电子元件手册
Electronic Components Manual

丁毅

(中国科学院大学，北京 100049)

Yi Ding

(University of Chinese Academy of Sciences, Beijing 100049, China)

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序言

本文为笔者本科时的电子元件手册，对学习过程中接触较多的元件作了系统性的介绍和总结，同时对部分元件进行了仿真或实际电路测试，给出了相应的参数曲线或波形图。

随着学习的不断深入，笔者对某些元件的认识一定会更加深刻，也会认识新的元件。因此，笔者打算将本手册作为一份长期更新的（真的很长期）电子元件手册，既是我个人对元件知识的总结，也是便于以后自己参考。读者可到我的 GitHub 下载手册的最新版本 https://github.com/YiDingg/LatexNotes，也可以在我的个人网站 待更新 上找到相关资料。

另外，有相当一部分元件（例如 Operational Amplifier）其实是基础元件所构成的模块化电路。在本书，我们不会详谈如何通过基本元件搭建出这些进阶元件，而是讨论如何对这些元件（模块化的电路）建立正确的认识，探究在不同情况下应该选用怎样的模型进行分析，以达到足够高的精度，同时尽可能地降低模型复杂度。实现它们的具体电路，以及 Oscillators、Amplifiers 和 Power Supplies 等模块化电路，会放到另一本书《电子电路手册》中，读者可到网址 GitHub (https://github.com/YiDingg/LatexNotes/tree/main/[Notes] Electornic Circuits Manual) 自行下载和阅读。为了提高读者的自学效率，笔者在这里推荐几个免费而优秀的电子学习网站：

(1) Electornics Tutorials：这个网站提供了丰富的电子学习资料，包括 Transistors、Amplifiers、Diodes、Filters 等，还提供了很多实用的电子工程师工具，例如在线电阻电感电容计算器等；

(2) Learn About Electronics：这个网站提供了电子学习的基础和进阶知识，包括 Semiconductors, Amplifiers, Oscillators, Power Supplies 等，最令人惊喜的是几乎所有资料都提供了 PDF 下载，方便读者下载后自行学习；

(3) Electronics Lab：这个网站不仅开源了很多电子电路设计实例，包括基础电路、模拟电路、数字电路等，还提供了丰富的学习资源（文章）在 here；

(4) Microchip：这是 Microchip 官方的开发者帮助网站，提供了大量的电子元件的 Data Sheet、Application Notes、Reference Manuals 等，是学习 Microchip 产品的重要参考网站，当然，在这里也可以找到与模拟电路、数字电路相关的的学习资料；

由于个人学识浅陋，认识有限，文中难免有不妥甚至错误之处，望读者不吝指正。读者可以将错误发送到我的邮箱 dingyi233@mails.ucas.ac.cn，也可以到笔者的 GitHub (https://github.com/YiDingg/LatexNotes) 上提 issue，衷心感谢。

Preface

This is an electronic components manual that I wrote during my undergraduate studies. It provide a systematic introduction and summary of the components that I encountered frequently during my studies, also includes simulations or actual circuit tests for part of the components, along with corresponding characteristics curves and waveform graphs.

As the study progresses, my understanding of certain components will certainly become more profound, and new components will be encountered, too. Therefore, I plans to use this manual as a long-term (very long-term) electronic components manual, both as personal notes of my knowledge of components and as a reference for my reference manual in the future. Readers can freely download the latest version of the manual from my GitHub (https://github.com/YiDingg/LatexNotes), or find related materials on my personal website to be updated.

Additionally, there are a considerable number of components (such as Operational Amplifier) that are actually modular circuits composed of basic components. In this book, we will not delve into how to build these advanced components using basic components, but rather discuss how to properly understand these components (modular circuits), and explore the models that should be used for analysis in different situations to achieve sufficient accuracy, while minimizing model complexity. The specific circuits for constructing these components, such as oscillators, amplifiers, power supplies etc., will be included in another book *"Electronic Circuits Manual"* which can also be found on my GitHub (https://github.com/YiDingg/LatexNotes/tree/main/[Notes] Electornic Circuits Manual).

In order to better enhance the reader's self-study efficiency, I recommends several free and excellent online learning websites here:

(1) Electornics Tutorials (https://www.electronics-tutorials.ws): This website provides a wealth of electronic learning resources, including Transistors, Amplifiers, Diodes, Filters, and many practical tools for electronic engineers, such as an online resistor, inductor, and capacitor calculator.

(2) Learn About Electronics (https://www.learnabout-electronics.org): The website provides basic and advanced knowledge of electronics, including Semiconductors, Amplifiers, Oscillators, Power Supplies, and the best part is that almost all the materials are provided in PDF format for easy download and offline learning.

(3) Electronics Lab (https://www.electronics-lab.com): This website not only opensource many electronic circuit design examples, including basic circuits, analog circuits, and digital circuits, but also provides a wealth of learning resources and articles here (https://www.electronics-lab.com/articles).

(4) Microchip (https://developerhelp.microchip.com): This is Microchip's official developer help website which provides a wealth of data sheets, application notes, and reference manuals for electronic components. It is an important reference website for learning about Microchip products, and of course, you can also find learning materials related to analog circuits and digital circuits here.

Due to my own limited knowledge and understanding, there may be inappropriate or even incorrect parts in this article. I sincerely hope readers will point out any errors or inaccuracies. Readers can send errors to my email address dingyi233@mails.ucas.ac.cn, or report issues on my GitHub (https://github.com/YiDingg/LatexNotes) with my utmost gratitude.

Contents

Chapter 1   Diodes

1.1 Introduction

Diodes are the most famous semiconductor devices, widely used in various circuits. They are made of semiconductor materials, mainly silicon (used to be selenium and germanium), and various compounds and metals are added according to the required functions.

Briefly speaking, diodes have unidirectional conductivity, allowing current to flow in only one direction. Fig.1.1 are the IEEE standard circuit symbols of diodes and you can refer to reference [1] and [2] for more details. Classified by different principles, diodes can be divided into the following types:

(1) PN junction diode (general diode, PN 结二极管, 通用二极管)

(2) Schottky diode (肖特基二极管)

(3) Zener diode (齐纳二极管)

(4) tunnel diode (隧道二极管)

(5) LED (light-emitting diode, 发光二极管)

(6) photo diode (光电二极管)

According to different application scenarios (circuits), they can be roughly divided into several types:

(1) rectifier diode (整流二极管)

(2) switching diode (开关二极管)

(3) regulator diode (稳压二极管)

(4) limiter diode (限幅二极管)

(5) freewheel diode (续流二极管)

(6) point contact diode (点接触二极管)

(7) LED (light-emitting diode, 发光二极管)

(8) varible capacity diode (varicap diode, 变容二极管)

(9) TVS (Transient Voltage Suppressor, 瞬态抑制二极管)

General Diode   Zener Diode or Voltage Regulator   TVS   Step Recovery Diode

LED   Photo Diode   Varicap Diode   Schottky Diode   Tunnel Diode
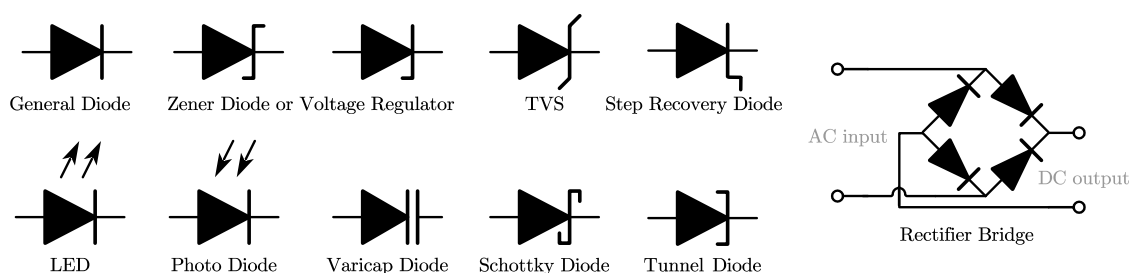
AC input   DC output   Rectifier Bridge

Figure 1.1: Diodes Circuit Symbols (IEEE Standard)

Fig.1.2 shows several common diodes and they are respectively:

(1) Three kinds of power rectifiers.

(2) A point contact diode (glass encapsulation) and a Schottky diode.

(3) A small signal silicon diode.

(4) Zener Diodes with glass or black resin encapsulation (树脂封装).

(5) A selection of light emitting diodes.
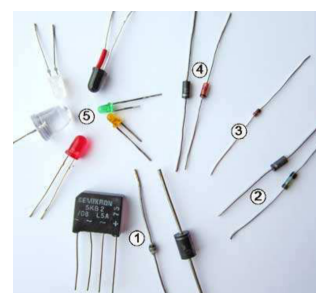

Figure 1.2: Some Common Diodes

1.2 General Diode (通用二极管)

1.2.1 Concepts and Models

The current flowing through a general diode (PN junction diode) satisfis:

$$I_\mathrm{D} = I_\mathrm{S} \left(\exp \frac{V_\mathrm{D}}{V_\mathrm{T}} - 1 \right) \tag{1.1}$$

Where I_S is the saturation current (bewteen 1 nA and 100 nA, typically 7 nA), $V_\mathrm{T} = \frac{k_B T}{q_e} \approx 26$ mV at 300 K, and V_D is the diode forward voltage.

Equation (1.1) is called the expotential model of diode, which is a good approximation for most situations, but too complicated for circuit analysis (especially if there are a lot of components). Therefore, we prefer to use some more simple models.

Fig.**??** shows several common models of diodes, including ideal diode model, constant voltage drop model, and piecewise linear model. Here are some tips for choosing the right model:

(1) To gain a intuition into the circuit, ideal mode could be a great choice, e.g. Fig.**??** (a).

(2) To analysis the exact behavior of the circuit, Fig.**??** (b) constant voltage drop model is a better choice.

(3) Fig.**??** (c) is an alternative to replace the expotential diode, which is called piecewise linear model.

1.2.2 1N4007 [GOODWORK (固得沃克)]

由 GOODWORK (固得沃克, 中国江苏) 生产的 1N4007 是一种功率/整流/通用二极管，常应用于整流电路等（同类型的有 1N4000, 1N4001, ..., 1N4006），可以在 立创商城 或 GOODWORK 官网 上找到它。
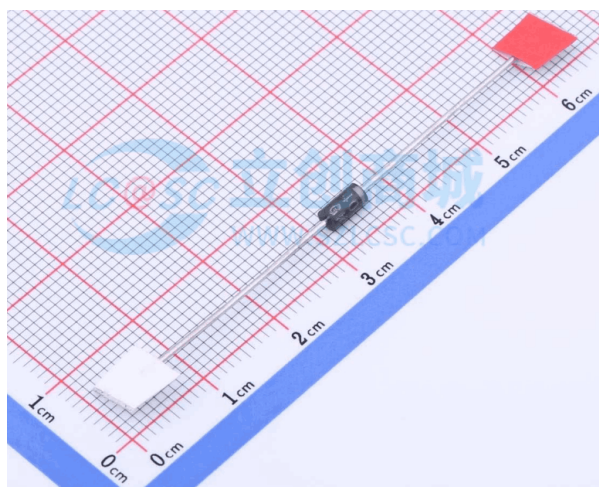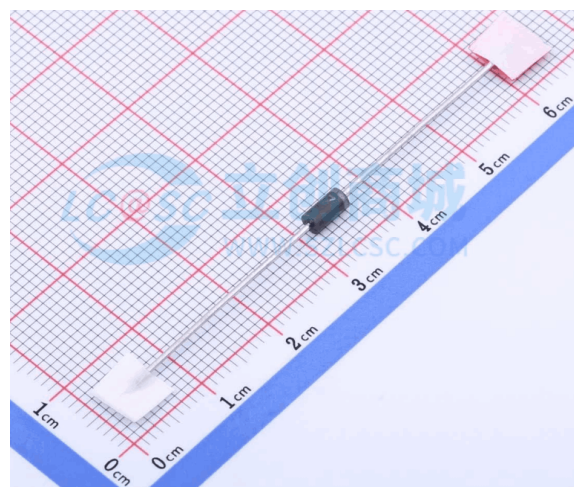
(a) The front side   (b) The back side

Figure 1.3: 1N4007 [GOODWORK (固得沃克)]

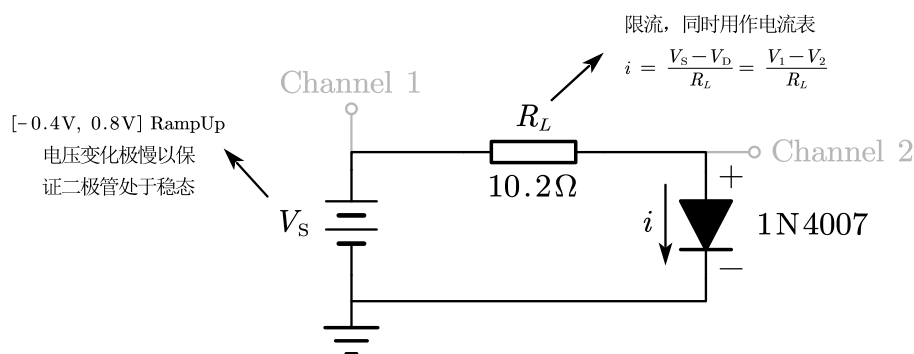Data Sheet 中的具体参数我们不再重复了，可到数据手册中自行查找。搭建测试电路如下，得到 Diodes 1N4007 的实际 I-V 工作特性如图 1.5 所示：

限流，同时用作电流表
$$i = \frac{V_S - V_D}{R_L} = \frac{V_1 - V_2}{R_L}$$

Channel 1

$[-0.4\,\text{V},\ 0.8\,\text{V}]$ RampUp
电压变化极慢以保
证二极管处于稳态

R_L

$10.2\,\Omega$

Channel 2

V_S

i

$1\text{N}4007$

Figure 1.4: Test Circuit for 1N4007 Operation Characteristics

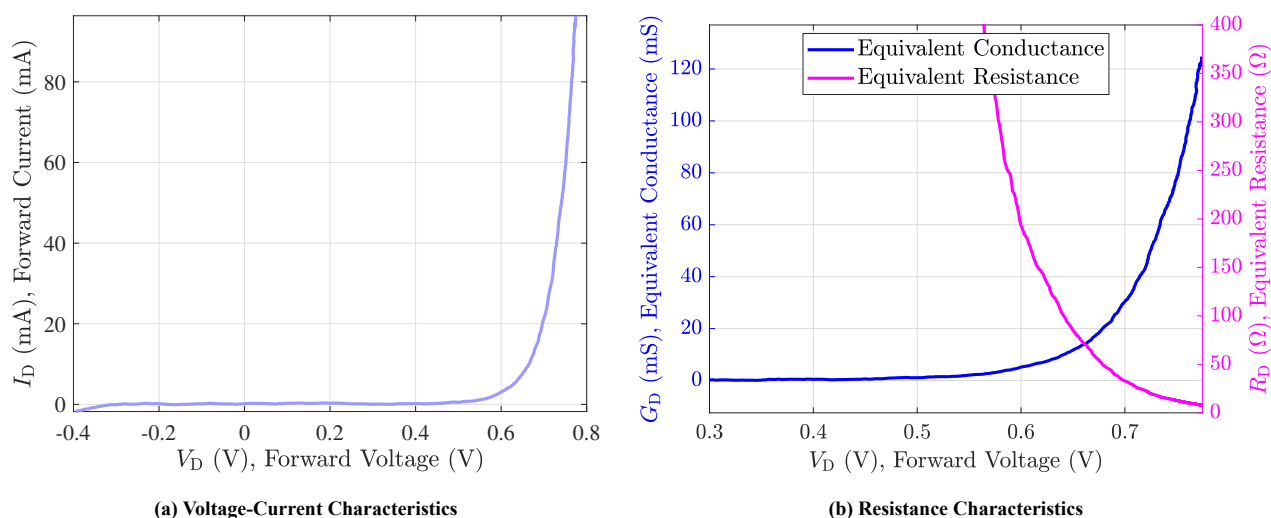**(a) Voltage-Current Characteristics**

(b) Resistance Characteristics

Figure 1.5: Operation Characteristics of 1N4007

1.3 Zener Diode (齐纳二极管)

1.4 LED (Light Emitting Diode, 发光二极管)

1.4.1 XL-302 [XINGLIGHT (成兴光)]

XL-302SURD (red)、XL-302SURC (white)、XL-302UYD (yellow)、XL-302UYC (green)、是由 XINGLIGHT
(成兴光, 中国广东) 生产的 LED，可以在 立创商城 或 XINGLIGHT 官网 上找到它们。其实物图如下：

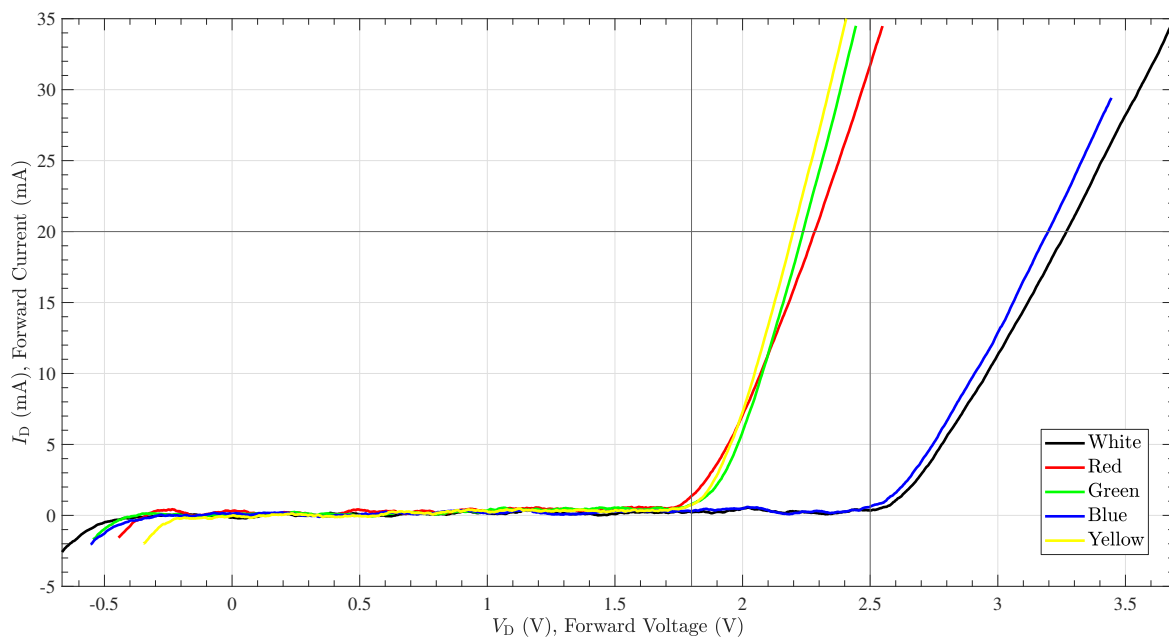## 1.4.2 LED [Txxbao (某宝)]

在某宝中购买大小和外观与 XL-302 相同的 LED，其电气特性如下：
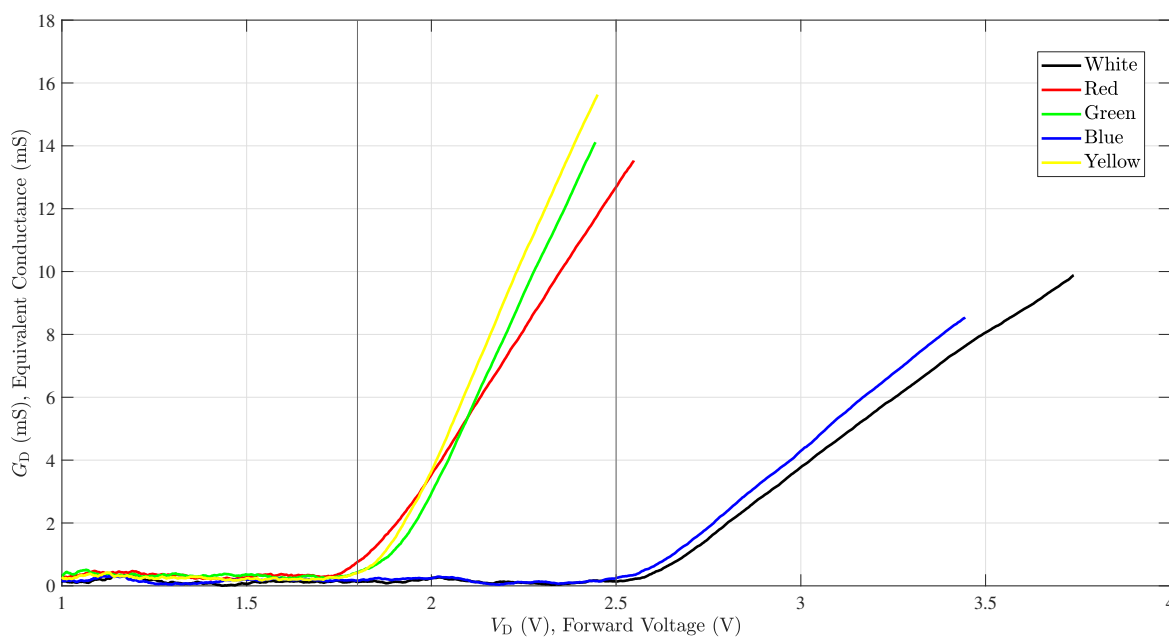
Figure 1.6: Voltage-Current Characteristics

Figure 1.7: Equivalent Conductance Characteristics

由图可以看到，黄绿红三色导通电压 V_{th} 和 20 mA 工作压降 V_{D} 分别为：

$$V_{\text{th}} = 1.8\text{ V}, \quad V_{\text{D}} = 2.3\text{ V} \quad \text{(Yellow, Green, Red)} \tag{1.2}$$

而蓝色和白色 LED 的导通电压 V_{th} 和 20 mA 工作压降 V_{D} 分别为：

$$V_{\text{th}} = 2.5\text{ V}, \quad V_{\text{D}} = 3.2\text{ V} \quad \text{(Blue, White)} \tag{1.3}$$

## 1.5 Schottky Diode (肖特基二极管)

Chapter 2   Transistors

2.1 BTJ (Bipolar Transistor Junction, 双极型晶体管, 三极管)

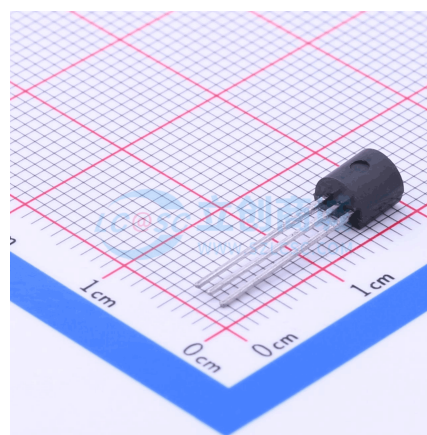## 2.2 JFET (Junction Field Effect Transistor, 结型场效应晶体管)

2.3 MOSFET (Metal-Oxide -Semiconductor Field Effect Transistor, 金属氧化物半导体场效应晶体管)

2.3.1 2N7000 [onsemi (安森美)]

     2N7000 [onsemi (安森美)] 是由 onsemi 公司生产的 N-Channel Enhancement Mode Field Effect Transistor (N-Channel Enhancement MOSFET)，可以在 立创商城 或 GOODWORK 官网 上找到它。其实物图如下：
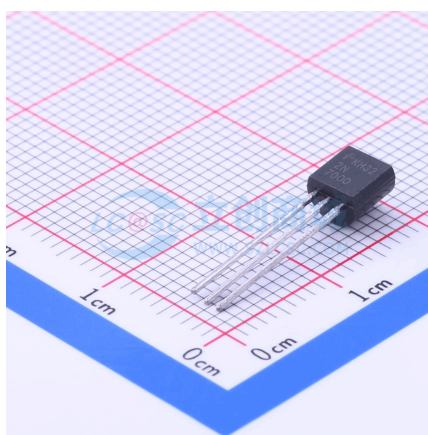
(a) The front side   (b) The back side

Figure 2.1: 2N7000 [onsemi (安森美)]

     用经典反相器结构，取合适的电阻 R_L 用作电流表（我们这里取 $R_L = 5.2\Omega$），固定 V_{GS}，同时改变 V_{DS}，可以得到 MOS 的工作特性 (Operation Characteristics) $I_{\mathrm{DS}} = I_{\mathrm{DS}}(V_{\mathrm{DS}})$，这包括了导通特性 (On-Region Characteristics) 和体二极管特性 (Body Diode Characteristics)。
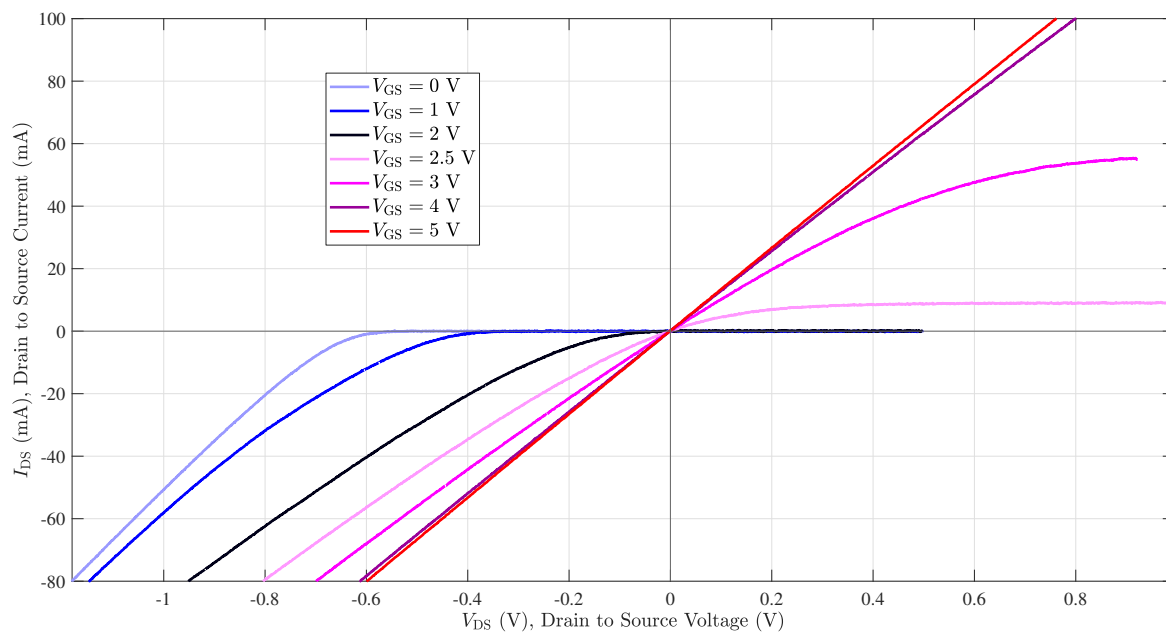
Figure 2.2: Operation Characteristics of 2N7000

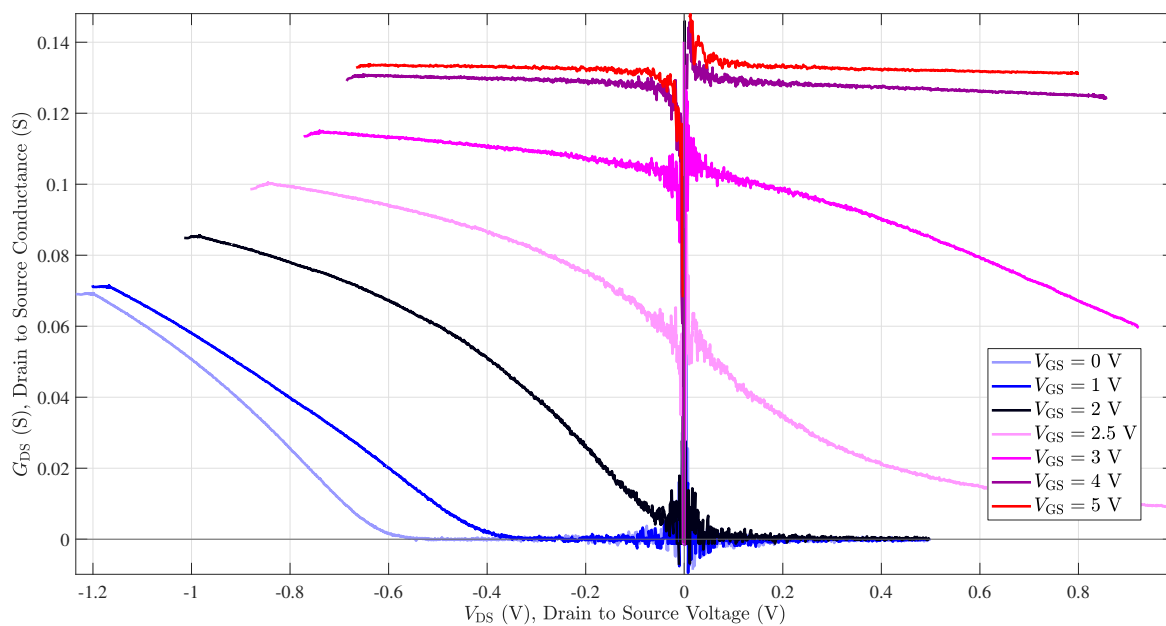依据实际测得的数据，可以计算出 MOS 的等效电导特性 (Equivalent Conductance Characteristics)，如下图所示：

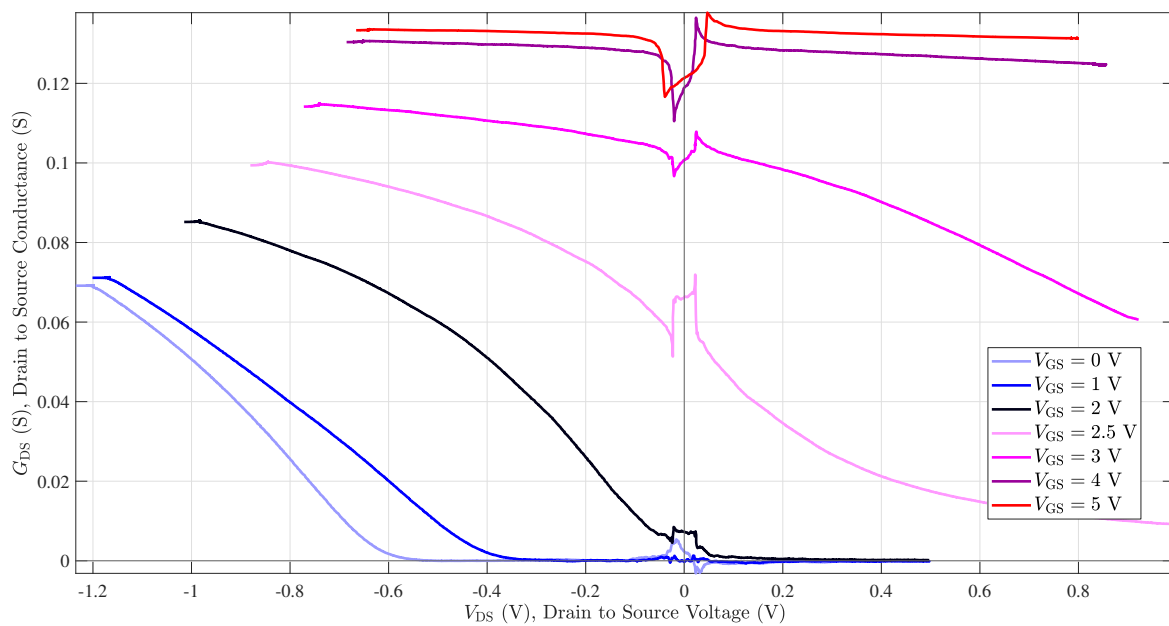**Figure 2.3: Equivalent Conductance Characteristics of 2N7000**

Figure 2.4: Filtered Equivalent Conductance Characteristics of 2N7000

固定 V_{DS}，改变 V_{GS}，串联万用表以测量 I_{DS}，得到 2N7000 的转移特性曲线 $I_{\text{DS}} = I_{\text{DS}}(V_{\text{GS}})$ 如下：
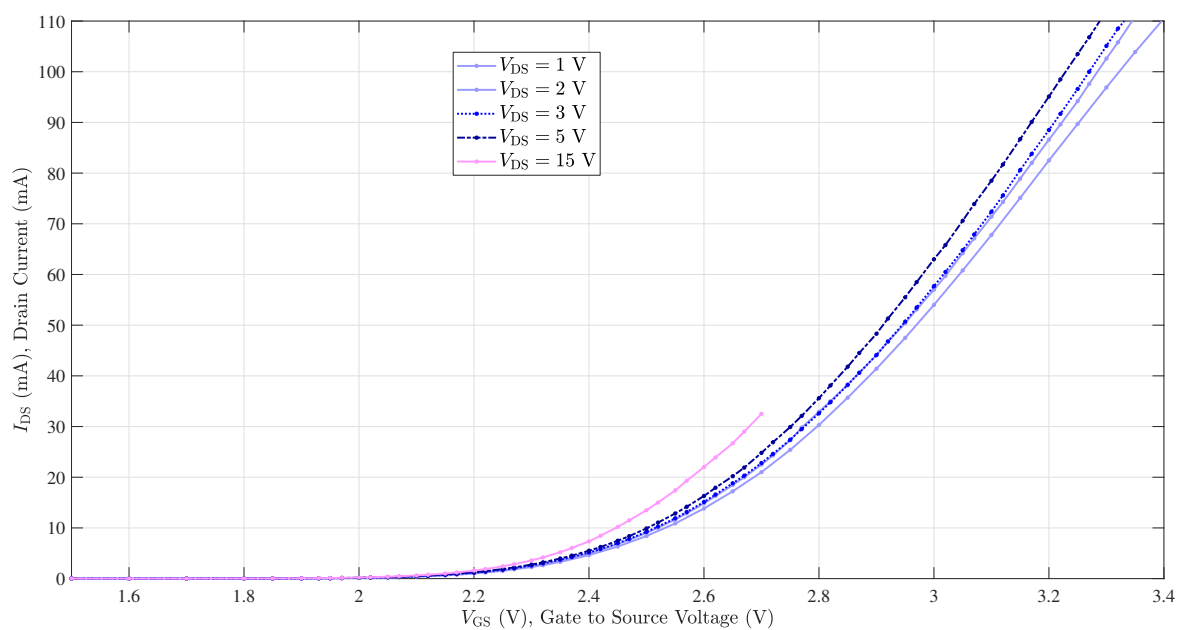
Figure 2.5: Transfer Characteristics of 2N7000

上图中 $V_{\text{DS}} = 15\,\text{V}$ 时仅测到 $V_{\text{GS}} = 2.7\,\text{V}$，这是因为往后 MOS 管发热严重，温度不断上升，无法得到稳定示数。用 $V_{\text{DS}} = 15\,\text{V}$ 时测得的数据拟合饱和电流公式 $I_{\text{DS}} = \frac{K}{2}\left(V_{\text{GS}} - V_{\text{T}}\right)^2$，其中 K 和 V_{T} 是待定参量，得到：

$$V_{\text{T}} = 2.109\,\text{V}, \quad K = 0.182\,\text{A} \cdot \text{V}^{-2} = 182\,\text{mA} \cdot \text{V}^{-2} \tag{2.1}$$

7
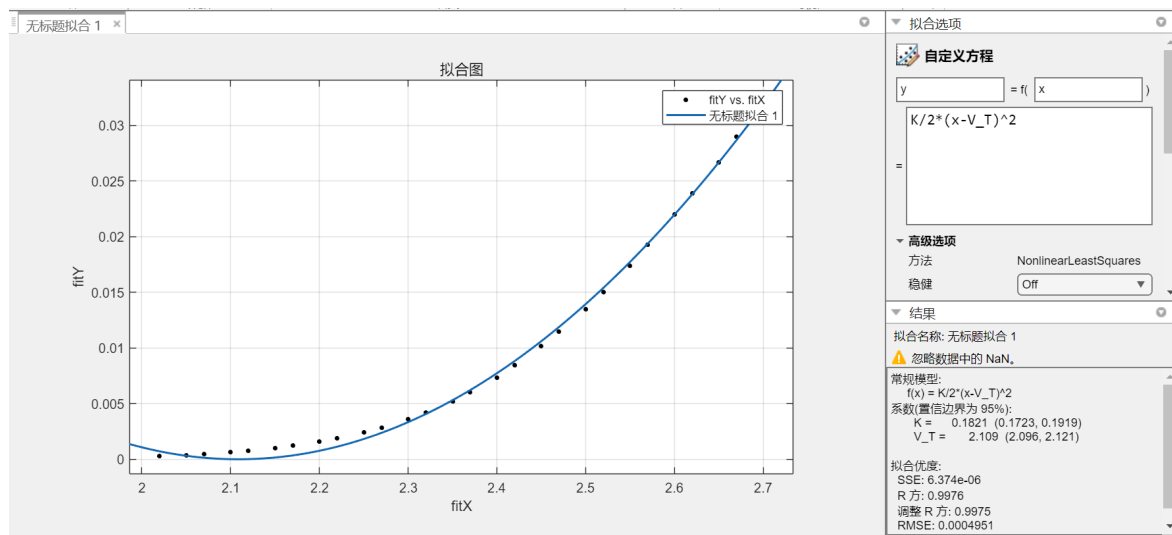
Figure 2.6: Threshold Voltage of 2N7000

用 $V_{\text{DS}} = 5\,\text{V}$ 时的数据，拟合得到

$$V_{\text{T}} = 2.156\,\text{V}, \quad K = 0.1742\,\text{A} \cdot \text{V}^{-2} = 174.2\,\text{mA} \cdot \text{V}^{-2} \tag{2.2}$$

2.3.2 FinFET (Fin Field-Effect Transistor, 鳍式场效应晶体管)

2.4 MODFET (Modulationdoped Field-Effect Transistor, 调制掺杂场效应晶体管)

2.5 Darlington Transistors (达林顿晶体管)

Reference

[1] IEEE Standard for Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters). *IEEE Std 315-1975 (Reaffirmed 1993)*, pages 1–176, 1975. https://ieeexplore.ieee.org/document/8996120.

[2] IEEE Standard American National Standard Canadian Standard Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters). *IEEE Std 315-1975 (Reaffirmed 1993)*, pages i–244, 1993. https://ieeexplore.ieee.org/document/985670.

[3] Behzad Razavi. *Fundamentals of Microelectronics*. University of California Press, 2nd edition, 2014.

[4] Behzad Razavi. *Design of Analog CMOS Integrated Circuits*. McGraw-Hill Education, 2nd edition, 2017.