

## **The Fabrication of an Inverter using Rubrene Single Crystal Organic Transistors**

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Organic field effect transistors (OFETs) have seen remarkable improvements in many aspects of their development in recent years: fabrication techniques, conduction maximizations, performance characteristics, and improved organic compounds. With these advances has come the field of thin film transistors (TFTs), and a great amount of research into applications has been initiated. However, TFTs are not suitable for the studies of the various physical and electronic properties, which are crucial for the further evolution of OFETs. Thus, it is necessary to study the underlying physical limitations of organic transistors using single crystal devices. The purpose of this project is to fabricate an inverter device using organic single crystal transistors. Single crystals of rubrene (5,6,11,12-tetraphenylnaphthacene) were grown by a physical vapor transport method with a nitrogen flow. Inverter devices were fabricated by laminating thus grown rubrene single crystals on SiO<sub>2</sub>/Si substrates, on which gold electrodes were lithographically patterned for inverter characteristics. The characterization of this inverter and the transistors were measured with a semiconductor parameter analyzer (HP VEE) using a computer program developed by myself.

# The Fabrication of an Inverter using Rubrene Single Crystal Organic Transistors

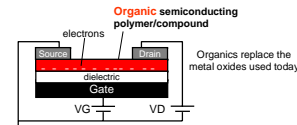
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## Introduction:

Currently researched thin-film organic field effect transistors are not suitable for studies of the various physical and electronic properties of organic transistors. Thus, it is necessary to study the underlying physical limitations of organic transistors using single crystal devices. This project fabricates an inverter device using organic single crystal transistors. Single crystals of rubrene were grown by a physical vapor transport method with a nitrogen flow. Inverter devices were fabricated by laminating thus grown rubrene single crystals on SiO<sub>2</sub>/Si substrates, on which gold electrodes were lithographically patterned for inverter characteristics. The characteristics of this inverter and the transistors were measured with a semiconductor parameter analyzer (HP VEE).

## Organic Field Effect Transistors:

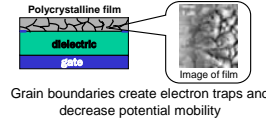
What is an Organic Field Effect Transistor?



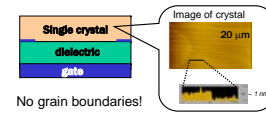
- |  |   |
|--|---|
| <p><b>Advantages:</b></p> <ul style="list-style-type: none"> <li>•Cheaper than Si</li> <li>•Printable</li> <li>•High mobilities</li> <li>•Flexible Substrates</li> </ul> | <p><b>Disadvantages:</b></p> <ul style="list-style-type: none"> <li>•Easily destroyed</li> <li>•Short lifetimes</li> <li>•n-type OFET - lower capabilities</li> </ul> |
|--|---|

Why Single Crystals?

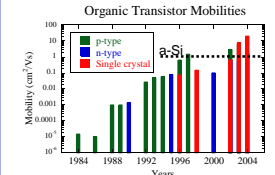
Thin Film Organic Field Effect Transistors



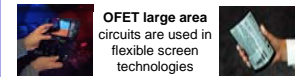
Single Crystal Organic Field Effect Transistors



Mobility advances



Increasing mobilities combined with organic materials can yield **awesome applications**



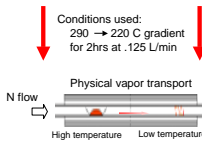
## Fabrication of the Inverter:

Single Crystal Fabrication:



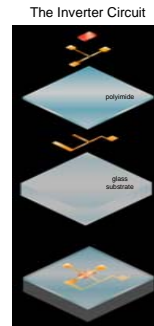
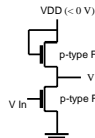
Physical Vapor Transport

- ◆ Sublimation of organic
- ◆ Transportation by noble gas
- ◆ Fast change in temperature
- ◆ Deposition of organic
- ◆ Formation of single crystal



- ◆ Dependant on conditions
  - Temperature gradient
  - Gas flow speed
  - Duration of process

Device Fabrication:



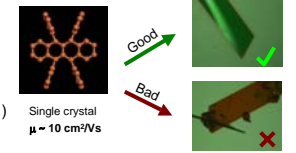
Fabrication Steps:

1. Schematic design
2. Create electrodes on glass substrate (lithography)
3. Crystal lamination onto electrodes

Crystal Quality:

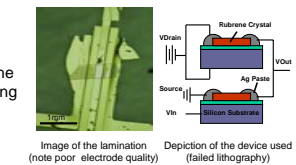
Quality indicators:

- Semi-translucent
- Film like color shifts
- Very thin (~1μm - 5μm)
- Not thick and red

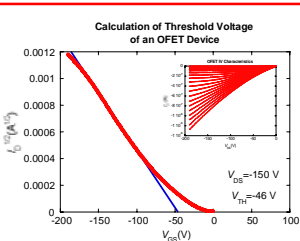


Lamination:

High quality crystals laminate *easily* onto the electrodes. Just placing the crystal on the electrodes should be enough.



## Characterization of Devices:



The above shows the calculation of a bipolar organic field effect transistor's threshold voltage using its I-V characteristics (inset).

$$I_d = \left( \frac{\mu_n C_{ox} W}{L} (V_{GS} - V_{TH}) \right) V_{DS}$$

Rubrene Two Device Inverter:

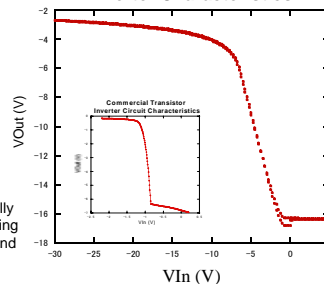
- Successful inversion
- The 'off' state is still 'high'
- Long period of inversion
- High threshold voltage

- No positive input voltage data

**How to Improve:**

All lithographed devices were short circuited and therefore immeasurable. Being able to use these would drastically decrease channel width, thereby lowering inversion time, the threshold voltage, and the 'off' state voltage.

Rubrene Two Device Inverter Characteristics



## Conclusions and Future Work:

The field of organic electronics is rapidly progressing past the capabilities of their traditional silicon counterparts. Continued research into the physical limits of these electronics will bring an increased understanding of the technology, leading to higher quality advanced applications.

The Iwasa lab will continue to work on OFET characterization, and will measure the inverter when better electrodes are available. Personally, I will begin senior thesis research on nanotube spectroscopy in the Kono group at Rice University.

**Acknowledgements:**

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