Bokeh** and **Matplotlib**.

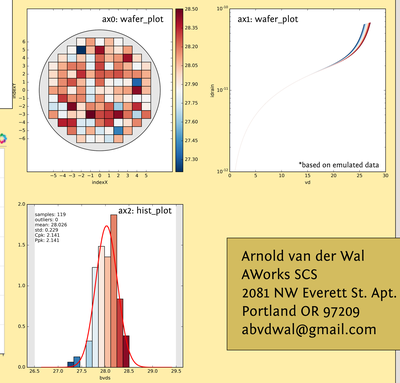
Bokeh

```python
from icelab.plotting.bokehlib import WaferComboPlot
from icelab.db.mongolib import query_db

# query database and import
qry = query_db(database='nmos', host='localhost', masksets='Jalapeno',
               run_id=(1,), devices=('nL22a', 'nL22b'),
               measurements={'bvds', 'vt', 'stress'})
# select data for plotting
data = qry.get('vd', 'idrain', 'bvds',
               conditions={'measurement':'bvds', 'abc':'nL22b'})
# plot data
p = WaferComboPlot(data, 'vd', 'idrain', field='bvds', **wafer_prop,
                   print_values=True, y_axis_type='log',
                   x_label_right='Vd [V]', y_label_right='Id [A]')
show(p)
```



Matplotlib

```python
from icelab.plotting.mpllib import sfigure
from icelab.db.mongolib import query_db

# query database and import
qry = query_db(database='nmos', host='localhost',
               run_id=1, devices='nA08', measurement='bvds')
# select data for plotting
data = qry.get('vd', 'idrain', 'bvds', 'abc')

# plot data
f, ((ax0, ax1), (ax2, _)) = sfigure(ncols=2, nrows=2,
                                    remove_last=True)
ax0.wafer_plot(data, 'bvds', diameter=300, pitchX=23,
               pitchY=20, color_bar=True)
ax1.line_plot(data, 'vd', 'idrain', 'bvds')
ax1.autoscale(enable=True, axis='both', tight=None)
ax1.set_yscale('log'); ax1.set_ylim([1e-12, 1e-10])
ax2.hist_plot(data, 'bvds', cb_colors=True, bins=10,
              lsl=26,5, usl=29,5, skip_outliers=False)
```



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