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VISIBLE-LIGHT AMORPHOUS SILICON ALLOY THIN FILM LIGHT EMITTING DIODES AND THEIR APPLICATIONS IN OPTOELECTRONICS

MR. WIROTE BOONKOSUM

ศูนย์วิทยทรัพยากร
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พิมพ์ต้นฉบับบทคัดย่อวิทยานิพนธ์ภายในกรอบสีเขียวนี้เพียงแผ่นเดียว

วิโรจน์ บุญโกสุมภ์ : ไดโอดเปล่งแสงแบบฟิล์มบางในช่วงที่ตามองเห็นชนิดวัสดุอะมอร์ฟัสซิลิคอนอัลลอยและการประยุกต์ใช้งานในออปโตอิเล็กทรอนิกส์ (VISIBLE-LIGHT AMORPHOUS SILICON ALLOY THIN FILM LIGHT EMITTING DIODES AND THEIR APPLICATIONS IN OPTOELECTRONICS) อ.ที่ปรึกษา : ผศ.ดร.ดุสิต เครืองาม และ ศ.ดร.สมศักดิ์ ปัญญาแก้ว, 195 หน้า . ISBN 974-633-233-3

ได้มีการคิดค้นการออกแบบและประดิษฐ์ไดโอดเปล่งแสงแบบฟิล์มบางชนิดวัสดุอะมอร์ฟัสสารกึ่งตัวนำ ได้สำเร็จเป็นครั้งแรก สิ่งประดิษฐ์มีโครงสร้างเป็นรอยต่อ p-i-n ของฟิล์มบางอะมอร์ฟัสซิลิคอนอัลลอยชนิดที่มีช่องว่างพลังงานกว้างซึ่งได้แก่ อะมอร์ฟัสซิลิคอนไนไตรด์ (a-SiN:H) อะมอร์ฟัสซิลิคอนคาร์ไบด์ (a-SiC:H) และอะมอร์ฟัสซิลิคอนออกไซด์ (a-SiO:H) ฟิล์มบางเหล่านี้เตรียมด้วยวิธี glow discharge plasma CVD ไดโอดเปล่งแสงแบบฟิล์มบางนี้สามารถเปล่งแสงสีต่าง ๆ ที่ตามองเห็นได้ตั้งแต่สีแดง สีส้ม สีเหลือง สีเขียว ไปจนถึงสีน้ำเงินขาว สีของการเปล่งแสงกำหนดจากขนาดของช่องว่างพลังงานของชั้น i

ในวิทยานิพนธ์นี้ฟิล์ม a-SiN:H, a-SiC:H และ a-SiO:H ถูกนำไปศึกษาคุณสมบัติพื้นฐานต่าง ๆ อย่างละเอียดและอย่างเป็นระบบทั้งคุณสมบัติทางโครงสร้าง (IR, ESR) คุณสมบัติทางแสง (การดูดกลืนแสง, ช่องว่างพลังงาน, การเปล่งแสงโฟโตลูมิเนสเซนซ์) และคุณสมบัติทางไฟฟ้า (สภาพนำไฟฟ้า) ผลการวิจัยพบว่าระดับพลังงานชนิด localized states ในช่องว่างพลังงานมีอิทธิผลมากต่อคุณสมบัติพื้นฐานของฟิล์ม ข้อมูลที่ได้ในการศึกษาคุณสมบัติพื้นฐานของฟิล์มเหล่านี้มีประโยชน์มากในการนำไปใช้ออกแบบ และประดิษฐ์ไดโอดเปล่งแสงแบบฟิล์มบาง ตลอดจนใช้ในการวิเคราะห์ลักษณะสมบัติต่าง ๆ ของไดโอดเปล่งแสงแบบฟิล์มบาง

ไดโอดเปล่งแสงแบบฟิล์มบางที่พัฒนาขึ้นสำเร็จในงานวิทยานิพนธ์นี้มีโครงสร้างพื้นฐานประกอบด้วยแผ่นกระจก/ฟิล์มโปร่งแสงที่นำไฟฟ้าได้ (ITO)/ฟิล์มอะมอร์ฟัสซิลิคอนอัลลอยชั้น p-i-n/ฟิล์มขั้วไฟฟ้า Al ไดโอดเปล่งแสงแบบฟิล์มบางนี้เปล่งแสงได้ด้วยหลักการของการฉีดกระแสไฟฟ้า กล่าวคือ ฉีดโฮลจากชั้น p และอิเล็กตรอนจากชั้น n ให้เข้าไปรวมตัวกันในชั้น i ซึ่งเป็นชั้นเปล่งแสง แรงดันไฟฟ้าที่ใช้ไบแอสเพื่อฉีดกระแสไฟฟ้ามีค่าประมาณ 5-15 โวลต์ ความสว่างสูงสุดของแสงที่เปล่งมีค่าอยู่ในช่วง 0.1~1 cd/m^2 โดยใช้กระแสไฟฟ้าประมาณ 100-1000 mA/cm^2 นอกจากนี้ได้มีการศึกษาหาความหนาที่เหมาะสมของชั้น i ทั้งทางทฤษฎีและการทดลอง พบว่าความหนาที่เหมาะสมของชั้น i มีค่าประมาณ 500 Å

ในวิทยานิพนธ์ได้มีการเปรียบเทียบคุณสมบัติการเปล่งแสงของไดโอดเปล่งแสงแบบฟิล์มบางที่ชั้น i ผลิตจากวัสดุอะมอร์ฟัสหลายชนิด ผลการวิจัยพบว่า ไดโอดเปล่งแสงแบบฟิล์มบางที่ชั้น i ผลิตจาก a-SiC:H จะเปล่งแสงได้สว่างสูงที่สุด และความสว่างรองลงมาได้แก่ a-SiN:H และ a-SiO:H ตามลำดับ

ได้มีความพยายามในการปรับปรุงความสว่างของไดโอดเปล่งแสงแบบฟิล์มบางหลายวิธี ได้แก่ 1) การปรับปรุงประสิทธิภาพของการรวมตัวแบบเปล่งแสงของพาหะ โดยการใช้แผ่นโลหะซึ่งมีคุณสมบัตินำความร้อนได้ดีและสะท้อนแสงได้ดีเป็นแผ่นฐานแทนแผ่นกระจก และ 2) ได้มีการปรับปรุงประสิทธิภาพของการฉีดพาหะ (โฮล) โดยการใช้ฟิล์มอะมอร์ฟัสซิลิคอนออกไซด์ (a-SiO:H) และไมโครคริสตัลไลน์ซิลิคอนออกไซด์ (μc-SiO:H) ชนิด p ซึ่งมีคุณสมบัตินำไฟฟ้าได้ดีและมีช่องว่างพลังงานกว้างเป็นชั้นฉีดโฮลแทน a-SiC:H ชนิด p ทำให้ความสว่างของไดโอดเปล่งแสงแบบฟิล์มบางสูงขึ้นถึงระดับ 10 cd/m^2

ในด้านการพัฒนาเป็นดิสเพลย์ ได้ประสบความสำเร็จในการประดิษฐ์ไดโอดเปล่งแสงแบบฟิล์มบางให้เปล่งแสงเป็นรูปร่างลักษณะต่าง ๆ อีกทั้งผลิตให้มีโครงสร้างเป็นเมตริกซ์และมีพื้นที่กว้างใหญ่ขนาดร้อยตารางเซนติเมตรได้สำเร็จ

ในวิทยานิพนธ์นี้ยังได้ประสบความสำเร็จในการประดิษฐ์โฟโตคัปเปลอร์ชนิดอะมอร์ฟัสสารกึ่งตัวนำเป็นครั้งแรก คือมีไดโอดเปล่งแสงแบบฟิล์มบางเป็นภาคเปล่งแสงและมีเซลล์แสงอาทิตย์ชนิดอะมอร์ฟัสซิลิคอนเป็นภาครับแสง

ข้อดีเด่นของไดโอดเปล่งแสงแบบฟิล์มบางชนิดอะมอร์ฟัสสารกึ่งตัวนำนี้ ได้แก่ 1) ต้นทุนการผลิตต่ำเพราะใช้วัสดุราคาถูกและผลิตด้วยวิธี CVD ที่อุณหภูมิเพียง 190°C 2) ผลิตเป็นฟิล์มบางพื้นใหญ่ ๆ ได้ง่าย ทำให้ได้ดิสเพลย์ขนาดใหญ่ 3) ผลิตบนแผ่นฐานวัสดุชนิดต่าง ๆ ได้ เช่น แผ่นกระจก แผ่นโลหะ แผ่นพลาสติก แผ่นเซรามิก ทำให้ได้ดิสเพลย์รูปร่างและการใช้งานหลากหลาย เป็นต้น

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

ภาควิชา วิศวกรรมไฟฟ้า ลายมือชื่อนิสิต ....

สาขาวิชา วิศวกรรมไฟฟ้า ลายมือชื่ออาจารย์ที่ปรึกษา Dusit Kruangam

ปีการศึกษา 2538 ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ....

C515853 : MAJOR ELECTRICAL ENGINEERING
KEY WORD: : THIN FILM LIGHT EMITTING DIODE / AMORPHOUS SILICON ALLOY / DISPLAY / PHOTOCOUPLER

WIROTE BOONKOSUM : VISIBLE-LIGHT AMORPHOUS SILICON ALLOY THIN FILM LIGHT EMITTING DIODES AND THEIR APPLICATIONS IN OPTOELECTRONICS. THESIS ADVISOR : ASST. PROF. DUSIT KRUANGAM, DR. AND PROF. SOMSAK PANYAKEOW DR. 195 pp. ISBN 974-633-233-3

A novel Thin Film Light Emitting Diode (TFLED) has been developed for the first time. The TFLED has a basic structure of glass/ITO/ p-i-n layers of amorphous silicon alloys/Al. The amorphous silicon alloys employed in this work are wide optical energy gap materials, so-called, hydrogenated amorphous silicon nitride (a-SiN:H), hydrogenated amorphous carbide (a-SiC:H) and hydrogenated amorphous silicon oxide (a-SiO:H). The TFLED can emit the visible light having the colors from red, orange, yellow to green and white-blue depending on the optical energy gap of the i-layer.

A detailed study has been done on the basic properties including structural properties (IR absorption, ESR), optical properties (absorption coefficient, optical energy gap, photoluminescence) and electrical properties (conductivity) of the amorphous films.

The TFLED is a carrier-injection type electroluminescent device. The light output comes from the radiative recombination of holes and electrons injected from the p- and n-layers, respectively, into the i-layer. The typical bias voltage is about 5-15 volt, the injection current density is about 100-1000 mA/cm^2, giving the brightness of about 0.1~1 cd/m^2. The theoretical and experimental results show that the optimal thickness of the i-layer is about 500 Å.

A study has been done on the effect of the material used in the i-layer on the performances of the TFLED. The result shows that the TFLED with a-SiC:H as the i-layer gives the highest brightness, while a-SiN:H gives the brightness better than a-SiO:H.

A series of trials has also been done on the improvement of the brightness of the TFLED. The first attempt is to improve the radiative recombination efficiency by using a metal substrate instead of a glass substrate. The metal substrate is good thermal conductive material so that it can dissipate heat from the TFLED to the ambient with better efficiency than a glass substrate. The other attempt is to improve the injection efficiency of holes by using p-type highly-conductive and wide optical energy gap amorphous silicon oxide (p-a-SiO:H) and microcrystalline silicon oxide (p-μc-SiO:H) instead of conventional p-a-SiC:H. The result shows that the brightness was improved to the level of 10 cd/m^2.

A series of experiments has been done on the fabrication of TFLED displays that can emit light with desired emitting patterns. A new type of dot matrix TFLED display has also been proposed and fabricated for the first time. The screen size for the demonstration is 8 x 8 cm^2.

In this thesis a new type of amorphous photocoupler having the amorphous TFLED as a light source and the amorphous silicon solar cell as a detector has been developed for the first time.

The advantages of the amorphous TFLED are as follows : 1) low-cost, because the TFLED is made from low-cost amorphous materials and uses a low temperature CVD process (190 °C), 2) it has the possibility to be produced as a large area display, 3) it can be deposited on various substrates, such as glass, metal, plastic, ceramic sheets; therefore various forms of displays can be realized, etc.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

ภาควิชา Electrical engineering ลายมือชื่อนิสิต W. Boonkosum
สาขาวิชา Electrical engineering ลายมือชื่ออาจารย์ที่ปรึกษา Dusit Kruangam
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(c) glass/ITO/p-a-SiC:H/i-a-SiO:H/n-a-SiC:H/Al.

(d) glass/ITO/p-a-SiO:H/i-a-SiC:H/n-a-SiC:H/Al.

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List of Symbols

CVD : Chemical Vapor Deposition
a-SiN:H : Hydrogenated amorphous silicon nitride
a-SiC:H : Hydrogenated amorphous silicon carbide
a-SiO:H : Hydrogenated amorphous silicon oxide
ITO : Indium Tin Oxide
RF power : Radio frequency power (13.56 MHz)
SiH_4 : Silane gas
NH_3 : Ammonia gas
CH_4 : Methane gas
C_2H_4 : Ethylene gas
B_2H_6 : Diborane gas
PH_3 : Phosphine gas
CO_2 : Carbon dioxide gas
N_2 : Nitrogen gas
H_2 : Hydrogen gas
Ar : Argon gas
LED : Light Emitting Diode
TFLED : Thin Film Light Emitting Diode
E_{opt} : Optical energy gap
E_c : Conduction band edge
E_v : Valence band edge
E_F : Fermi level
EB : Electron Beam
IC : Integrated Circuit
TFT : Thin Film Transistor
LCD : Liquid Crystal Display

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IR	Infrared	
α	Optical absorption coefficient	(1/cm)
ω	Angular frequency	(1/s)
k	Wave number	(1/cm)
σ	Electrical conductivity	(S/cm)
n	Defractive index	
c	Velocity of light	
E	Electric field	(V/cm)
h	Planck's constant	(J.s)
ESR	Electron Spin Resonance	
DPPH	Diphenyl Picryl Hydrazyl	
n	Carrier density	($1/cm^3$)
e	Electronic charge	(C)
K	Boltzman's constant	(J/K)
T	Absolute temperature	(K)
σ_D	Dark conductivity	(S/cm)
T_S	Substrate temperature	(°C)
$h\nu$	Photon energy	(eV)
J	Current density	(A/cm^2)
τ	Life time of carrier	(s)
λ	Wave length	
PL	Photoluminescence	
EL	Electroluminescence	
E_{opt}	Optical energy gap	(eV)
ΔE_c	Conduction band discontinuity	(eV)
ΔE_v	Valence band discontinuity	(eV)
ϕ_B	Barrier height for tunneling	(eV)
d	i-layer thickness	(Å)
V	Applied voltage	(V)

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$n(x)$: Electron density at position x $(1/cm^3)$

$p(x)$: Hole density at position x $(1/cm^3)$

B : Brightness (cd/m^2)

m_e^* : Effective mass of electron

m_h^* : Effective mass of hole

γ_p : Hole range (μm)

μ_n : Electron mobility $(cm^2/V.s)$

μ_p : Hole mobility $(cm^2/V.s)$

τ_p : Nonradiative recombination life time of holes) (s)

α_c : Dispersive parameter of electron

α_v : Dispersive parameter of hole

E_X : Excitation energy (eV)

E_{EL} : Peak energy of EL spectra (eV)

E_{PL} : Peak energy of PL spectra (eV)

m^* : Effective mass of free electron (kg)

q : Charge of free electron (C)

J_n : Current density based on electrons (A/cm^2)

J_p : Current density based on holes (A/cm^2)

x : Position in the i-layer (μm)

d_{max} : Optimal i-layer thickness (Å)

f_c : Cut-off frequency (Hz)

I_{leak} : Leakage current in dot matrix TFLED (mA)

σ : Conductivity of p-layer (S/cm)

d : Thickness of p-layer (Å)

V : Potential drop between adjacent ITO electrodes (V)

s : Spacing distance of ITO electrodes (μm)

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l : Lenght of ITO electrode (cm)

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