Piezoelectric pressure sensor based on flexible gallium nitride thin film for harsh-environment and high-temperature applications

Venci Freeman*

School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University

ABSTRACT:

This is a reading note about an article named *Piezoelectric pressure sensor based on flexible gallium nitride thin film for harsh-environment and high-temperature applications*. In this study, gallium nitride (GaN) thin film is used as a sensing material because it has a notable piezoelectric coefficient and demonstrates the greatest potential to replace the zirconate titanate (PZT). This note will mainly summarize the thin film characteristics, deposition methods and related parameters mentioned in the article.

KEYWORDS

Piezoelectric pressure Sensor; Gallium nitride; High temperature and pressure

1 Introduction

1.1 Article information

The article [1] referenced in this reading note was published in Sensors and Actuators A: Physical in April 2020. In this study, GaN thin film is used as a sensing material, where the sensor is made by a simple layer transferring process after the removal of silicon substrate. The study has also verified its performance under different circumstances and proved its reliability in harsh-environment and high-temperature applications.

1.2 Article background

Nowadays, demand for pressure sensing in a variety of applications is remarkably increasing. These sensors need a piezoelectric pressure sensing material, in-situ sensing of pressure in some harsh environments demands robustness as well as high sensitivity, and zirconate titanate ($Pb[Ze_xTi_{1-x}]O_3$, a.k.a. PZT) is one of the most investigated materials[1], and many paper have also studied materials such as ZnO, quartz, $GaPO_4$ and SiC, etc., but they all have some disadvantages. So, in this work, they investigate the flexible piezoelectric pressure sensor with GaN thin film fabricated on flexible metal foil as a transducer operating in harsh conditions (high temperature and pressure range with long-term reliability) [1].

1.3 Article results

This work investigated the piezoelectric performance of GaN sensor at high temperatures, and showed that the sensor can function properly up to ~350°C, and the measurement reliability and stability of the sensor was also demonstrated with several pressure levels and elevated temperatures [1]. The conclusion is that the piezoelectric flexible GaN pressure sensor is very promising for high pressure and high temperature applications.

1.4 The structure of the note

I divided the content about thin film into three parts: the first part introduces the application of the thin film in the sensor; the second part introduces the thin film deposition method; the third part introduces the thin film parameters.

2 Application

2.1 Principle and application

First of all, we should know the application of piezoelectric pressure sensors. <u>This kind of sensors utilizes the piezoelectric effect to measure changes in acceleration,</u>

strain, pressure, and force by converting them into electrical charge [2].

In a piezoelectric pressure sensor, piezo-electric film is a strong, lightweight and flexible plastic, which comes in a wide range of thicknesses and areas [3]. A piezoelectric is a material that develops a dielectric displacement (or polarization) in response to an applied stress and, conversely, develops a strain in response to an electric field. To achieve the piezoelectric response, a material must have a crystal structure that lacks a center of symmetry [2].

2.2 PZT and GaN thin film

PZT is one of the most investigated materials because of its high piezoelectric constants. But the utilization of the PZT in some important applications is still limited by its toxicity for environments and human bodies and limited operation temperature (~200˚C) by piezoelec-tric characteristics loss related to Curie temp-erature (TC) [1], which is the main motivation of the present study.

So recently some researches proposed gallium nitride (GaN) as thin film materials. GaN thin film has [1]:

1) Excellent output voltage
2) Indicating outstanding sensitivity
3) High electromechanical coupling factor
4) Rapid response time
5) Chemical and mechanical stability
6) High thermal resistance
7) Excellent biocompatibility

3 Deposition method

3.1 Common methods

In processing piezoelectric thin films, several methods are available, including [2]

1) Physical vapor deposition (PVD)
2) Chemical vapor deposition (CVD)
3) Solution deposition (SD)

And each method has unique advantages and disadvantages. PVD and CVD methods can offer uniform thickness films and good step coverage, but it's difficult to control the correct stoichiometry; SD method offers excellent control of the chemistry of the thin film, but is not appropriate when uniform film thickness over surface features is required [2].

3.2 In this work

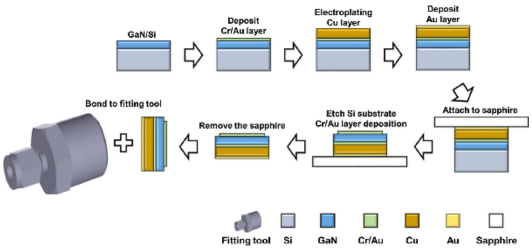

Figure 1 Process steps for fabrication of sensing element

In this study, the researchers used meta-lorganic chemical vapor deposition (MOCVD) method and electron beam (E-beam) evaporation. Fig.1 [1] shows the who-le process steps for fabrication of thin-film flexible piezoelectric sensing element:

1) Use MOCVD to epitaxially grown a ~2.5 um GaN layer on a Si (111) substrate;

2) Use E-beam evaporation to deposit a 10 nm chromium (Cr) layer and a 100 nm gold (Au) layer on GaN film;

3) Use electroplating at a current density of 0.05 A/cm^2 with 1.5 V to form a 10 um copper (Cu) supporting layer;

4) Use polymeric glue to attach a sapphire substrate to the top of the Au layer;

5) Use 49% HF acid, 50% acetic acid and 70% nitric acid to wet-etch the Si substrate, the volumetric ratio is 0.80 : 0.15 : 0.05;

6) Remove Cr and Au layers to make the thin film mechanically bendable;

7) Use acetone and isopropyl alcohol to detached the sapphire layer;

8) Use high-temperature glue to bond the GaN sensor to the diaphragm of the sensor housing.

4 Parameters and characterizations

In 3.2, we can see that the thickness of the GaN layer is about 2.5 um. The dielectric constant of GaN is 8.9 C/V·m, and the effective density of states in the conduction band for

GaN is $4.3\times10^{14}\times T^{3/2}/cm^3$. This part will show some other parameters and characterizations about GaN thin film to prove the deposition method is effective.

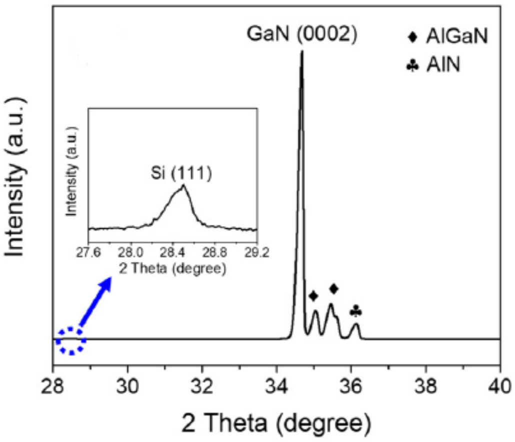

Figure 2 XRD 2θ-ω scan of GaN thin film

Fig.2 shows the XRD 2θ-ω scan of GaN thin film. This scan fix the ω at grazing angle，and move the detector to collect the data, only radiate the thin film and get collective diffraction only from film, not from the sub-strate, which is suitable for single crystal (epitaxial) thin film growth. This figure shows that the GaN thin-film epitaxial material possesses excellent crystal quality from a sharp peak of GaN (0002) diffraction, and the epitaxial thin film was well aligned in out-of-plane direction parallel with the [0001] dire-ction of wurtzite structure [1].

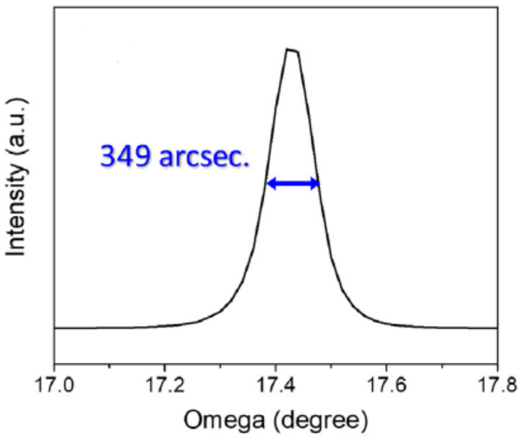

Figure 3 XRD rocking curve of GaN plane

Fig.3 shows the XRD rocking curve of GaN plane. The FWHM (the full width at half-maximum, often used to determine the crystallinity of synthesized or fabricated materials) is very narrow, ~0.1° (349 arcsec.), which means the small tilt and almost no defects in the GaN film [1].

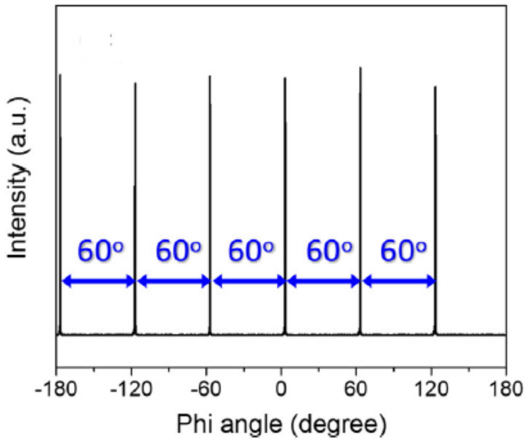

Figure 4 XRD rotational φ scan around GaN planes

And Fig.4 shows 6 sharp peaks with 60◦ spacing, confirms the GaN crystal properly aligned in in-plane directions along <10-10> directions of wurtzite [1].

According these three parameters, we can say that permanent dipole moment originating from the non-centrosymmetric crystalline stru-cture is already well aligned without further electric poling process [1], achieved high quality.

5 Conclusions

In this work, researchers designed, manu-factured and verified a piezoelectric pressure sensor which can utilize the piezoelectric effect to measure changes in acceleration, strain, pressure, and force by converting them into electrical charge.

The sensor used GaN thin film as the piezoelectric pressure sensing material, and also used Cr and Au film to make the thin film flexible. The two adopted MOCVD and E-beam evaporation separately.

the thickness of the GaN layer is about 2.5 um, and XRD 2θ-ω scan, FWHM and XRD rotational φ scan showed good parameters, finally the sensitivity of GaN sensor is 0.523 mV/psi, and can function properly up to ~350 °C. In a word, the piezoelectric flexible GaN pressure sensor is very promising for high pressure and high temperature applications.

References

[1] Nam-In Kim, et al. Piezoelectric pressure sensor based on flexible gallium nitride thin film for harsh-environment and high-temperature applications, Sensors and Actuators A: Physical, Volume 305, 2020;

[2] Vahid Mohammadi et al, Piezoelectric Pressure Sensor Based on Enhanced Thin-Film PZT Diaphragm Containing Nanocrystalline Powders, Open access peer-reviewed chapter (2013), DOI: 10.5772/54755;

[3] Steve Shen, PZT thin-film sensors and actuators, Mechanical Engineering, University of Washington, www.me.washington.edu/research/faculty/ishen/actuators_sensors.