# Physical models for micro and nanosystems
# Part 1: Introduction

Andras Kis
andras.kis@epfl.ch

École Polytechnique Fédérale de Lausanne (EPFL)
Electrical Engineering Institute

# What is the goal of this course?

- Learn the basics of modeling and computational thinking (based on finite elements) for different classes of micro/nano devices that involve
  - Electrical forces
  - Magnetic forces
  - Motion of charges (X-ray detectors)
  - Mechanical deformation (NEMS/MEMS)
  - Heat dissipation / transfer
  - Fluid motion (microfluidic devices)

# How do we get there?

- Ex-cathedra lectures (<50% time)

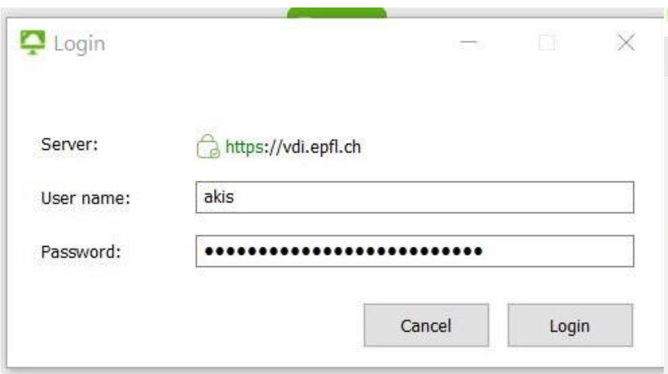
- Work on computers (Comsol,  computer room CO 05) (>50% time)
- Alternative: Comsol running on a virtual machine “STI-WINDOWS”, hosted at vdi.epfl.ch

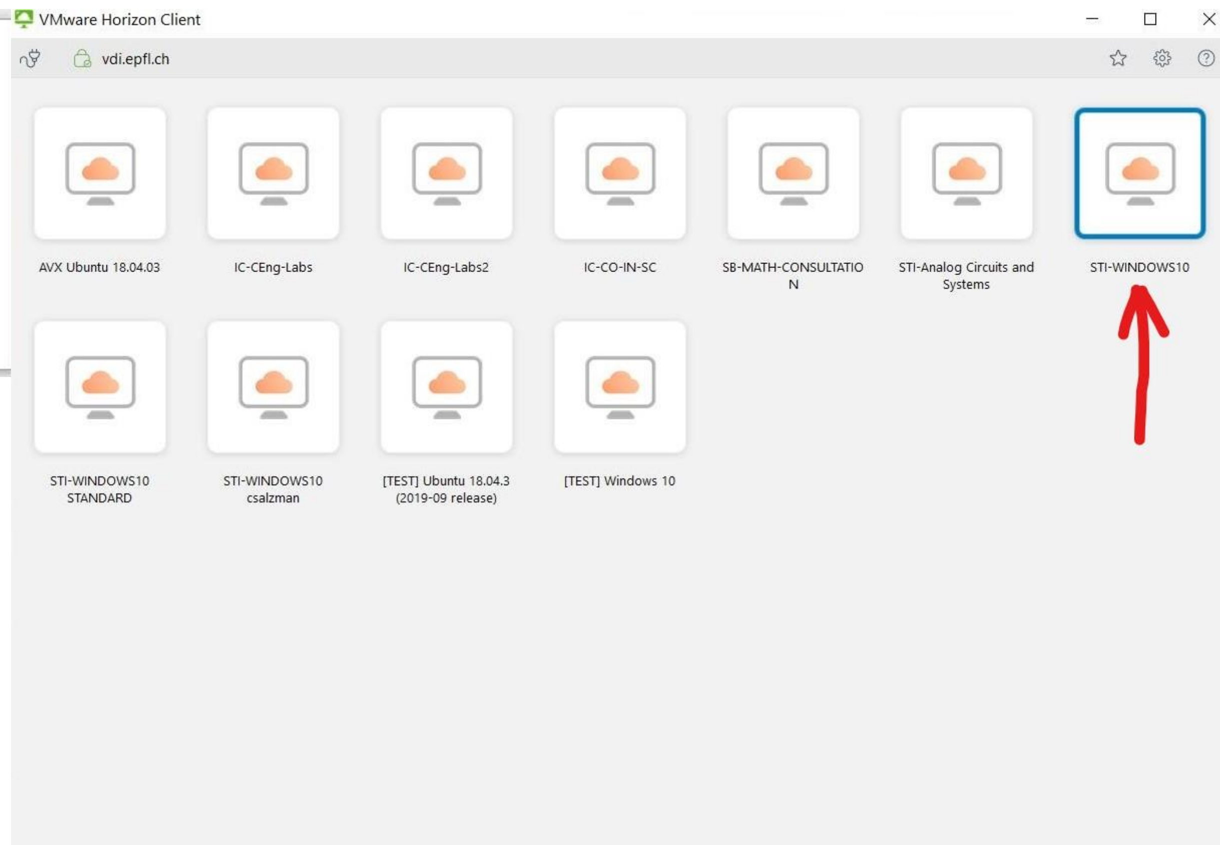
- Homework
  - repeating basic concepts from general physics
  - solving exercises
  - mini-project (groups of students will model a “real” device, write a report and present their work; projects will be assigned in November)

- Project presentation during the last session

# Comsol on a virtual machine

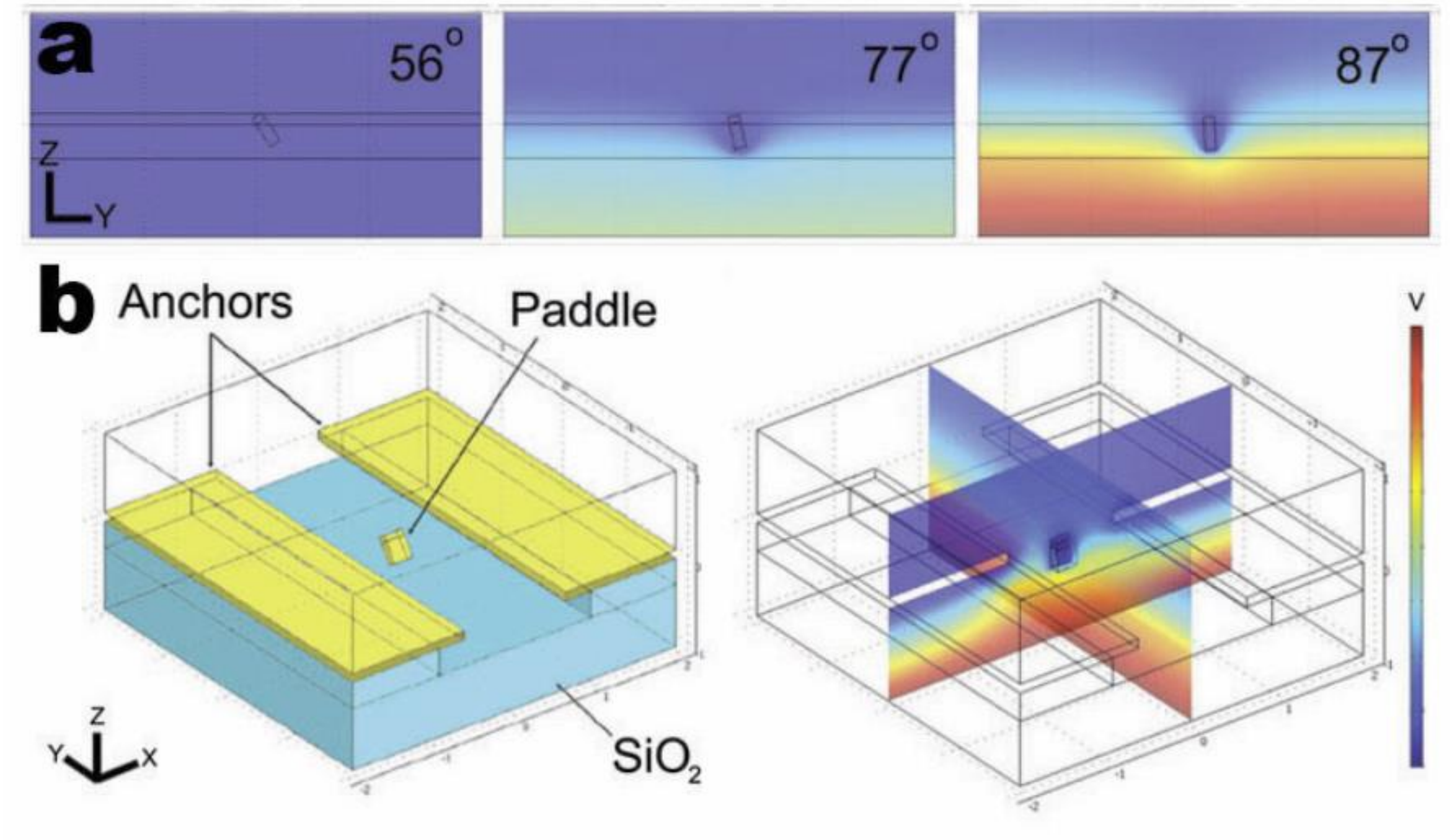
- vdi.epfl.ch
- Install the client
- Start it, log in with your EPFL credentials
- Important: do not run the VPN in background, slows things down



# Example of a system we will cover: NEMS with nanotubes

- Carbon nanotube – based torsional oscillator

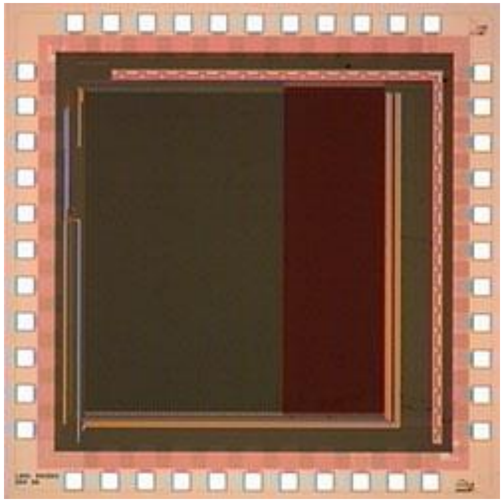


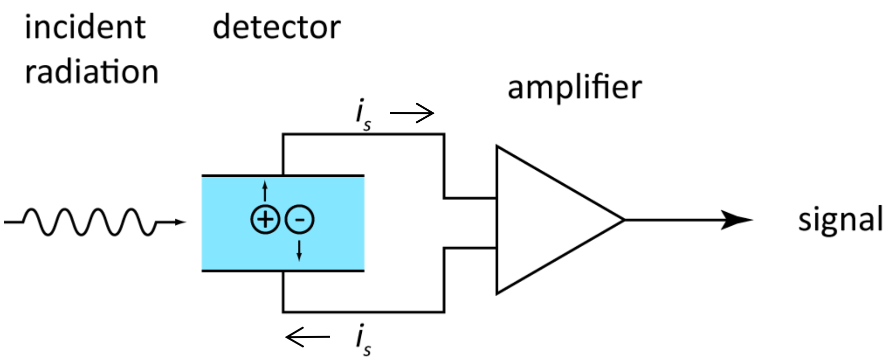

A. Hall, PhD thesis, Chappel Hill 2007

Papadakis et al., PRL 93, 146101 (2004)

# Example of a system we will cover: X- and γ-ray detectors

X-ray detector






X-ray image of a backpack

Modeling issues:

Penetration depth for radiation

Shape and magnitude of the output current pulse

# Course outline

- Background
  - Mathematics – div, curl and that stuff
  - Electrostatics (accent on Gauss' law)
  - Magnetostatics (accent on Biot-Savart law)
- Finite element method
- MEMS/NEMS
- X and $\gamma$-ray detectors
- Microfluidics
  - Fluid mechanics
  - Heat transfer

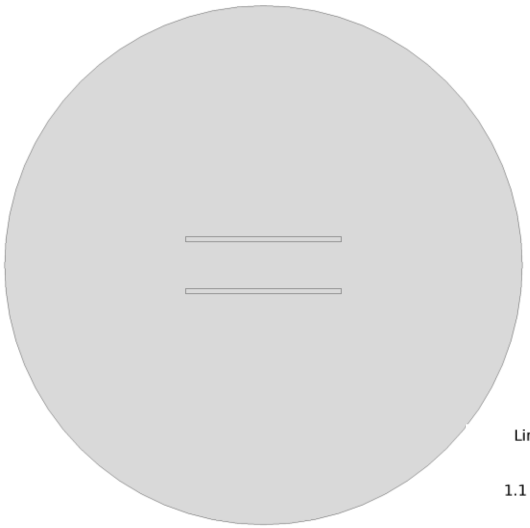
# Why repeat the background

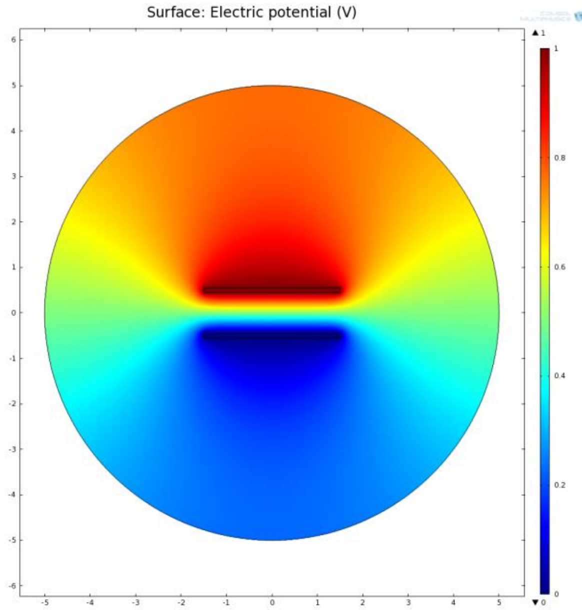
- Present it in a way that is compatible with computational thinking
  - Express basic relations for:
    - Electrostatics
    - Heat transfer
    - Fluid transfer

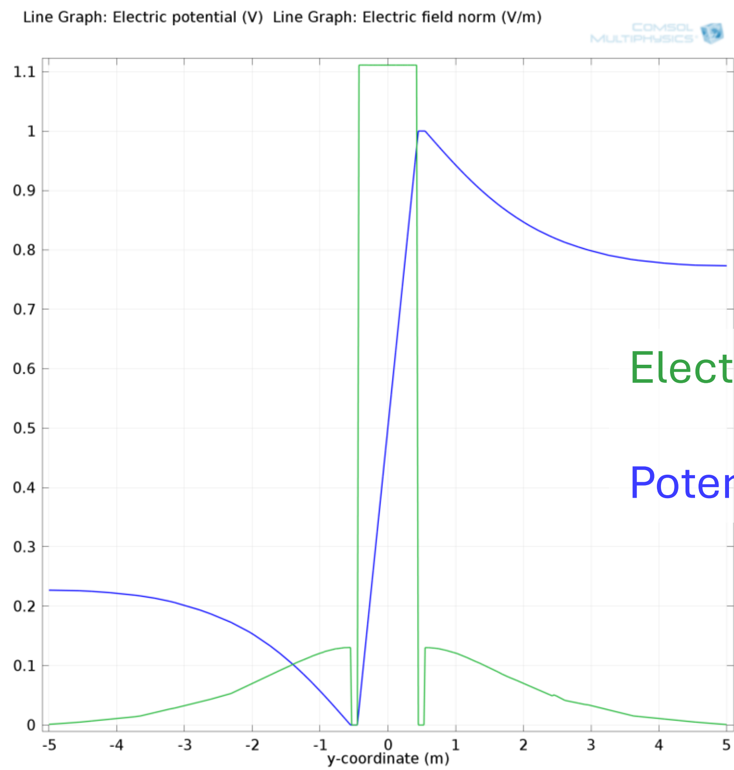
    in terms of a single variable
- Identify the boundary conditions
- Role of different materials: conductors, insulators, ferro-, para-, diamagnets…

# Example: finite element modelling of a capacitor

Geometry



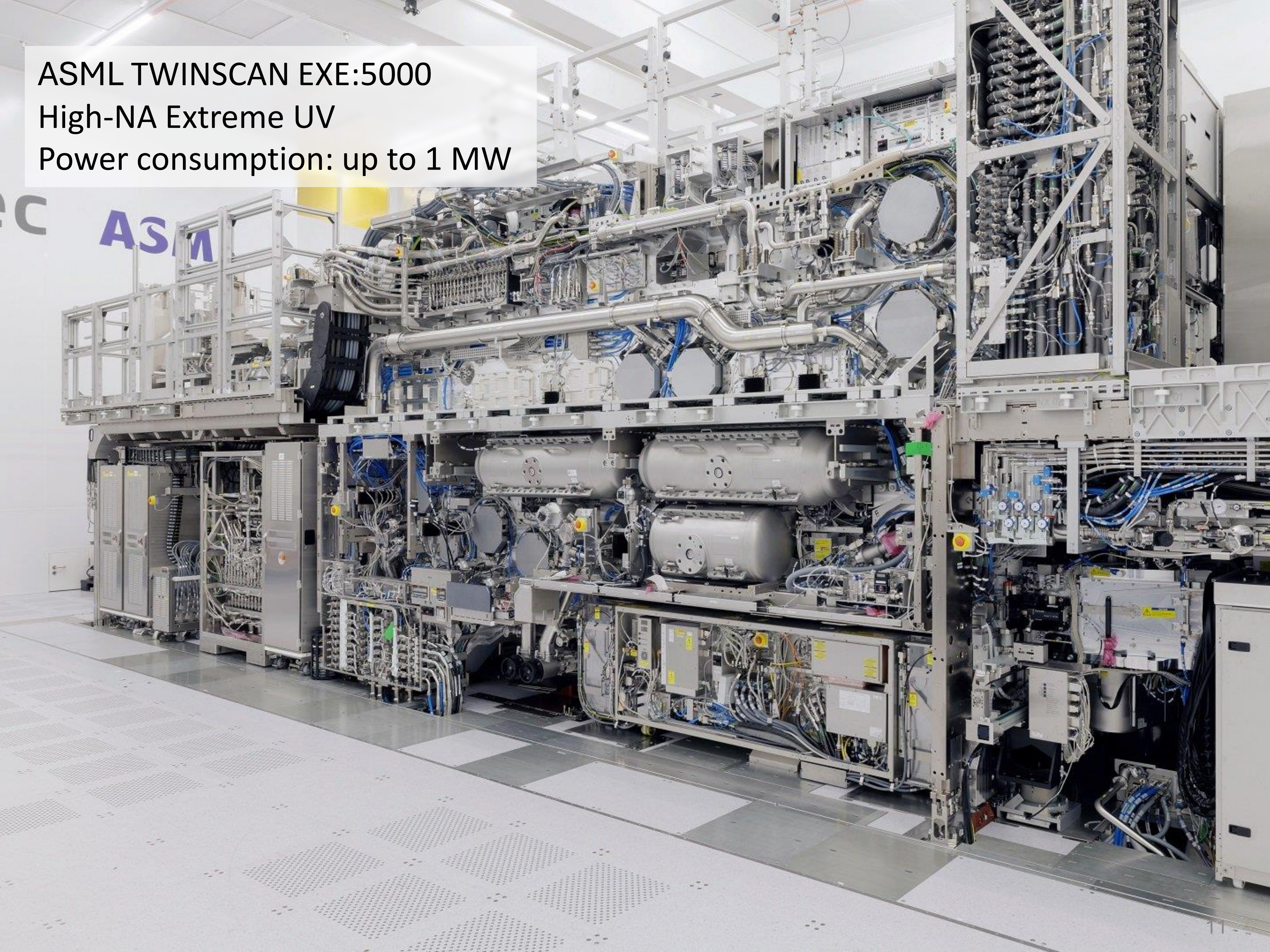


# Why is modeling important?

- Micro and nanosystems are complex
- Complex means:
  - More that one constituent in the system
  - Constituents cannot be considered independent – they may interact with one another
- Experimental characterization is challenging
- Analysis of the solution leads to increased understanding of a phenomenon or process, which can lead to radical improvements in design and operation
- **Manufacturing micro and nanosystems is expensive in terms of money, time and resources: modeling is essential for making this sustainable**

ASML TWINSCAN EXE:5000
High-NA Extreme UV
Power consumption: up to 1 MW



# How do we do it?

- Introduce a physical model
  - Describe as faithfully as possible the system under investigation
  - Define the physical qualities of interest

Reality


Models

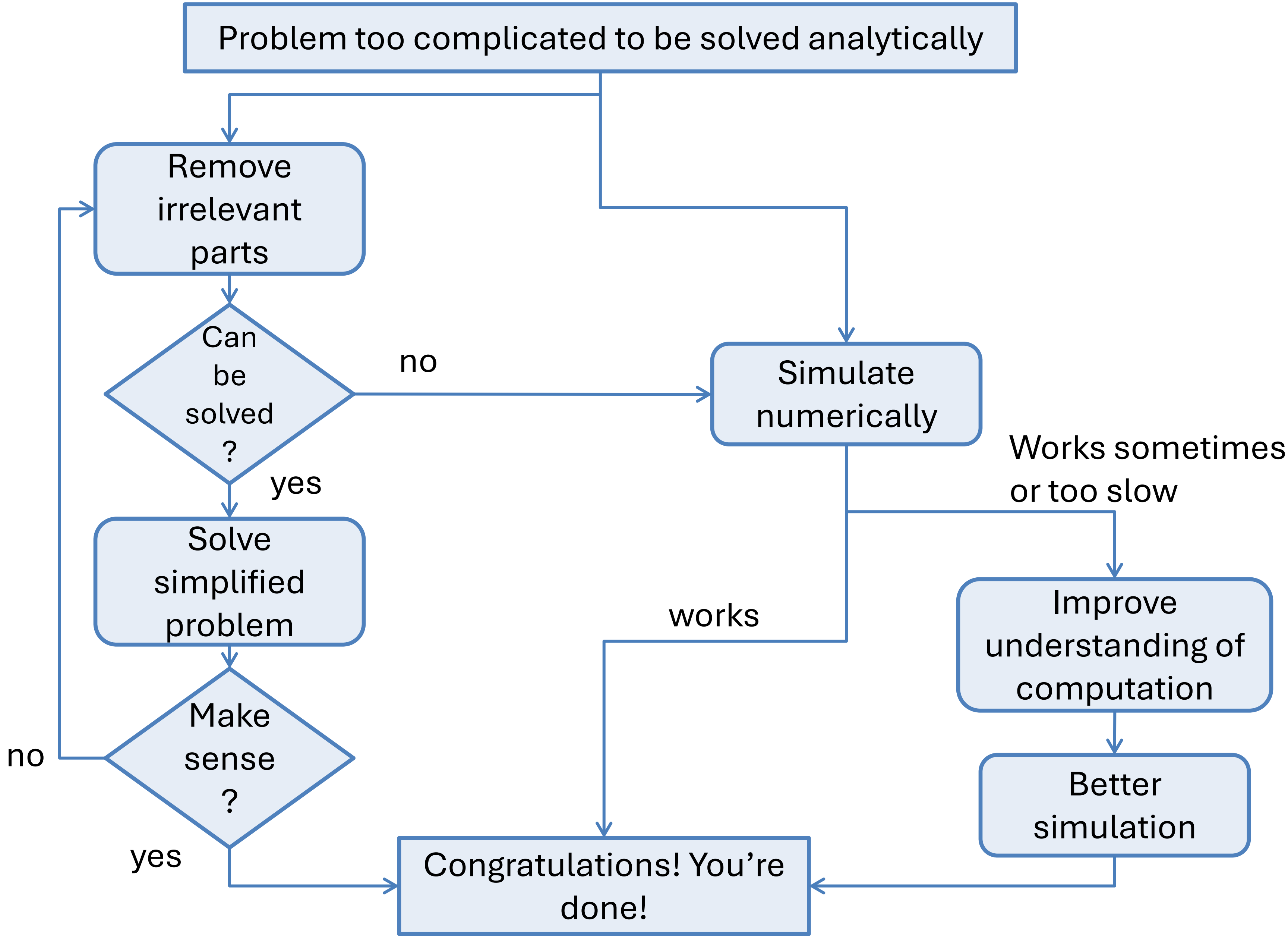

# How do we do it?

- Introduce a mathematical model
  - Describe as faithfully as possible the system under investigation
  - Define the physical qualities of interest

  - A model is essentially an idealized version of the system under exam, simple enough so that it can be solved but not too simple

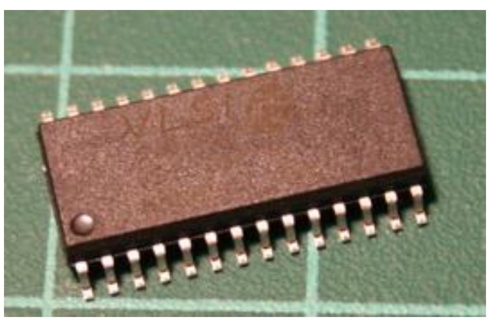
- Study the model
  - Solve the appropriate equations, either analitically or numerically
  - This allows us to calculate the physical quantities of interest

# The modeling scenario

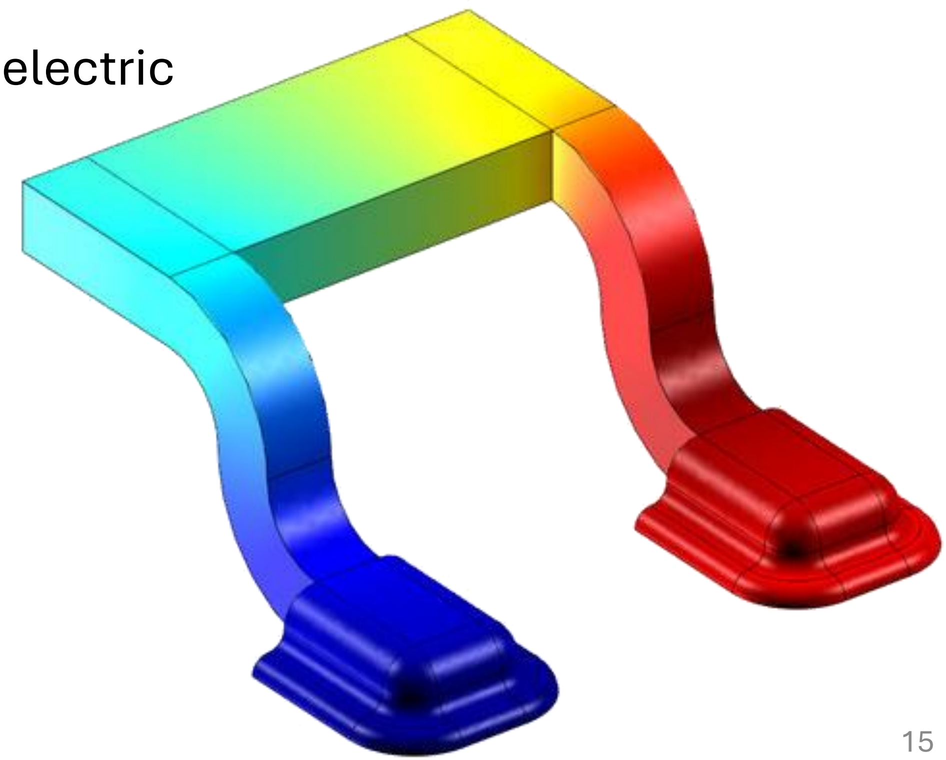


# Finite element method

- One of the most powerful approaches for getting a numeric solution to a wide range of engineering problems
- Basic concept: divide a complex structure into smaller elements – ***finite elements***
- The original structure is then considered as an assemblage of these elements, conected at ***nodes***
- Equations are solved for each of these elements, with continuity at nodes
- Example: shielded conductor on a dielectric

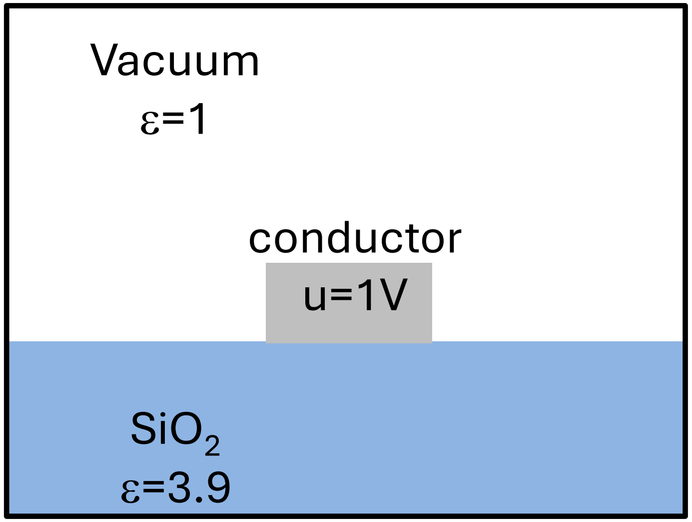


Picture from www.femlab.com

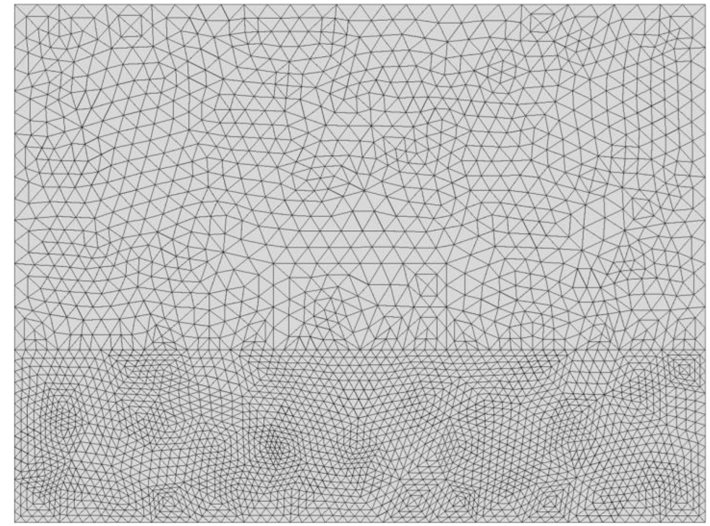


# Example: shielded conductor on a dielectric

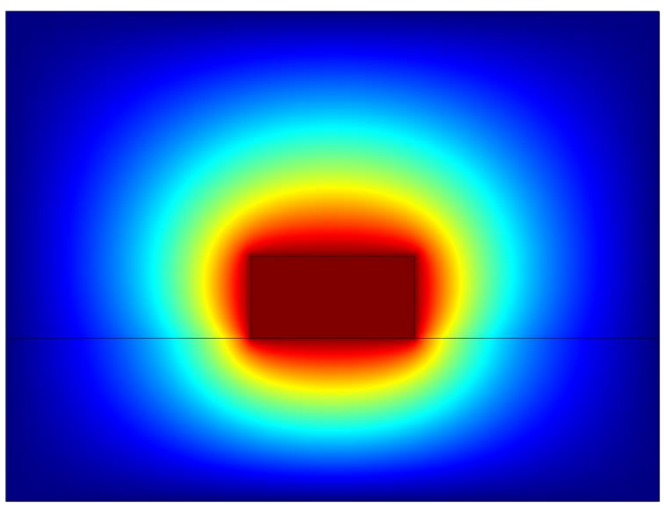
Grounded box
u=0V



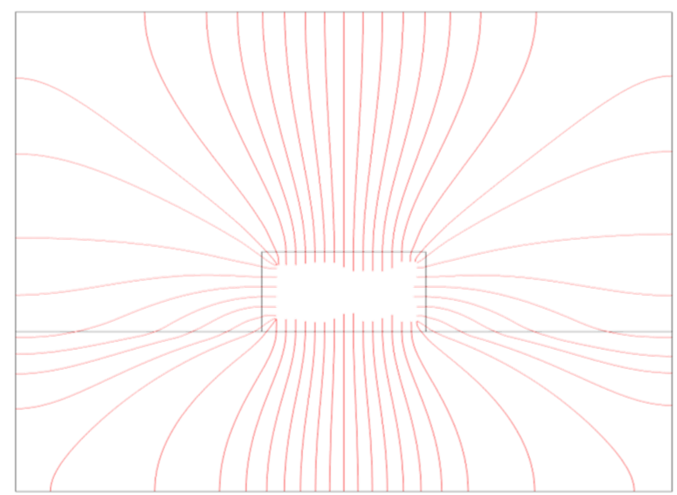

Model



Mesh

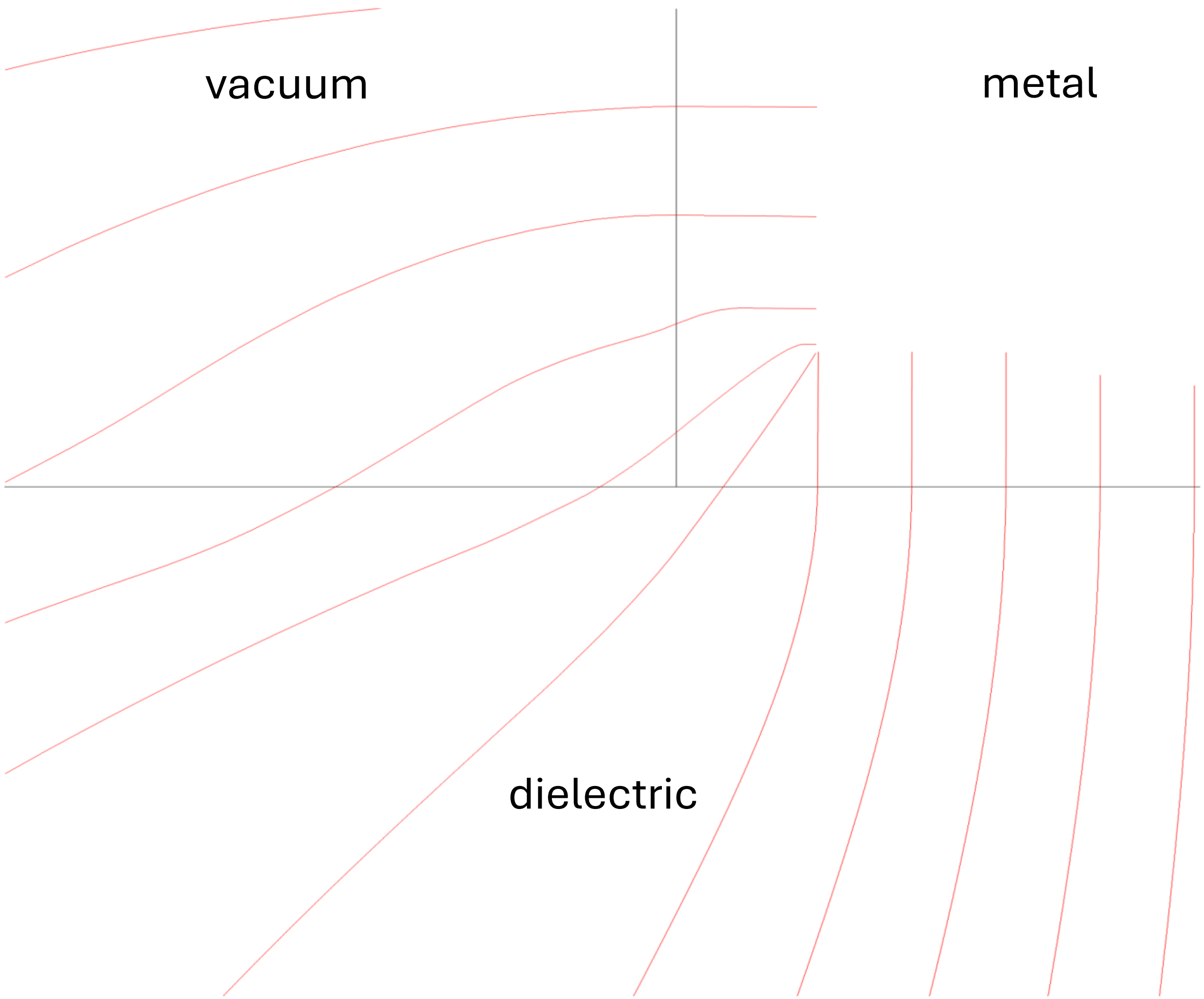


Potential distribution



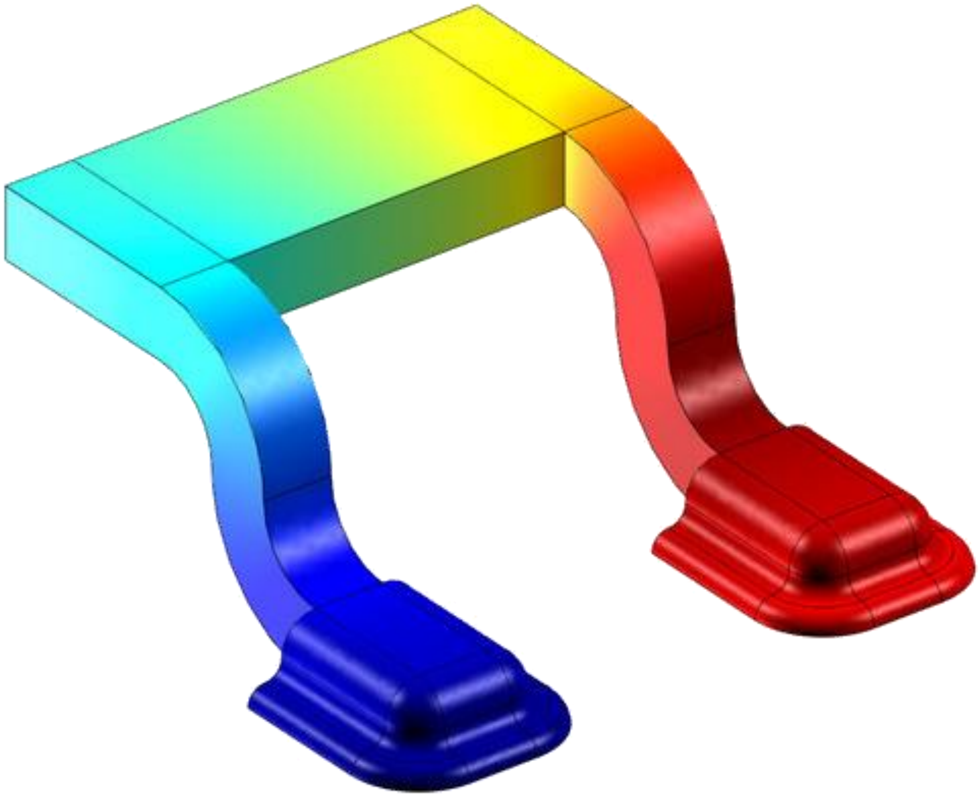
Electric field lines

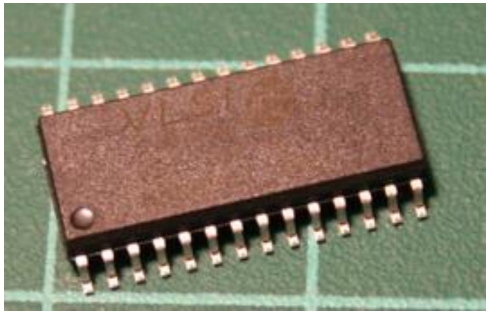
# Example: shielded conductor on a dielectric



# Finite element method

- Joule Heating in an electrical conductor





Picture from www.femlab.com

DC current heats the conductor

↓

Electrical conductivity changes

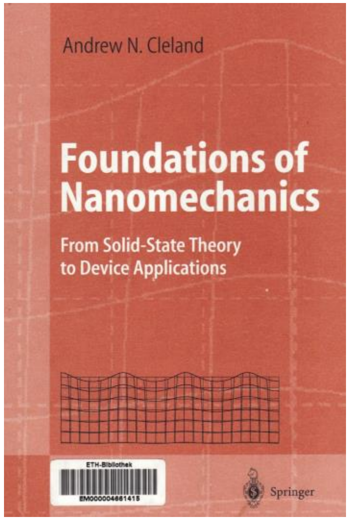
↓

DC current changes

↓

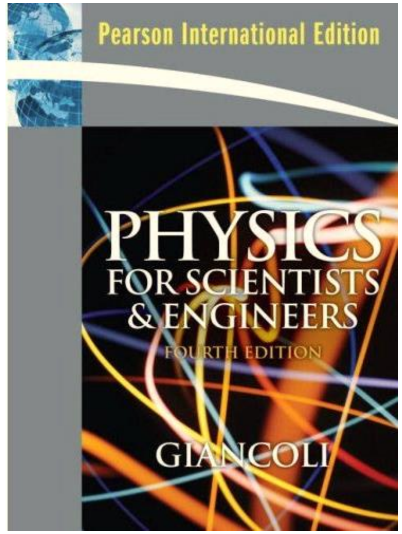
Joule heating is affected

# Literature

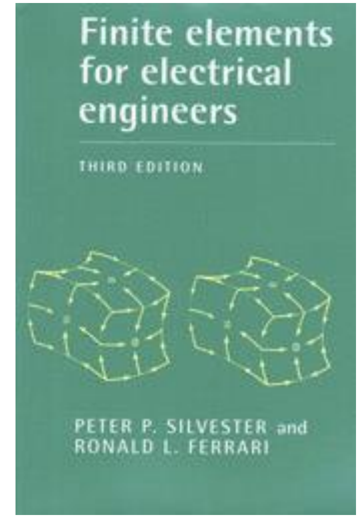



Foundations of Nanomechanics

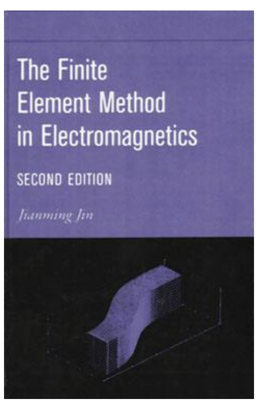
Andrew N. Cleland



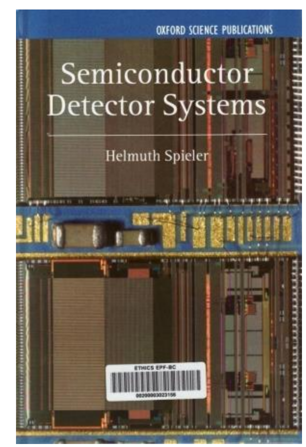

Physics for Scientists and Engineers
by Douglas C. Giancoli




Finite Elements for electrical engineers
by Peter P. Silvester and Ronald Ferrari




The Finite Element Method in Electromagnetics
by Jianming Jin




Semiconductor detector systems

Helmuth Spieler