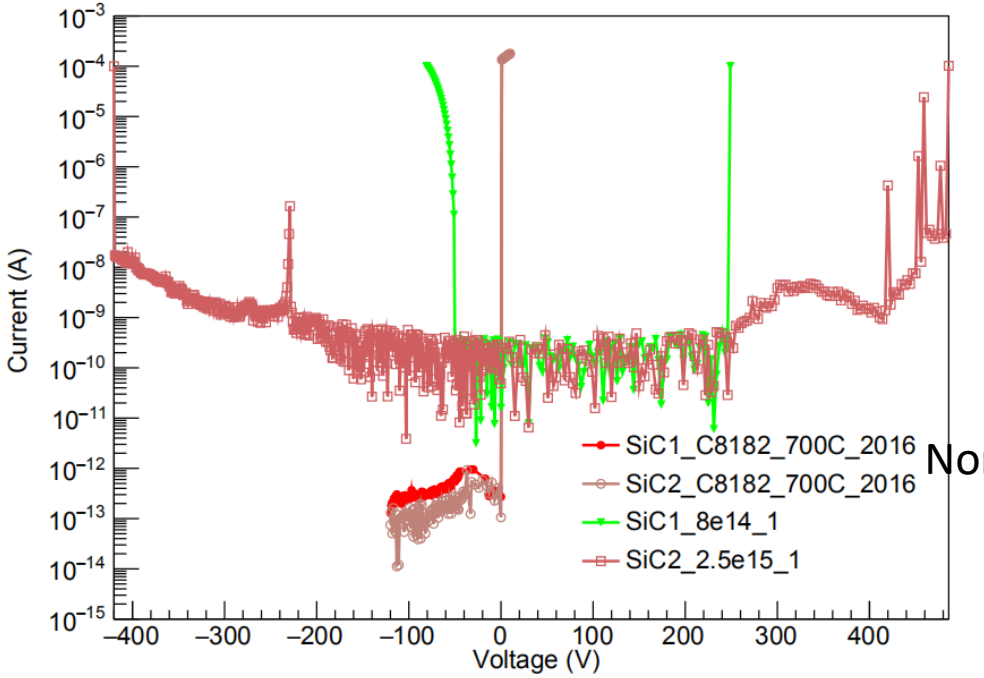
SiC JSI irradiation measurement

2021.3.24

IV 测试：

反偏　　正偏

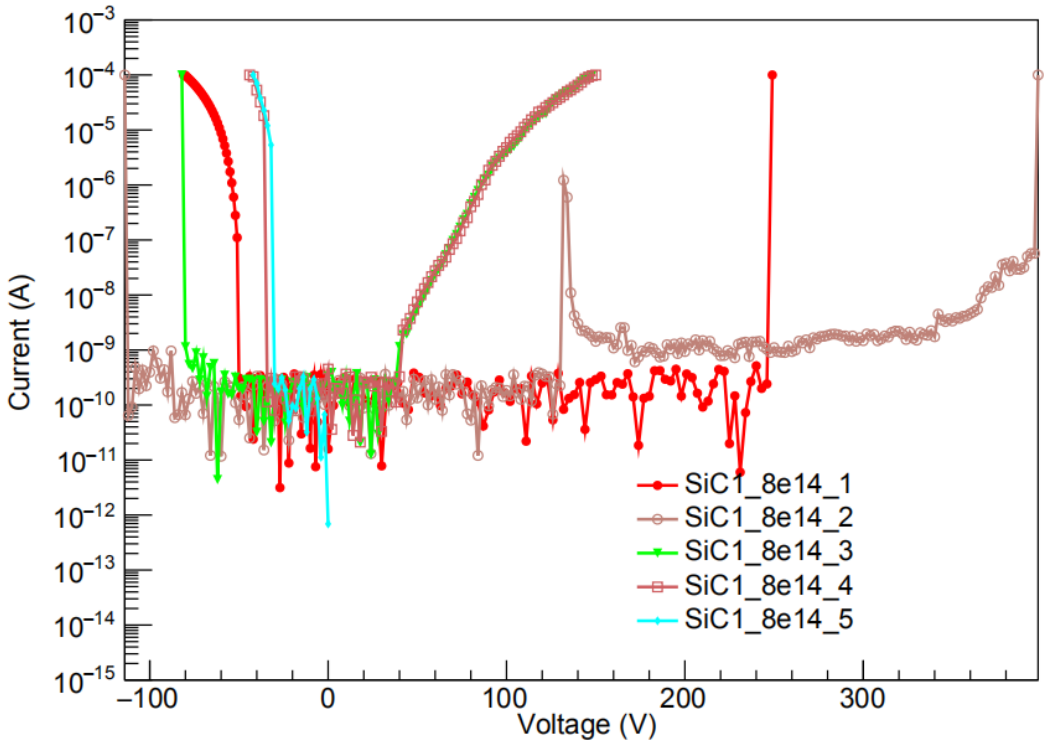


Non-irradiation

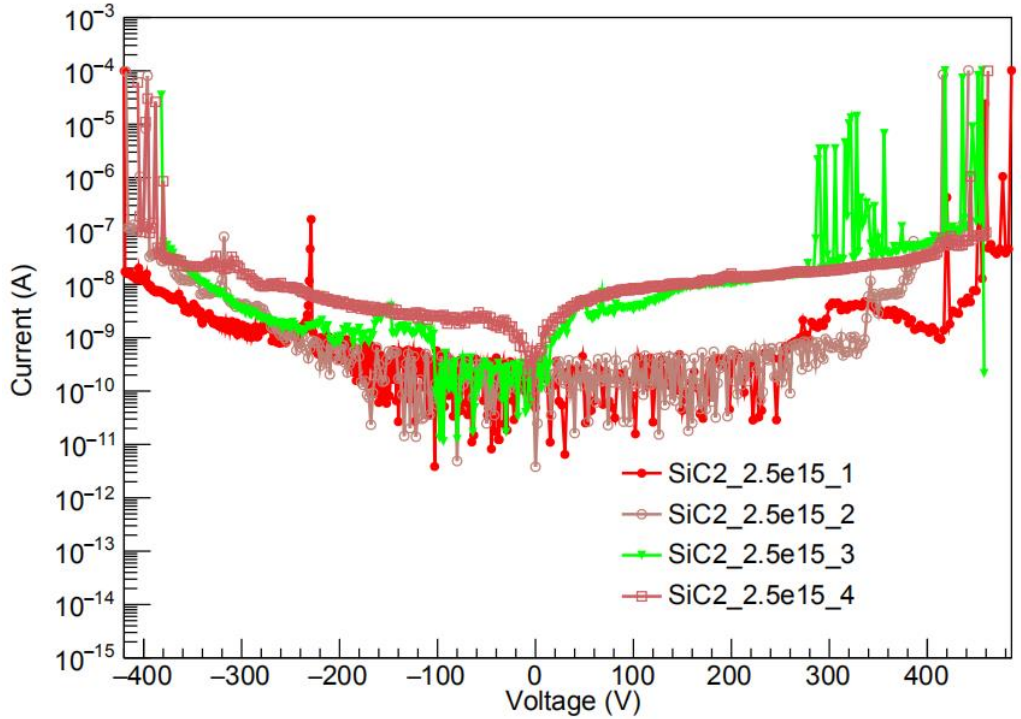
- 辐照令反偏电流从1e-12升到1e-10
- 正偏的“击穿电压”随辐照强度的增加而增加
- 正偏的“击穿电压”随辐照强度的增加先减小后增加？
- 是否有之前测试的此芯片的未辐照的IV和其击穿电压？？

重复测量：

8e14



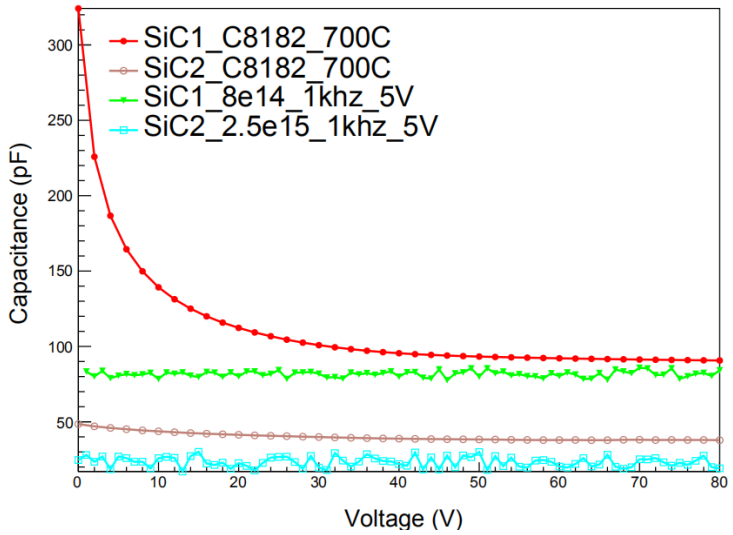
2.5e15



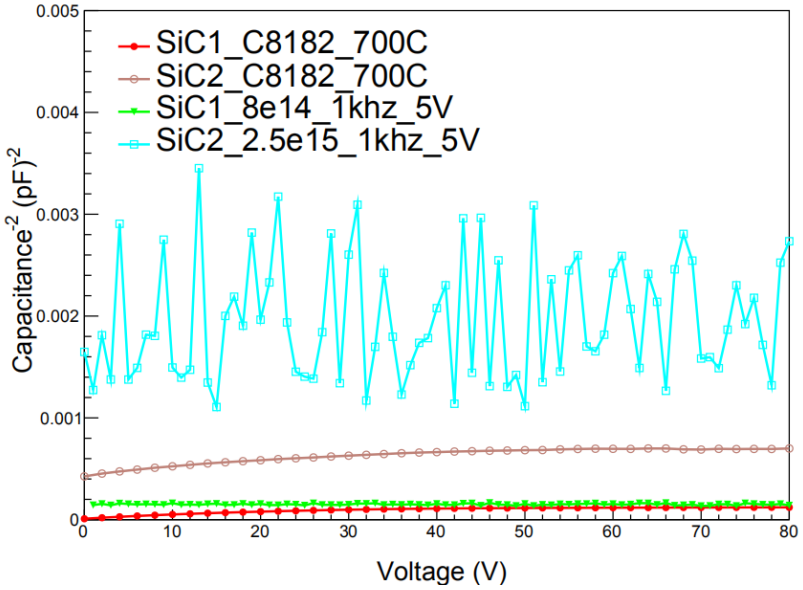
- 8e14辐照后的芯片的击穿测试为破坏性测试，不能重复。且击穿电压大致随测试次数减小
- 2.5e15辐照后的芯片的四次测量的击穿电压基本稳定，但两次测量后，漏电流有明显增加

CV 测试:

C-V



$1/C^2$ –V



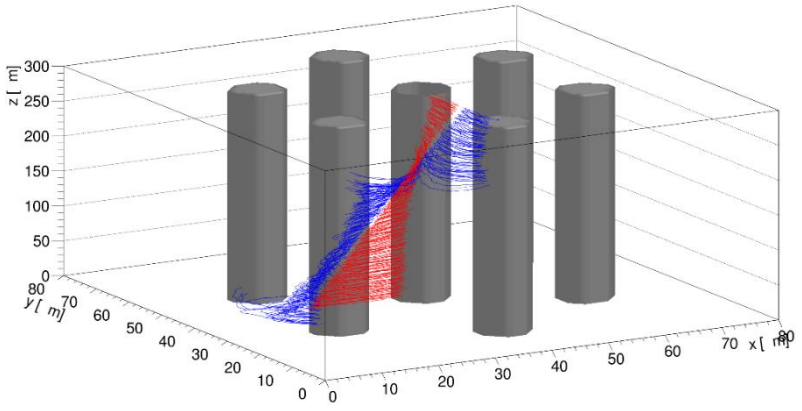
- 辐照后, SiC的全耗尽电容减小
- 辐照后，电容随电压基本不变
- 2.5e15 辐照后，稳定性很差

下一步计划：

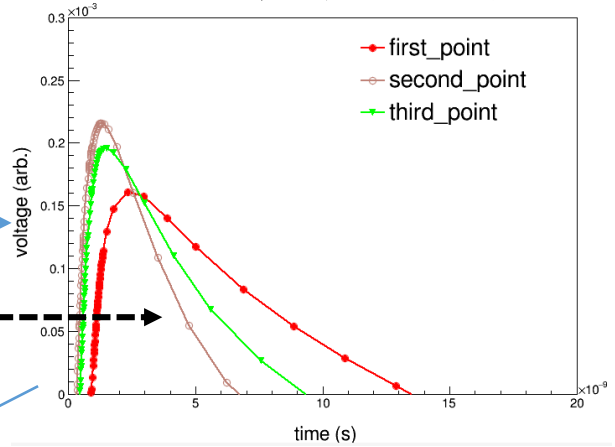
- 大连理工芯片结构，计算大概的电场
- 理解数据
- 尝试beta测试时间

3D Si 时间分辨模拟：

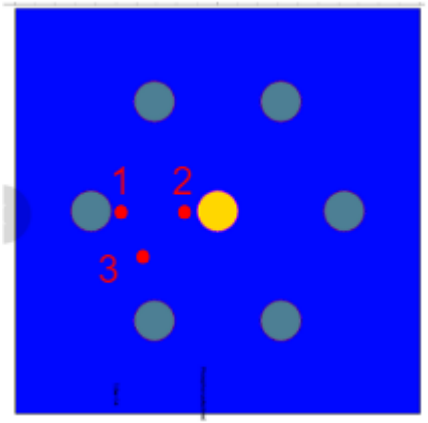
3D Si 的结构



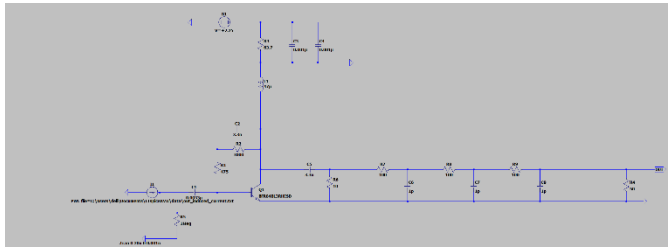
经过电子学的感应电流



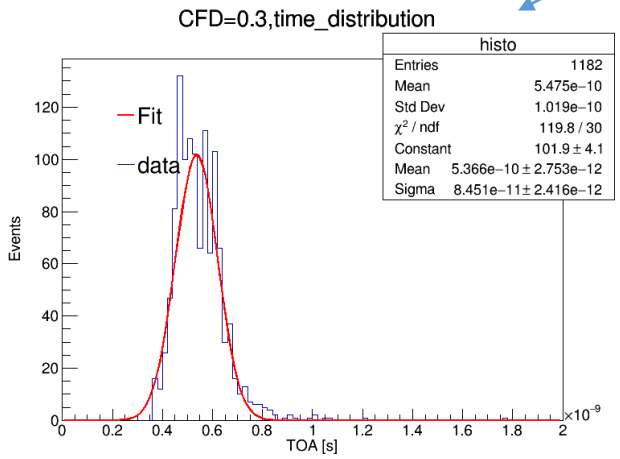
击中位置



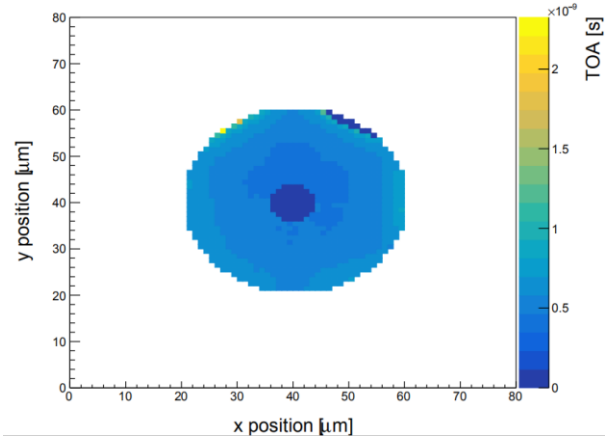
电子学



取最高点的30%的横坐标



平面TOA的分布



TOA分布不均匀意味着电场的不均匀

3D-Si 模拟流程以及如何转变为3D-SiC：

- 计算电场和加权场
- 模拟电荷的产生
- 产生电荷的漂移和漂移产生的感应电流
- 后端电子学

1.3D-Si 电场和加权场的计算：

Electric field

$\nabla \vec{D} = e_0 N_{eff}(\vec{r})$, $\vec{D} = \varepsilon\varepsilon_0 \vec{E}$, $\vec{E} = -\nabla U(\vec{r})$,

$$\nabla(\varepsilon(\vec{r})\nabla U(\vec{r})) = -\frac{e_0 N_{eff}(\vec{r})}{\varepsilon_0}$$

Boundary conditons:

$\frac{\partial U}{\partial x} = 0$, $\frac{\partial U}{\partial y} = 0$, $\frac{\partial U}{\partial z} = 0$ at borders of simulated volume

U = voltage at electrodes

Weigthing field

$\Delta U_w(\vec{r}) = 0$, $\vec{E}_w = \nabla U_w(\vec{r})$,

$\frac{\partial U_w}{\partial x} = 0$, $\frac{\partial U_w}{\partial y} = 0$, $\frac{\partial U_w}{\partial z} = 0$ at borders of simulated volume

$U_w = 1$ at readout electrode and $U_w = 0$ at all other electrodes

$$\nabla^2 U(\vec{r}) = -\frac{e_0 N_{eff}(\vec{r})}{\epsilon_{Si}\epsilon_0}$$

$$\vec{E} = -\nabla U(\vec{r}) \quad ,$$

- 3D-SiC 需要改变介电常数。 SiC不同方向的介电常数是否不同？

2.3D-Si 电荷的产生：

The energy lost in silicon was obtained from

$$\Delta E_{\mathrm{Si}} = \sum_{i=1}^{N} (\frac{dE}{dx})_i \Delta x_i \qquad (7.8)$$

where the sum runs over all tracking steps in silicon, usually $N = 1$ to 4. From $(\frac{dE}{dx})_i$ the bucket charge for the i-th tracking step was calculated as

$$Q_i^{bucket} = \frac{1}{3.6\ \mathrm{eV}} (\frac{dE}{dx})_i \ \Delta x_{bucket} \quad , \qquad (7.9)$$

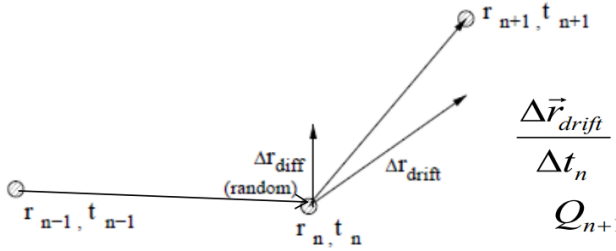
- 3D-SiC 需要改变dE/dx,和产生电子空穴对的平均能量

	产生电子空穴对的平均能量	MIP粒子经过探测器损失的能量[μm]	经过100μm，产生的电子空穴对
SiC	8.4eV	432eV	5100
Si	3.6eV	273eV	7583

3.电离产生电荷的漂移引起的感应电流：

Basics – Simulation of charge transport

- Charge/current induced by a point-like charge q



$$\vec{r}_{n+1} - \vec{r}_n = \Delta\vec{r}_{drift} + \Delta\vec{r}_{diff} \qquad D_{e,h} = \left(\frac{k_B T}{e_0}\right)\mu_{e,h} \quad ,$$

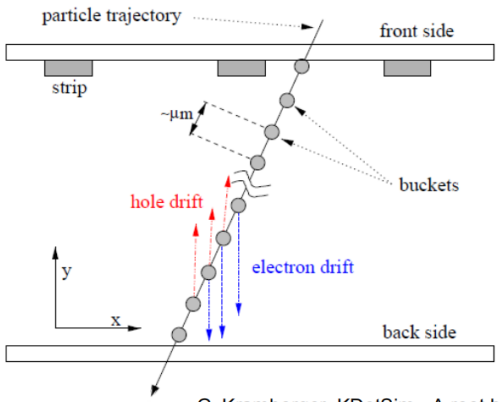
$$\vec{F} = \vec{E} + \mu_{He,h}\,\vec{E}\times\vec{B}$$

$$\frac{\Delta\vec{r}_{drift}}{\Delta t_n} = \mu\cdot\vec{F}(\vec{r}_n(t_n)) \quad , \quad \Delta\vec{r}_{diff} = \vec{G}aus(\sqrt{2D\Delta t_n})$$

$$Q_{n+1} - Q_n = q\cdot P(t_n,\tau_{eff})\cdot[U_w(\vec{r}_{n+1}) - U_w(\vec{r}_n)]$$

difference in U_w

P=0 or P=1 - trapping



$$I = \frac{Q_{n+1} - Q_n}{t_{n+1} - t_n}$$

$$I(t) = \sum_{buckets} I_e(t) + I_h(t)$$

Different models are already included (Gaussian beam, exponential attenuation of beam, minimum ionizing particle), but you can easily make your own function which distributes buckets q around the sensor

G. Kramberger, KDetSim - A root based 3D simulation tool for semiconductor detectors, 27th RD50 Workshop, CERN

➢ 若想改为3D-SiC：

1.SiC与Si中可能不同的模型：迁移率与温度的关系，与电场的关系，与掺杂浓度的关系

2.SiC中的载流子的扩散模型可能不同

3. 多电极感应电流的计算

Si中迁移率与温度，电场和掺杂浓度的关系：

$$
\begin{aligned}
\mu_{e,h}^{LI} &= \mu_{e,h}^{min} + \frac{\mu_{n,p}^{L} - \mu_{e,h}^{min}}{1 + \left(\frac{N_{eff}}{C_{e,h}^{ref}}\right)^{\alpha_{e,h}}} \\
\mu_{e,h}^{min} &= K_{e,h} \cdot \left(\frac{T}{300\ \mathrm{K}}\right)^{-0.45} \quad , \quad T > 200\ \mathrm{K} \quad , \quad K_e = 85\frac{\mathrm{cm}^2}{\mathrm{V\,s}}, \quad K_e = 45\frac{\mathrm{cm}^2}{\mathrm{V\,s}} \\
\mu_{e}^{min} &= K_{e,h} \cdot \left(\frac{200\ \mathrm{K}}{300\ \mathrm{K}}\right)^{-0.45} \cdot \left(\frac{T}{300\ \mathrm{K}}\right)^{-0.15} \quad , \quad T < 200\ \mathrm{K} \\
C_{e,h}^{ref} &= S_{e,h} \cdot \left(\frac{T}{300\ \mathrm{K}}\right)^{3.2} \quad , \quad S_e = 1.12 \cdot 10^{17}\ \mathrm{cm}^{-3}, S_h = 2.23 \cdot 10^{17}\ \mathrm{cm}^{-3} \\
\alpha_{e,h} &= 0.72 \cdot \left(\frac{T}{300\ \mathrm{K}}\right)^{0.065} \quad .
\end{aligned}
\tag{C.3}
$$

Deviations from the ohmic low-field mobility are given for both electrons and holes by

$$
\begin{aligned}
\mu_{e,h} = \mu_{e,h}^{LIF} &= \frac{2 \cdot \mu_{e,h}^{LI}}{1 + \left(1 + \left(\frac{2\,\mu_{e,h}^{LI}\,E}{v_{n,p}^{sat}}\right)^{\zeta_{e,h}}\right)^{\zeta_{e,h}^{-1}}} \quad , \quad \zeta_e = 2 \quad , \quad \zeta_h = 1 \\
v_e^{sat} &= 1.45 \cdot 10^7\ \mathrm{cm/s} \cdot \sqrt{\tanh\left(\frac{155\ \mathrm{K}}{T}\right)} \\
v_h^{sat} &= 1.45 \cdot 10^7\ \mathrm{cm/s} \cdot \sqrt{\tanh\left(\frac{312\ \mathrm{K}}{T}\right)}
\end{aligned}
\tag{C.4}
$$

Si的后端电子学：

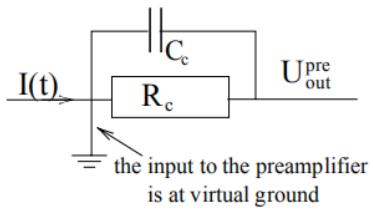
后端电子学由一个电荷灵敏放大器，一个CR电路和n(3)个RC电路组成：

下面是三种电子学的传递函数：

- 3D-SiC的后端电子学需要对这些电阻和电容的参数进行适当的改变。

下一步：

- 理解3D-Si的如何实现上述流程的代码



an ideal integrator
(preamplifier equivalent circuit)

Preamplifier

An ideal preamplifier is considered as a current integrator. Its equivalent circuit is shown in Fig. 2.9. The response - voltage at the output stage of the preamplifier can be calculated from

$$I(t) = C_c \frac{dU_{out}^{pre}}{dt} + \frac{U_{out}^{pre}}{R_c} \tag{2.43}$$

$$\frac{I(t)}{C_c} = \frac{dU_{out}^{pre}}{dt} + \frac{U_{out}^{pre}}{\tau_{pre}} \quad , \quad \tau_{pre} = R_c C_c \tag{2.44}$$

with a solution

$$U_{out}^{pre}(t) = \frac{1}{C_c} e^{\frac{-t}{\tau_{pre}}} \int_{-\infty}^{t} I(t') e^{\frac{t'}{\tau_{pre}}} dt' \quad , \tag{2.45}$$

CR-circuit (differentiation)

The equivalent circuit is shown in Fig. 2.9. The transfer function can be derived from

$$U_{in} = \frac{Q}{C} + U_{out}^{CR} \tag{2.46}$$

Differentiating both sides

$$\frac{dU_{in}}{dt} = \frac{1}{C}\frac{dQ}{dt} + \frac{dU_{out}^{CR}}{dt} \quad , \quad \frac{dQ}{dt} = I = \frac{U_{out}^{CR}}{R} \tag{2.47}$$

$$\frac{dU_{in}}{dt} = \frac{1}{\tau_{CR}} U_{out}^{CR} + \frac{dU_{out}^{CR}}{dt} \quad , \quad \tau_{CR} = C\ R \tag{2.48}$$

The solution of the differential equation 2.48 can be calculated as

$$U_{out}^{CR}(t) = U_{in}(t) - \frac{1}{\tau_{CR}} e^{\frac{-t}{\tau_{CR}}} \int_{-\infty}^{t} U_{in}(t') e^{\frac{t'}{\tau_{CR}}} dt' \tag{2.49}$$

RC-circuit (integration)

A equivalent circuit is shown in Fig. 2.9. The transfer function can be derived in the same way as for an CR circuit from

$$U_{in} = I\,R + U_{out}^{RC} \tag{2.50}$$

Substituting

$$I = \frac{dQ}{dt} = C\frac{dU_{out}^{RC}}{dt} \tag{2.51}$$

one gets

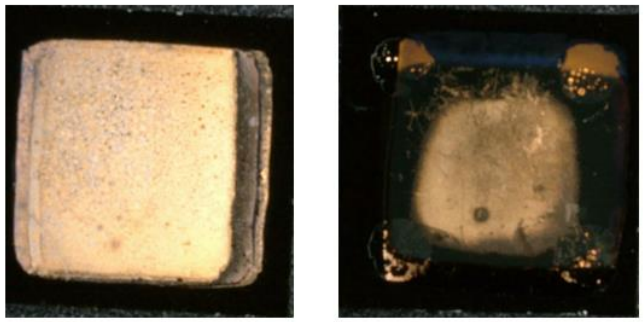
$$U_{in} = \tau_{RC}\frac{dU_{out}^{RC}}{dt} + U_{out}^{RC} \quad , \quad \tau_{RC} = RC \quad . \tag{2.52}$$

Eq. 2.52 has the solution

$$U_{out}^{RC}(t) = \frac{1}{\tau_{RC}} e^{\frac{-t}{\tau_{RC}}} \int_{-\infty}^{t} U_{in}(t') e^{\frac{t'}{\tau_{RC}}} dt' \quad ,$$

Backup

辐照的芯片：

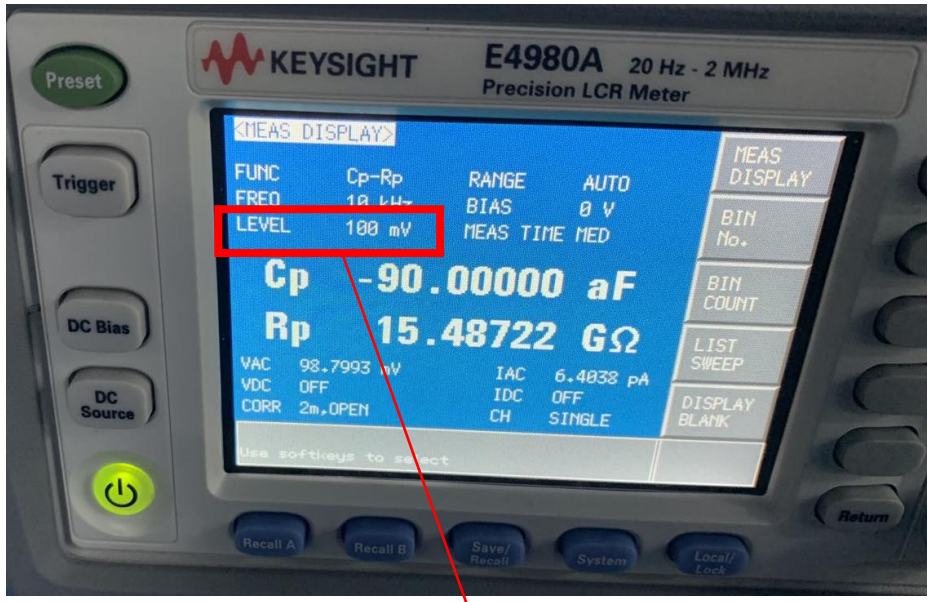


芯片外形

芯片编号



问题：
这个芯片的结构和每层结构的厚度？

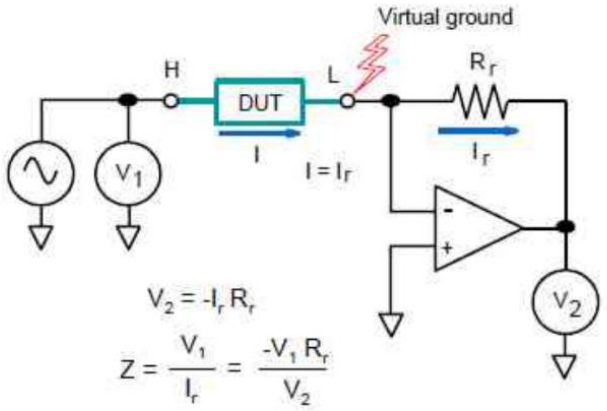


这个值必须大于5V，不然电流会超过100uA

5V为E4980A给的内部交流电压

2. 通用 LCR 电桥的原理模型?

随着现代模拟和数字技术的发展，特别是高速运放，微处理器技术的发展，现代阻抗测量大都使用自动平衡电桥法，如下图：



上图中：首先由信号源发生一个一定频率和幅度的正弦交流信号，这个信号加到被测件 DUT 上产生电流流到虚地“0V”，由于运放输入电流为零，所以流过 DUT 的电流完全流过 Rr，最后根据欧姆定律 DUT 的阻抗：Z = -V1*Rr/V2。因为运算放大器虚地功能的引入，使这种测量方法的精度和抗干扰能力产生了质的飞跃。

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