Chapter 1

Introduction

1.1 General Background and Motivation

In recent years, Organic Thin Film Transistors(OTFTs) based on conjugated polymers, oligomers or other molecules have attracted tremendous attention due to their potential advantages of low-cost, low-temperature, large coverage area, simple structure, and compatibility with plastic substrates. They can be applied to large area and low cost display devices such as AMLCD/AMOLED, or low end electronics such as smart card, car keys, and identification tags. With the development of material and process technology, the performance of OTFTs based on pentacene even can compare with hydrogenated α-Si TFTs [1.1],[1.2].

The classification, deposition method, field-effect mobility, and conducting carrier type of several commonly used organic semiconductors are listed in Table 1-1. Deposition methods of organic semiconductor film include vacuum evaporation, solution-processed deposition, Langmuir-Blodgett technique [1.4], and electro-polymerization. Among most commonly used organic semiconductors, we chose poly-3-hexylthiophene or P3HT as active layer of OTFT in our research because P3HT can be deposited by spin coating. The key feature that makes organic semiconductors attractive for low-cost manufacturing is the possibility for them to be deposited from spin coating, enabling very homogeneous films with perfect control of their thickness over large area. In addition to solution process, P3HT has shown the field-effect mobility 0.01 to 0.1[1.3],[1.4],[1.5].

1.2 Introduction to Poly-3-hexylthiophene, P3HT

The structure of the polymer chain of P3HT has been shown in Fig. 1-1. The 3-alkyl substituents can be incorporated into a polymer chain with two different regioregularities: head to tail (HT) and head to head (HH) [1.6],[1.7]. Here R represents the alkyl side chain (C_6H_{13} for P3HT), which allows P3HT to be dissolved in solvents like chloroform. A regiorandom P3HT consists of both HH and HT 3-hexylthiophenes in a random pattern while a regioregular P3HT has only one kind of 3-hexylthiophene backbone, either HH or HT. With a higher ordering, or regioregularity, much higher field-effect mobility can be obtained than those polymers with regiorandom (disordered side chains) structure [1.8] Polymers with regioregular molecular structure exhibit very different properties from their regiorandom counterpart including a smaller band gap, better ordering and crystallinity in solid states and substantially improved electroconductivities [1.9]. The P3HT material we used in this experiment consists 98% or more head-to-tail linkages. Except regioregularity, the length of alkyl side chain also affects the ordering and hence the mobility. A study of P3ATs (A=hexyl, octyl, dodecyl, hexadecy) showed that the mobility decreases with increasing the length of side chain [1.10].

Two different methods are usually applied to deposit the P3HT film. One is spin coating while the other is dip coating (or solution casting), in which the samples are dipped in the P3HT solution and we wait until the solvents evaporates naturally. The mobility of spin-coated films is usually lower than that of the cast films, perhaps because for cast films, the evaporation rate of solvents is slower and results in a slower crystal growth with better ordered polymer structure [1.9], [1.11].Althought dip coating provides higher mobility than spin coating, it can not be applied for large coverage area. Therefoer, we used spin coating method to deposite P3HT thin film. After being deposited on the substrate, P3HT backbones may form two different morphologies, that is, edge-on or face-on of the lamella structure as shown in Fig. 1-2.

The mobility is much higher for edge-on structure since the carriers can move more efficiently through intra-chain transport along the direction of π-π stacking [1.12].

1.3 OTFTs beased on P3HT with Bottom-Contact Structure

There are two different structures for OTFTs, top-contact and bottom-contact. As shown in Fig. 1-3, top-contact structure involves both source and drain electrodes deposited on the top of active layer through a shadow mask, while bottom-contact structure involves source and drain electrodes patterned on the gate insulator prior to the active layer. In general, OTFTs with top-contact structure exhibit field-effect mobility twice than those with bottom-contact due to higher structure order of P3HT chains [1.11]. We chose bottom-contact structure because pattern process can use conventional lithography technique. The schematic diagram and layout of OTFT in our experiments is shown in Fig. 1-4. A n+ silicon wafer was formed as common gate electrode. The device is complete after P3HT is deposited.

1.4 Operation of Organic Thin Film Transistor

Refer to [1.3], the operation of OTFT based on P3HT is described in detail. Instead of inversion mode operation of silicon MOSFETs, the OTFTs are primarily operated as a p-type accumulation-mode enchancement transistor.

Mode (A)：When zero bias is applied to all three contacts of OTFT, as shown in Fig 1-5(a), if a small drain bias V_D is applied in this condition, the source-drain current I_{SD} will be small and ohmic.

Mode (B)：When a negative gate bias V_G is applied, as shown in Fig 1-5(b), the voltage is dropped over the insulator and semiconductor near insulator/semiconductor interface, accumulating more positive charge in the accumulation region. The additional positive chare is supplied by the ohmic source and drain contact and it will reduce channel resistance. If a small drain bias V_D is applied, the source-drain current I_{SD} will become larger than that of Mode (A).

Mode(C)：When a positive gate bias V_G is applied, the band bending occurs in the semiconductor at the insulator interface. Charge will reject from the interface and depletion region will form as shown in Fig. 1-5(C). The channel resistance is large so the source-drain current will become smaller than that of Mode (A). Because of the large band gap, inversion layer cannot be observed in organic TFTs.

Mode(D)：When a negative enough drain bias than gate V_D is applied in mode(a), the positive charge near the drain contact will be swiped to drain electrode and form a depletion region as shown in Fig. 1-5(d). This condition is similar to saturation mode of silicon MOSFETs. In this mode the source-drain current I_{SD} will not increase with the increasing drain bias voltage.

1.5 Thesis Organization

In chapter 1, we described background and motivation of our research.

In chapter 2, we fabricated OTFTs with SiO_2 as gate insulator by PECVD and LPD. To reduce gate leakage current, we demonstrated a stacked structure which is raised by SiO_2 as an isolation layer by Selective LPD(S-LPD) under source and drain electrodes.

In chapter 3, we discussed the electrical characteristics of devices under various plasma treatment on the surface of gate insulator. Devices with plasma treatment showed irregular variance on both field-effect mobility and threshold voltage. We also found optimal condition according to various plasma sources and exposure time in our experiment of plasma treatment.

In chapter 4, conclusions and recommendation for future works were given.

	Material	Film Deposition Method	Carrier Mobility	Carrier type
Oligomers	Pentacene	1. Monocrystalline growth 2. vacuum evaporation 3. solution-processed from precursor	1.7/2.7 1.2 10^{-2}	e^-/h^+ h^+ h^+
	α-sexithiophene	Vacuum evaporation	0.7/1.1	e^-/h^+
	Perylene	Monocrystalline growth	5.5	e^-
	C_{60}	Vacuum evaporation	0.002-0.08	e^-
	TCNQ	Vacuum evaporation	1.9×10^{-5}	e^-
	$F_{16}CuPc$	Vacuum evaporation	0.03	e^-
Polymers	Regioregular-P3HT	Solution processed	0.01-0.1	h^+
	Polyfluorene copolymers	Solution processed	0.03	h^+
	PTV	Solution processed from precursor	10^{-3}	h^+

TABLE 1-1 Characteristics of some of the most commonly used organic semiconductors

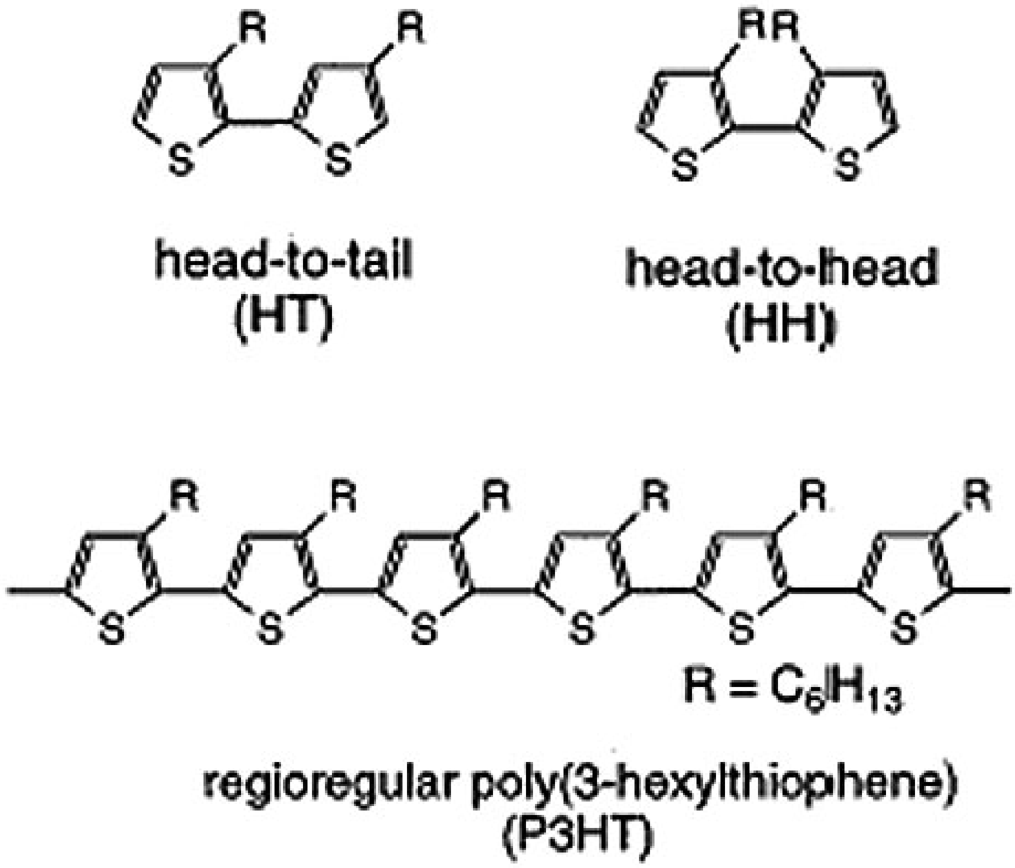


Figure 1-1 Molecular structure of poly-3-hexylthiophene

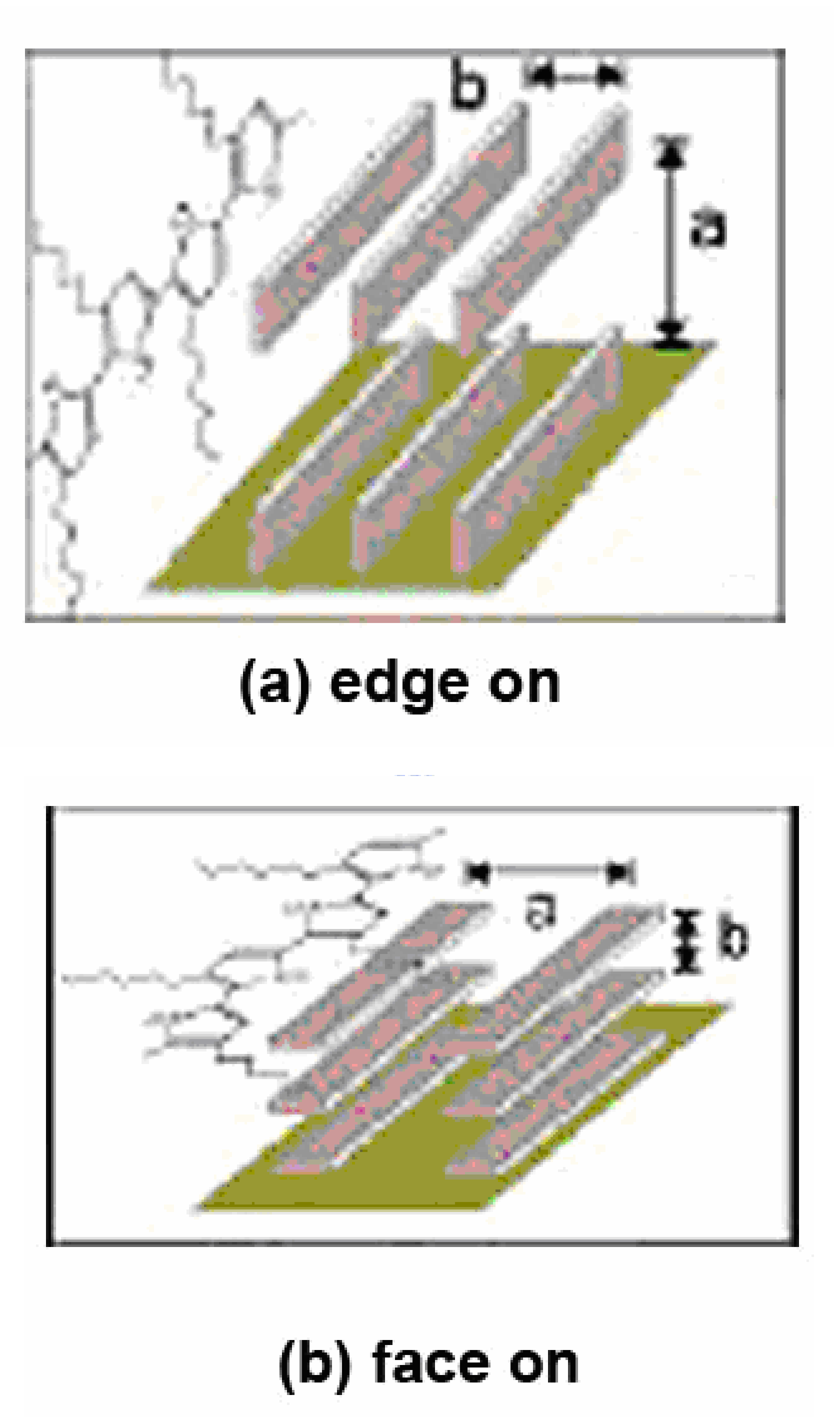
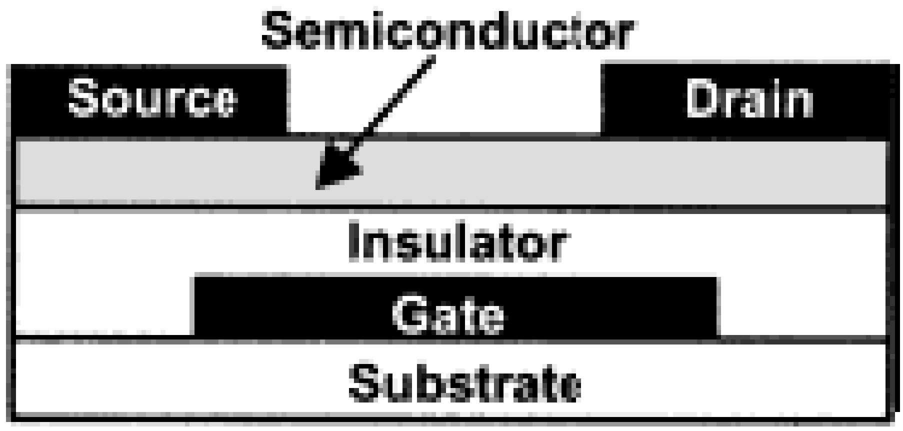


Figure 1-2 Two different orientations of ordered P3HT lamella structure with respect to the substrate

(a)



(b)

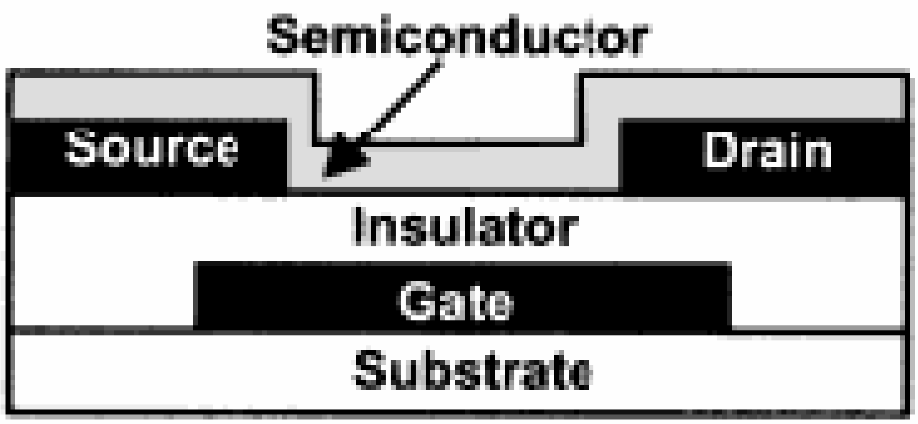
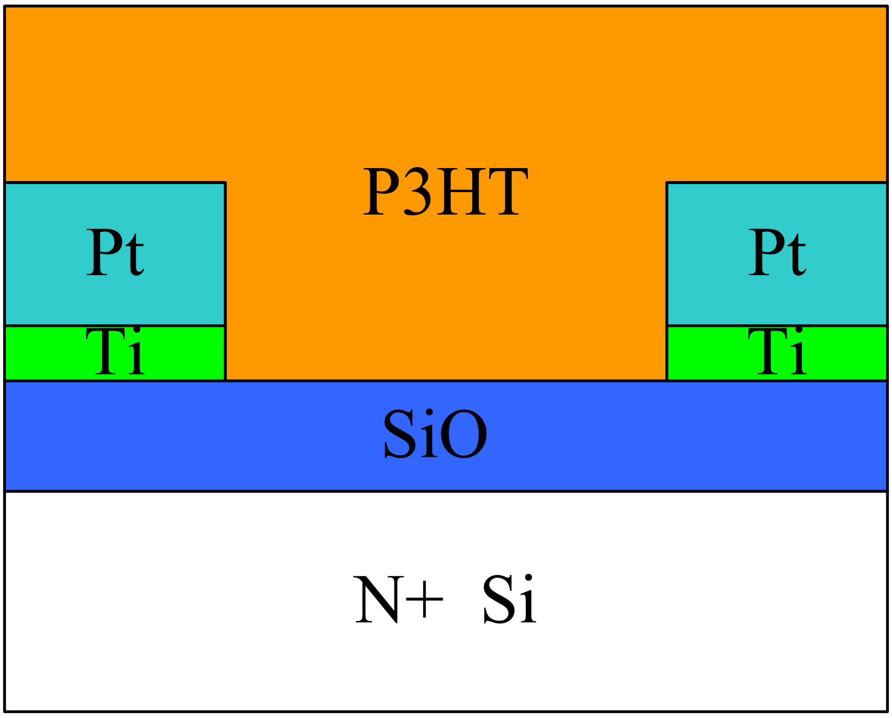


Figure 1-3 OTFT device configurations：(a)Top-contact device, with source and drain electrodes evaporated onto the organic semiconducting layer through a mask. (b) Bottom-contact device, with the organic semiconductor deposited onto the gate insulator and the prefabricated source and drain electrodes[1.13].

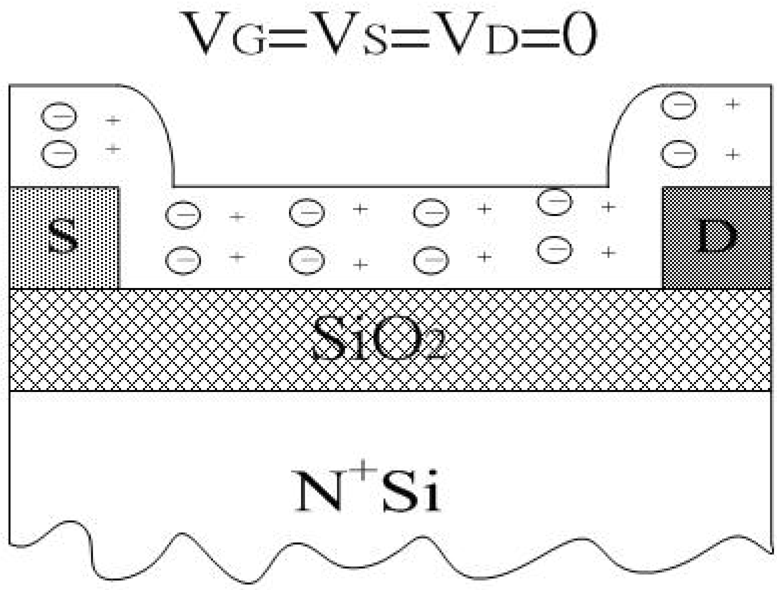
(a)



(b)

Figure 1-4 (a)the schematic diagram of bottom-contact OTFT. (b)the layout of comb structure for source and drain electrodes.

(a)



(b)

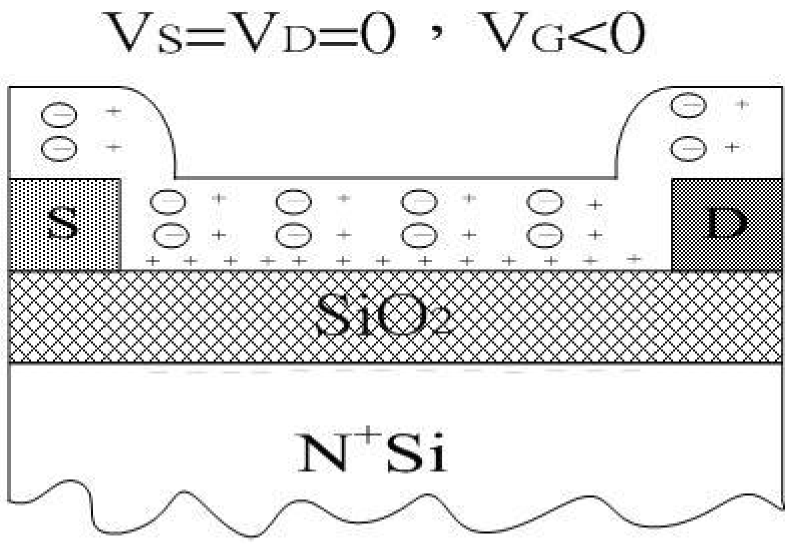
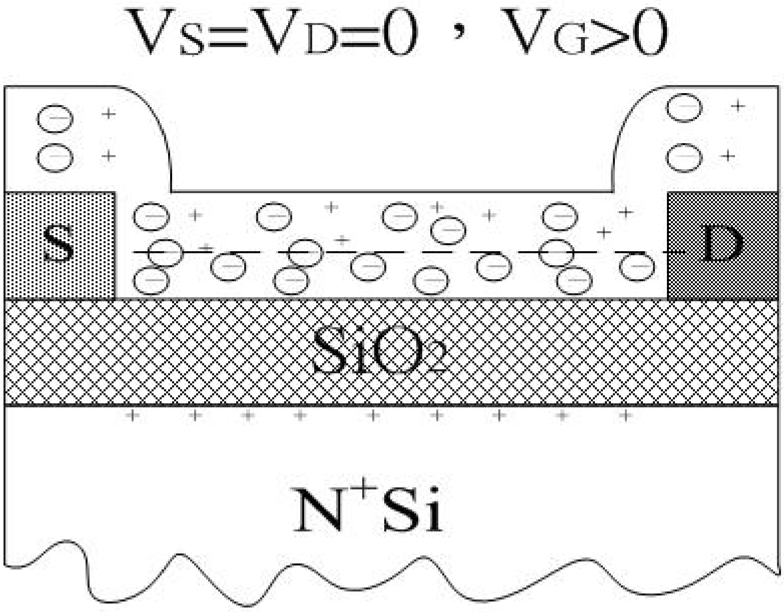


Figure 1-5 Schematic of operation modes of organic thin film transistor, showing a lightly p-doped semiconductor： + indicates a positive charge in semiconductor ; - indicate a negative charge counterion(a) no-bais (b) accumulation mode (c) depletion mode (d) channel pinch-off.(continue)

(c)



(d)

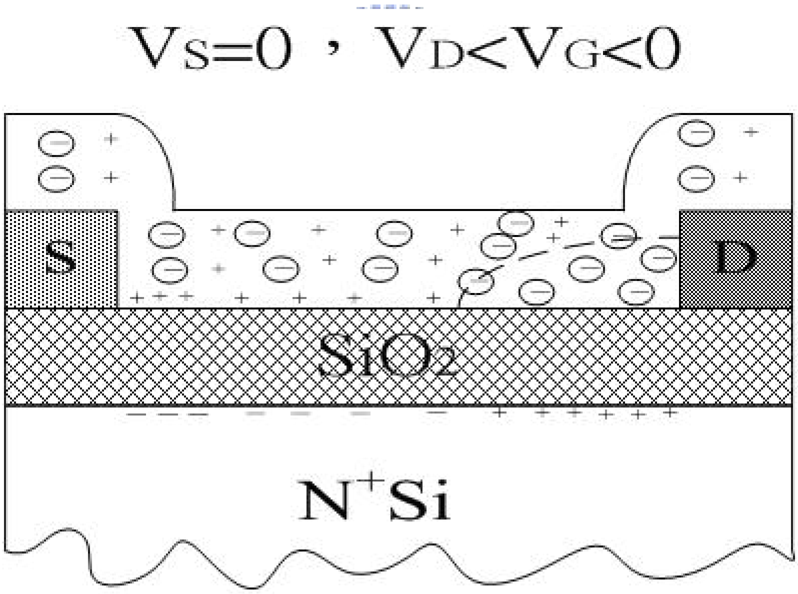


Figure 1-5 Schematic of operation modes of organic thin film transistor, showing a lightly p-doped semiconductor ： + indicates a positive charge in semiconductor ; - indicate a negative charge counterion(a) no-bais (b) accumulation mode (c) depletion mode (d) channel pinch-off.