Report for Silicon Detector Physics

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调研结果

- I-V：漏电流、噪声

$$I = qA\left(\frac{D_n n_{p0}}{L_n} + \frac{D_p p_{n0}}{L_p}\right)\left(e^{qV_f/kT} - 1\right).$$

$$I_R \propto T^2 \exp\left(-\frac{E_g}{2kT}\right)$$

- C-V：临界电压、掺杂分布

$$\frac{1}{C^2} = \frac{2(N_a + N_d)\Delta V}{q\varepsilon\varepsilon_0 N_a N_d} = K\Delta V$$

- 调研了部分实验，其中有较早研究LGAD的。

物理原理

- 信号电荷

$$Q_s = \frac{E}{E_i} e$$

  - 带隙越大，信号电荷越小
  - 需要小静态电流的强场，高电阻，带隙增加，影响信号电荷
- Sensor Volume：
  - PN结电流：理论和实验互相印证了特殊曲线。
  - pn junction内建电压
  - 探测器边缘损坏增大漏电流
  - 掺杂浓度

$$N = \frac{2}{\frac{d(1/C^2)}{dV}} \frac{1}{\varepsilon \varepsilon_0 q A^2}$$

物理原理

- 电荷收集
  - 信号收集的效率与灵敏度
  - 收集时间：

$$t_c = \frac{d^2}{2\mu V} \log\left(\frac{V + V_d + 2V_{bi}}{V - V_d}\right)$$

$$t_c \approx \frac{d}{v} = \frac{d}{\mu \overline{E}} = \frac{d^2}{\mu V}$$

  - 偏压越大，收集越快

$$|E(x)| = \frac{2V_d}{d}\left(1 - \frac{x}{d}\right) + \frac{V - V_d}{d}$$

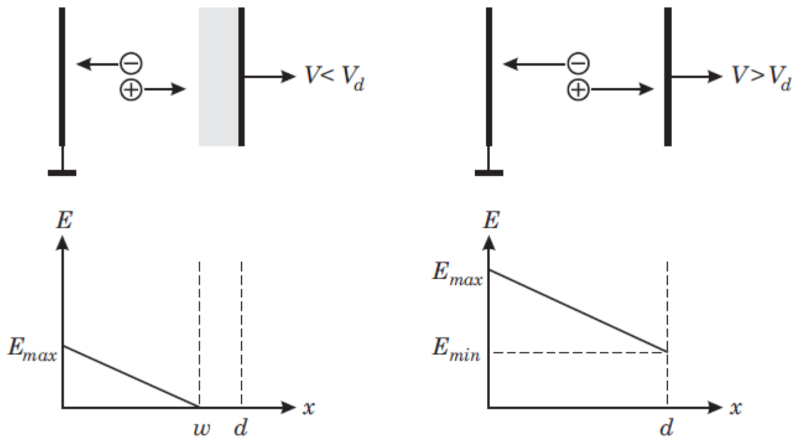


FIG. 1.16. Electric field distributions in a partially depleted detector (left) and a detector operated with overbias (right).

物理原理

- 耗尽电压
  - 一般的

$$V_d = \frac{Ned^2}{2\varepsilon}$$

  - N型

$$V_{dn} = 4\left[\frac{\Omega\cdot\text{cm}}{(\mu\text{m})^2}\right]\cdot\frac{d^2}{\rho_n} - V_{bi}$$

  - P型

$$V_{dp} = 11\left[\frac{\Omega\cdot\text{cm}}{(\mu\text{m})^2}\right]\cdot\frac{d^2}{\rho_p} - V_{bi}$$

- 能量分辨
  - 信号量子N，能量分辨即信号量子分辨

$$\frac{\Delta E}{E} = \frac{\Delta N}{N} = \frac{\sqrt{FN}}{N} = \sqrt{\frac{FE_i}{E}}$$

物理原理

- 位置分辨
  - $\sqrt{12}$的来源：

$$\sigma^2 = \int_{-p/2}^{p/2} \frac{x^2}{p} dx = \frac{p^2}{12}$$

  - 漂移电荷横向扩散不影响位置分辨
  - 浮动电极法可提升位置分辨率

部分实验——I-V Curve

- SCIPP
  - Al block——散热、导电
  - 2.4μm扎针，probe接地
  - 全封闭盒子，避光
  - 编程，自动化记录

部分实验

- 哥廷根的HPK实验——LGAD

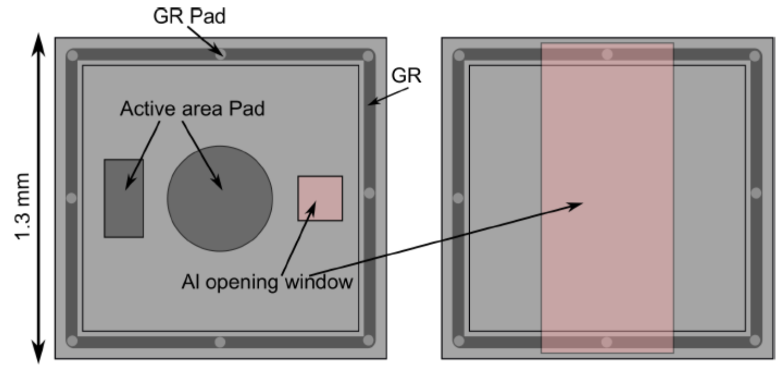
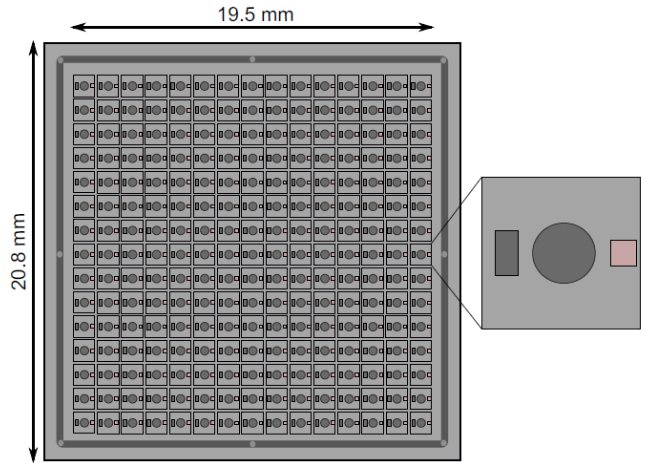


Figure 5.3: Single pad sensor from HPK surrounded by a guard ring with contact pads for probing on the active area and guard ring and an opening in the Al for testing. The opening on the backside is coloured in red. The front of a single pad sensor is shown on the left, the back on the right.



- “开窗”是为了照射激光，模拟粒子辐射对sensor的损伤

部分实验

- 哥廷根的HPK实验——LGAD
  - I-V测量电路：大体一致，我们掌握更多细节

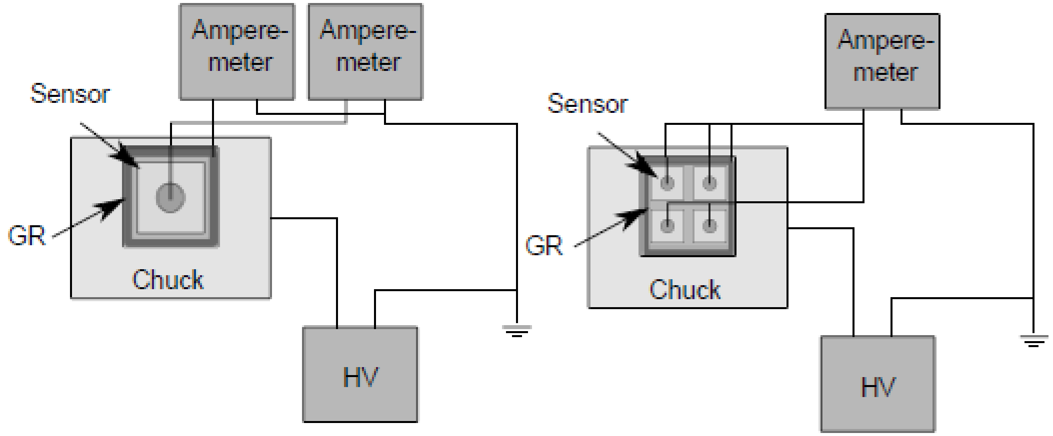
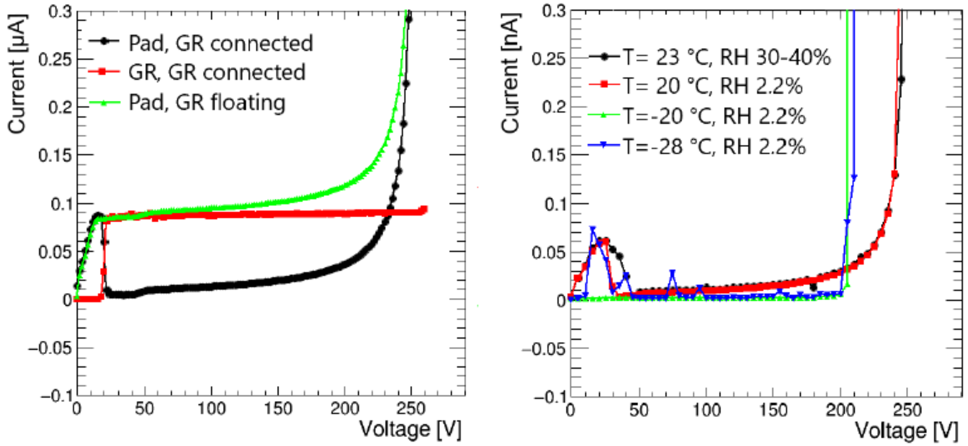


Figure 6.1: Schematic drawing of the measurement set-up in the probe-station with the HV-source and the amperemeter. A single pad sensor with a needle connected to the sensor pad and one needle connected to the guard ring (GR) (left) and a 2×2 array with alls four pads and the guard ring connected to the amperemeter (right).

哥廷根HPK实验结果

- 环境测量



- GR的连线不影响击穿电压V_{BD}的测量
- V_{BD} 达到1微安的外偏压
- 温度与V_{BD}呈正相关，湿度不影响V_{BD}

哥廷根HPK实验结果

- 型号测量

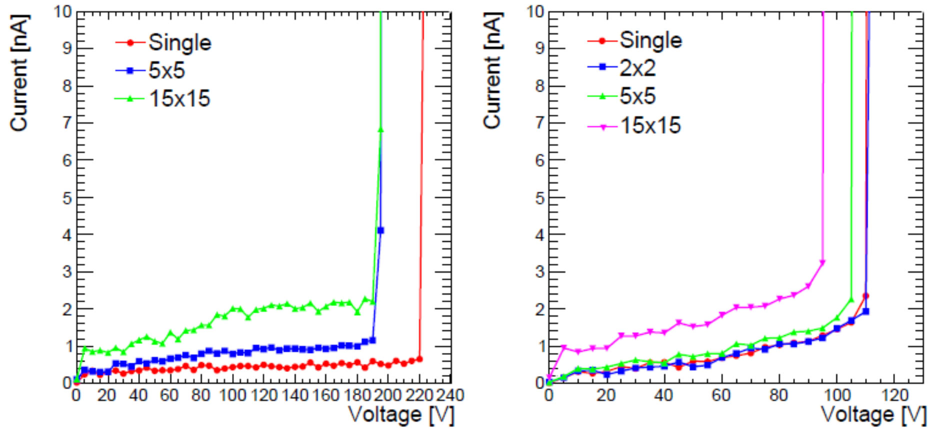


Figure 6.3: Comparison of IV-curves of single pad sensors, 5×5, and 15×15 measurements "Type 3.1" (left) and IV-curves of single pad sensors, 2×2, 5×5, and 15×15 of "Type 3.2" (right).

- 阵列越大，整体电流越大，击穿电压越小。因为相邻的sensor互相影响
- 3.2型比3.1型更容易被击穿，因为前者掺杂较多

哥廷根HPK实验结果

- 均匀性测量（3.2型）
  - 样本平均击穿电压：125.4V
  - 样本标准差：0.4V
  - 所有pad均值127V，标准差5V

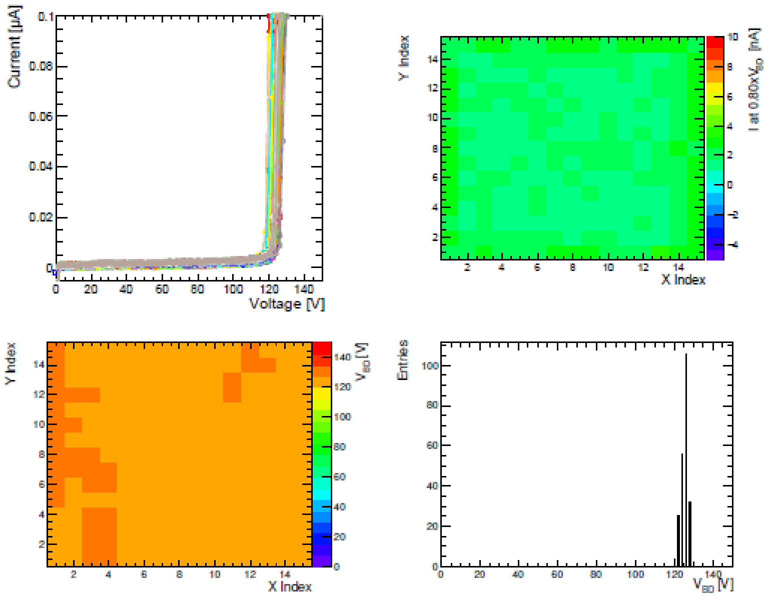


Figure 6.4: On the top left, the IV-curves of all pads of the 15×15 array of wafer 18 with an inter-pad gap of 95 μm, and a slim edge of 500 μm of set P2 are shown. The top right plot is a 2D plot of the currents at 80 % of the breakdown voltage. The bottom left plot shows the breakdown voltage of the sensor as a 2D plot and the bottom right plot shows a histogram of the breakdown voltage.

哥廷根HPK实验结果

- 均匀性测量（3.1型）
  - 样本平均击穿电压：192.65V
  - 样本标准差：0.06V
  - 所有pad均值200V，标准差8V

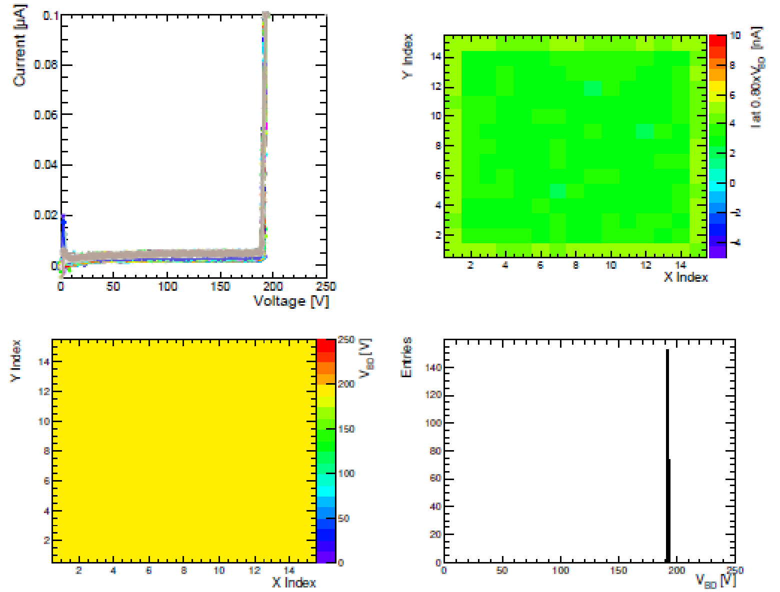
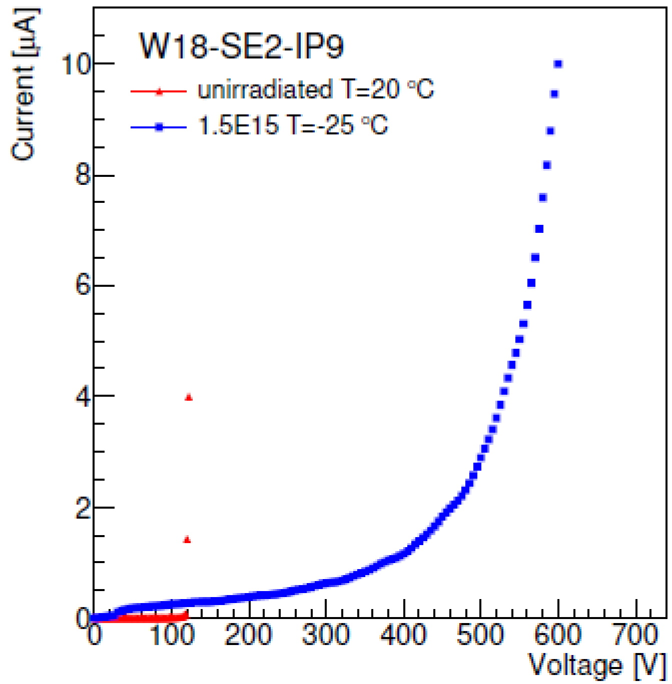


Figure 6.5: The complete analyses of the measurement of W18-LG15x15-SE5-IP9-P3 sensor. On the top left, the IV-curves of all pads of the sensor are shown. The top-right plot is a 2D plot of the currents at 80 % of the V_{BD}. The bottom left plot shows the V_{BD} of the sensor as a 2D plot, and the bottom right plot shows a histogram of the V_{BD}.

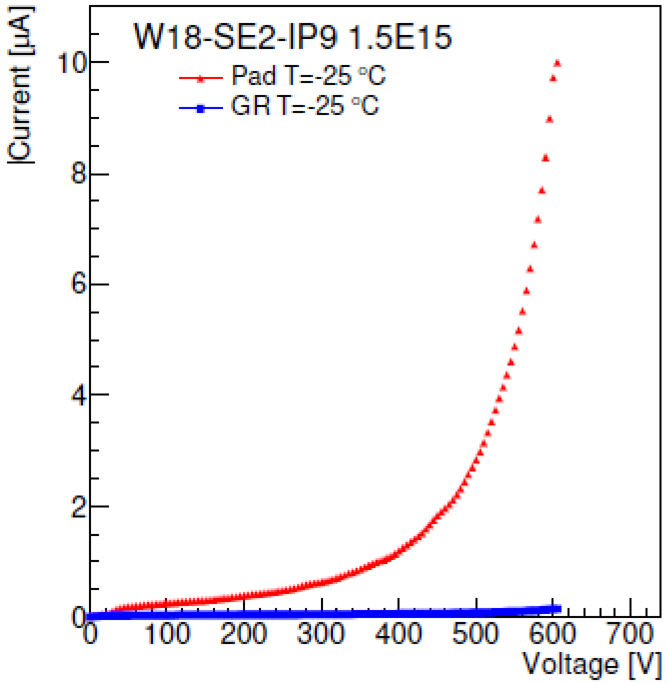
哥廷根HPK实验结果

- Yield
  - Good sensor：两种型号都在99%以上
  - Perfect sensor：阵列越大，比例越小
- 辐照后IV测量：1.5E15中子当量
  - I-V曲线
  - 辐照后的漏电流成因复杂，有待理论分析



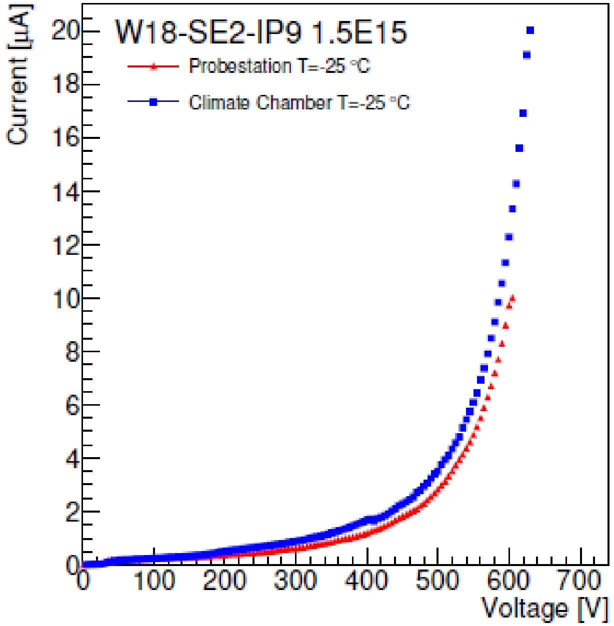
哥廷根HPK实验结果

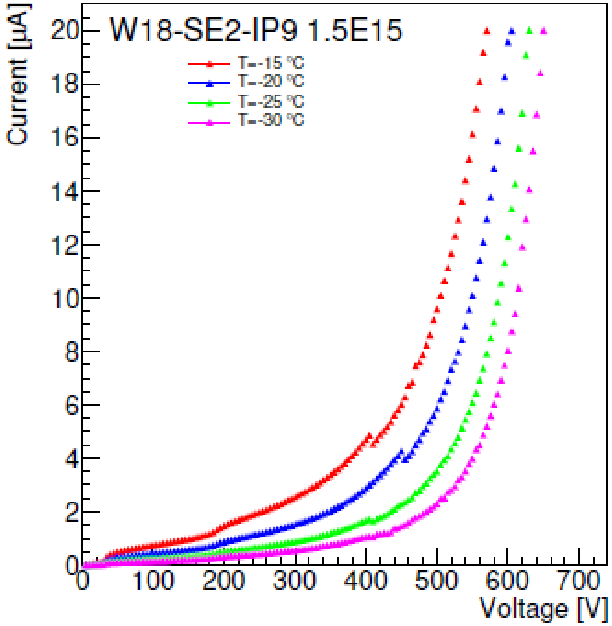
- 辐照后IV测量：1.5E15中子当量
  - 辐照后V_{BD}：5μA的外偏压
  - Pad和GR的I-V测量：为排除GR等的干扰



哥廷根HPK实验结果

- 辐照后IV测量：1.5E15中子当量
  - Probe-station与Climate Chamber测量的比较
  - （意义未明）





下一步计划

- 输入与输出的函数，即多少输入会有多少输出和多少噪声，查阅或计算其阈值。
  - 例如：e-h pair，亮度
- ATLAS的探测要求

谢 谢！