Thyristors: *pnpn* Devices

Ryan Curtin
ECE3080

Introduction To Thyristors

What is a thyristor?
» Introduction To Thyristors
» Band Structure
How does it work?
How is it used?
Cutting-edge developments
Questions and Comments

A thyristor is a three-junction device used mainly in high-power switching applications.

Band Structure

What is a thyristor?
» Introduction To Thyristors
» Band Structure
How does it work?
How is it used?
Cutting-edge developments
Questions and Comments

- Region 1: highly-doped p-type (10^{19} cm^{-3})
- Region 2: lightly-doped n-type (10^{14} cm^{-3})
- Region 3: moderately doped p-type (10^{18} cm^{-3})
- Region 4: very highly-doped n-type (10^{20} cm^{-3})

I-V Curve

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

Breakdown voltage drops are several orders of magnitude higher than voltage drops in the conducting region.

Diode Model

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

Modeling the device as three diodes (and ignoring the gate input) shows switching characteristics of the device.

Forward biasing the device enough will cause diode J2 to break down.

Reverse bias will cause diodes J1 and J3 to break down.

This model does not account for the conduction region.

Transistor Model

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

The device can also be modeled as two transistors.

The Ebers-Moll model (or other models) can then be used to solve for the I-V characteristics.

Band Analysis (1)

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

Reverse-biased junction J2 allows no current to pass.
Electrons and holes injected into regions 2 and 3 recombine.

Band Analysis (2)

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

As more charge is injected into regions 2 and 3, it cannot recombine and the extra charge forces the reverse bias to decrease.

Band Analysis (3)

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

When enough charge accumulates, junction J2 is effectively forward biased and large amounts of current can flow.

Band Analysis (4)

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

This effect does not occur in reverse bias because charge does not accumulate.

Gate Voltage

What is a thyristor?

How does it work?
» I-V Curve
» Diode Model
» Transistor Model
» Band Analysis (1)
» Band Analysis (2)
» Band Analysis (3)
» Band Analysis (4)
» Gate Voltage

How is it used?

Cutting-edge developments

Questions and Comments

Current can be injected into the gate to force junction J2 to being forward biased.

Switching Applications

What is a thyristor?
How does it work?
How is it used?
» Switching Applications
» Switching Characteristics
» Switching Circuit
» Different Types of Thyristors
Cutting-edge developments
Questions and Comments

To get from blocking to conducting mode:

- Inject current into the gate
- Apply a high enough voltage to anode

To get from conducting to blocking mode:

- Force a current from the gate (reverse-bias J2)
- Allow the anode-cathode current to drop low enough to deplete the excess charge near J2

Switching Characteristics

What is a thyristor?
How does it work?
How is it used?
» Switching Applications
» Switching Characteristics
» Switching Circuit
» Different Types of Thyristors
Cutting-edge developments
Questions and Comments

A current pulse to the gate turns the thyristor on, and it turns off when the charge in J2 depletes.

Switching Circuit

What is a thyristor?
How does it work?
How is it used?
» Switching Applications
» Switching Characteristics
» Switching Circuit
» Different Types of Thyristors
Cutting-edge developments
Questions and Comments

This coilgun firing circuit injects a current into the thyristor to activate the firing mechanism.

Different Types of Thyristors

What is a thyristor?
How does it work?
How is it used?
» Switching Applications
» Switching Characteristics
» Switching Circuit
» Different Types of Thyristors
Cutting-edge developments
Questions and Comments

- SCR - silicon-controlled rectifier
- RCT - reverse-conducting thyristor
- LASCR - light-activated SCR
- GTO - gate turn-off thyristor
- BOD - breakover diode

Using Heterostructures

What is a thyristor?

How does it work?

How is it used?

Cutting-edge developments
» Using Heterostructures
» Emitter Turn-Off Thyristor
» Other Recent Developments

Questions and Comments

This design uses heterostructures for higher-speed switching.

Emitter Turn-Off Thyristor

What is a thyristor?
How does it work?
How is it used?
Cutting-edge developments
» Using Heterostructures
» Emitter Turn-Off Thyristor
» Other Recent Developments
Questions and Comments

- Developed by Dr. Alex Q. Huang, at Virginia Tech
- By placing low voltage MOSFETs in series with a gate turn-off thyristor, the anode current can be used to provide the turn-off energy

Other Recent Developments

What is a thyristor?
How does it work?
How is it used?
Cutting-edge developments
» Using Heterostructures
» Emitter Turn-Off Thyristor
» Other Recent Developments
Questions and Comments

- Singh and Waltz: Using 4H-SiC thyristors
- Silber et al: 13kV light-triggered asymmetrical thyristors
- Thapar and Baliga: trench dual-gate MOS controlled thyristor
- Burke, Weiner, and Zhao: Using GaAs and AlGaAs to make thyristors

Important Sources

What is a thyristor?
How does it work?
How is it used?
Cutting-edge developments
Questions and Comments
» Important Sources
» Questions and comments?

Anderson, Betty Lise, and Anderson, Richard L. **Fundamentals of Semiconductor Devices**, McGraw-Hill, 2005.

Pierret, Robert F. **Semiconductor Device Fundamentals**, Addison-Wesley, 1996.

James Paul. **Thyristor Fired Coilgun**, 2006. `http://www.coilgun.eclipse.co.uk/`

Phase Triggering the Thyristor Tutorial, 2008. `http://www.hobbyprojects.com/thyristor_triac_and_diac/phase_triggering_the_thyristor.html`

Questions and comments?

What is a thyristor?
How does it work?
How is it used?
Cutting-edge developments
Questions and Comments
» Important Sources
» Questions and comments?

These slides were created in LaTeX.