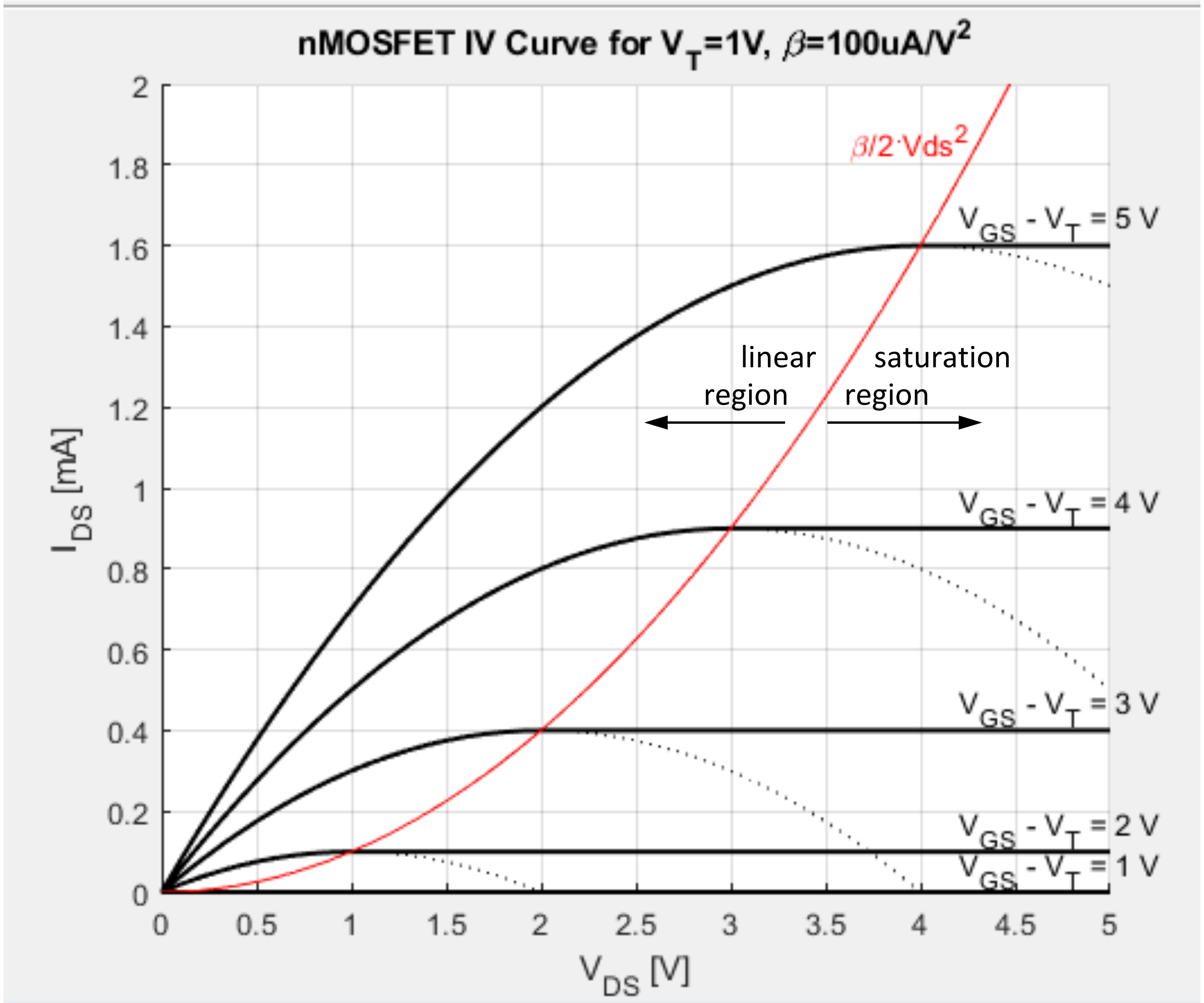
MOSFETs

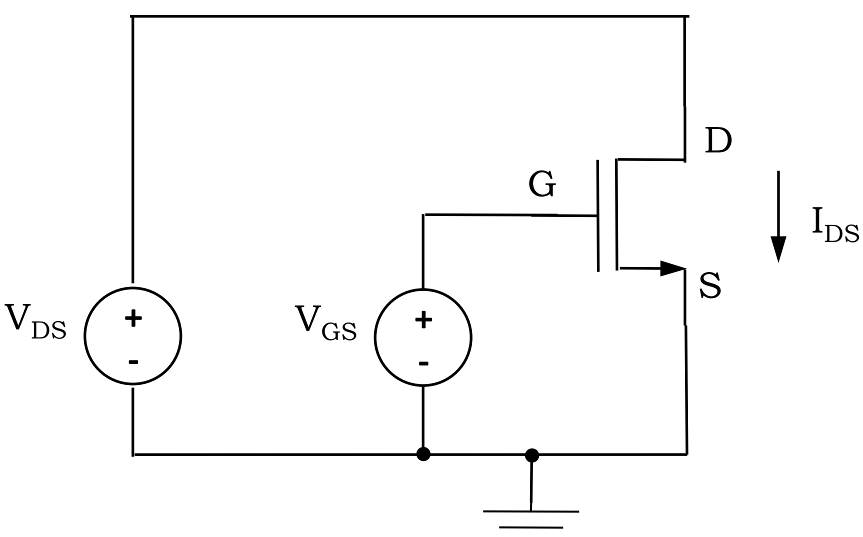
- nMOS
  - Threshold Voltage:
    - V_T = 1.0V (for example)
  - Transconductance Parameter:
    - $\beta = 100\mu A/V^2V$ (depends on process and geometry)
- OFF State $V_{GS} <= V_T$
  - $I_{DS} = 0\,[A]$
- ON State if $V_{GS} > V_T$
  - "Linear" Region if $V_{DS} < V_{GS} - V_T$
    - $I_{DS} = \beta\cdot[(V_{GS} - V_T) - V_{DS}/2]\cdot V_{DS}$
  - Saturation Region if $V_{DS} >= V_{GS} - V_T$
    - $I_{DS} = \beta/2\cdot(V_{GS} - V_T)^2$

nMOSFET IV Characteristic



nMOS Transistor IV Characteristic

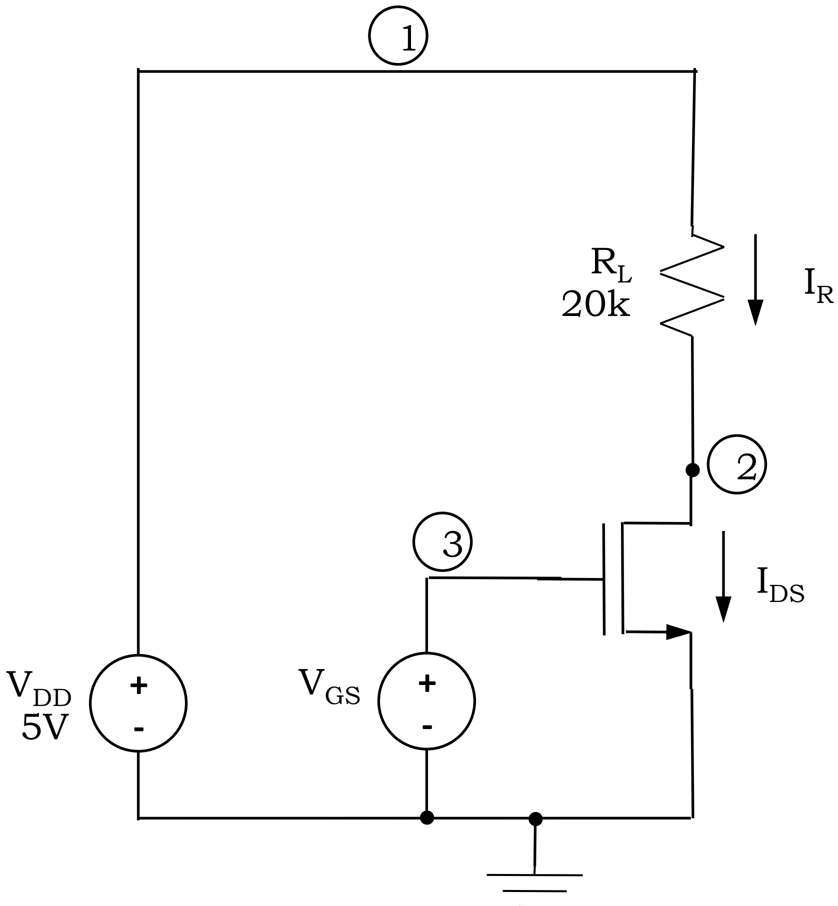
- nMOS
  - as a 3 terminal device
    - G – “gate”
    - S – “source”
    - D – “drain”
  - charge carriers are electrons
    - (negatively charged) electrons flow from source to the drain
  - I_{DS} is drain to source current
    - conventional current



side note:

- In *pMOS* the charge carriers are holes
  - effectively a positive charge
- When nMOS and pMOS are used together it’s known as CMOS which stands for Complementary MOS

nMOS Inverter



Case 1: V_{GS} = 5V

Is transistor in linear or saturation?

Let's find Ids if transistor is in saturation:

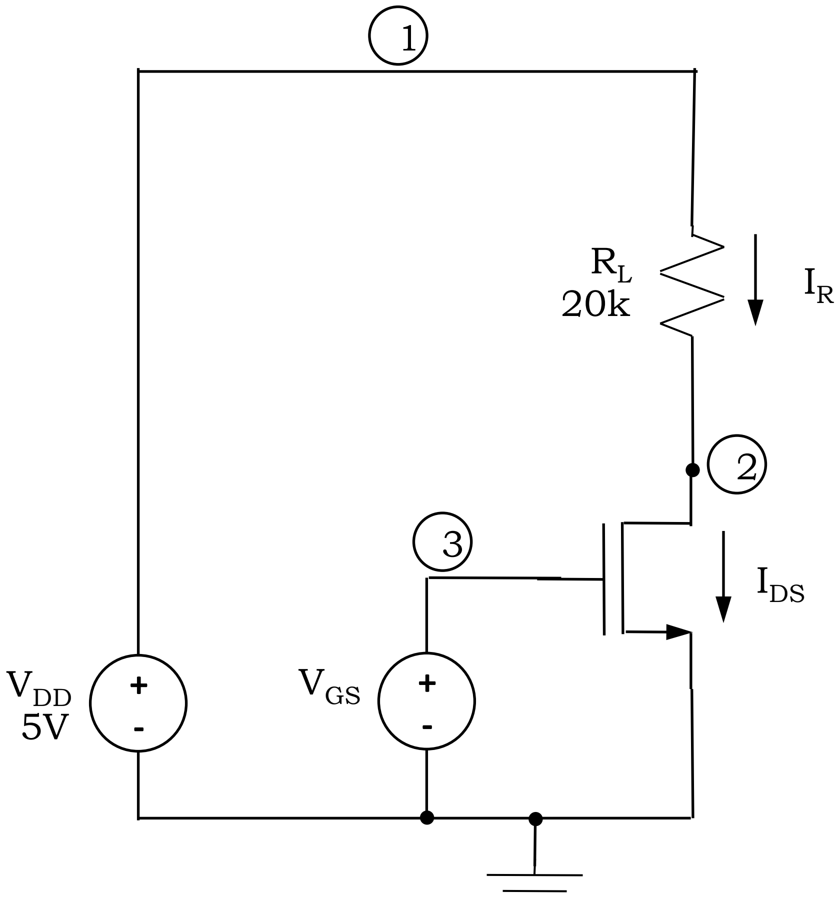
$$I_{DS} = \beta/2\cdot(V_{GS} - V_T)^2$$
$$= 100\mu A/V^2/2\cdot(5V-1V)^2$$
$$= 1.6mA$$

But this would mean voltage drop across $V_{RL} = I\cdot R = 1.6mA*20k\Omega = 32V$!

This can't be, because the power supply (V_{DD}) is 5V. The maximum current which could flow through R_L is $I_{Rmax} = V_{DD}/R_L = 5V/20k\Omega = 250uA$

[note: $I_R = I_{DS}$]

nMOS Inverter



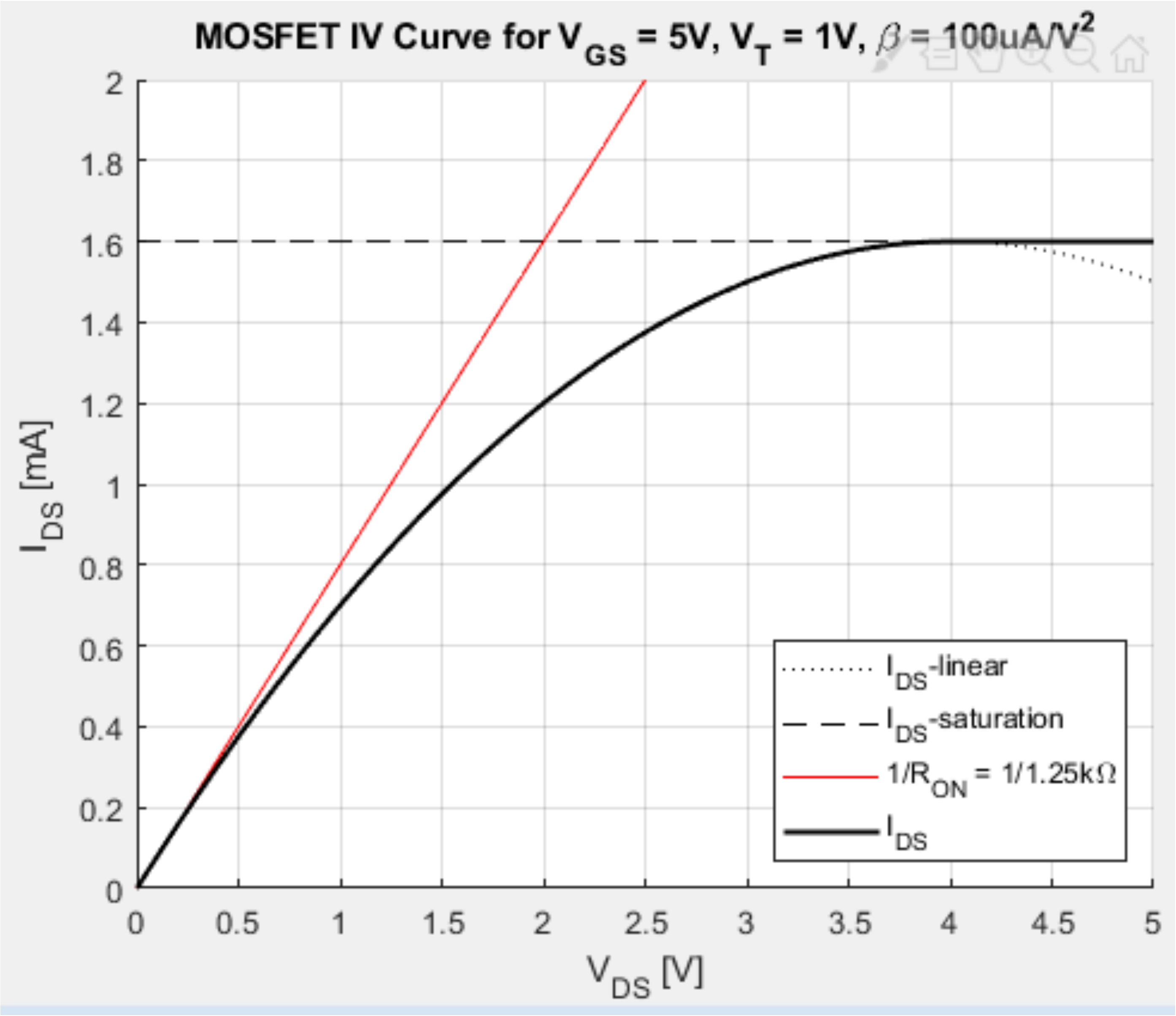
Case 2: $V_{GS} = 0$
from transistor characteristic:
$I_{DS} = 0$ (and thus I_R=0)
Thus $V_R = 0$ and $V_2 = 5V$

That is, the MOSFET is in the OFF state, so no current flows, and thus no current flowing in the resistor. If a resistor has no current flowing through it, the voltage (drop) across it is zero. Thus voltage and node 2 and voltage at node 1 are equal.

ON Resistance

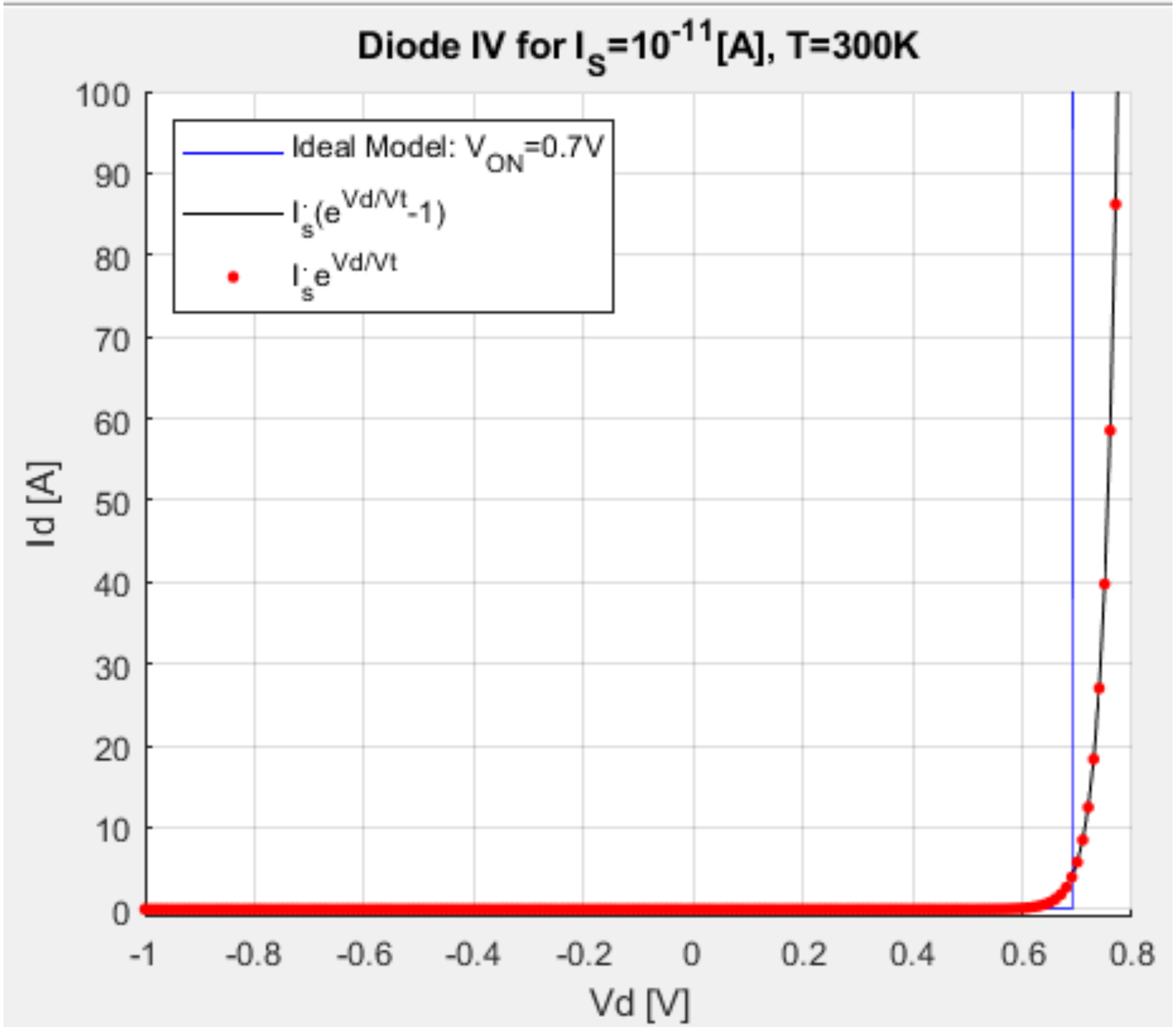
- Linear Region: $I_{DS} = \beta \cdot [(V_{GS} - V_T) - V_{DS}/2] \cdot V_{DS}$
  - **If** $V_{DS}/2$ is very small compared to $V_{GS} – V_T$, then I_{DS} can be approximated as:
  - $I_{DS} = \beta \cdot (V_{GS} - V_T) \cdot V_{DS}$
- This now looks like Ohm's Law, stated as R=V/I
  - So, $R_{ON} = V_{DS} / I_{DS} = 1/[\beta \cdot (V_{GS} - V_T)]$

nMOSFET IV Characteristic



Diodes

Diode IV Characteristic – Forward Bias



Diode IV Characteristic – Reverse Bias