Deposition of the Immobilization Layer 3-Aminopropyltriethoxysilane on Gallium Nitride for Extremophile-Based Biosensors

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Abstract:

Biosensors composed of biomolecules and electromechanical components have enabled new sensing modalities for chemical sensing, pathogen detection and disease therapy. Traditional biosensors are silicon-based, but silicon has a known limited radiation lifetime. Gallium nitride (GaN), however, is radiation-hard and shows potential for use in biosensors to detect radiation. To support the development of a biosensor based on GaN and the radiation-tolerant extremophile bacteria *Deinococcus radiodurans* (*D. radiodurans*), we studied the attachment of an interfacial organosilane immobilization layer to GaN. More specifically, we attached 3-aminopropyltriethoxysilane (APTES) to GaN using molecular layer deposition. We defined the shape of the layer using die-level photolithography and lift-off, and we used goniometry, ellipsometry, and fluorescence microscopy to characterize the attachment properties of this layer. Optimization of this attachment will allow for long-lasting radiation detectors for applications such as medical radiation therapy and deep space exploration.

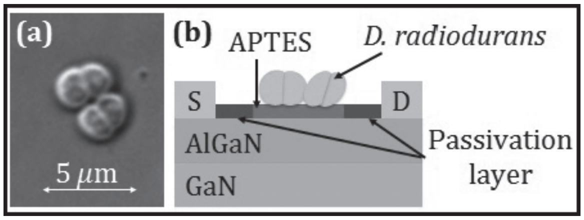

Figure 1: GaN biosensor HEMT device depiction.

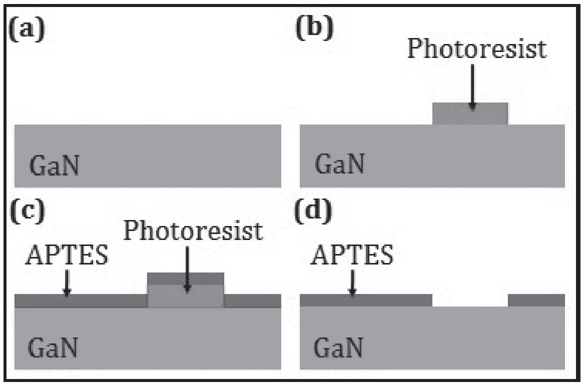

Figure 2: Process flow: (a) hydroxylation, (b) patterning of photoresist by photolithography, (c) deposition of APTES, and (d) patterning of APTES by liftoff.

Introduction:

Biosensors are biomedical or biological microelectromechanical systems (BioMEMS), systems that combine microelectronic materials such as semiconductors with biological components such as bacteria. These systems are largely used for biomedical or biological purposes such as diagnosing DNA and protein arrays [1]. By utilizing biological components composed of radiation-resistant extremophiles, biosensors may also be used in radiation-intense environments to detect radiation.

While traditional biosensors are silicon based and have a limited radiation lifetime [2, 3], gallium nitride (GaN) has a high radiation lifetime due to its large band-gap [4], making GaN ideal for radiation detection. The extremophile bacteria *Deinococcus radiodurans* (*D. radiodurans*) is also radiation-resistant [5, 6] and responds to radiation by generating ions [6]. We intend to combine *D. radiodurans* with GaN to build a biosensor that operates as a high-electron mobility transistor (HEMT), which has a high sensitivity to ions [4]. The biocompatibility of GaN has been shown [4], but no information exists on functionalizing GaN for D. radiodurans. We intend to interface GaN to *D. radiodurans* with the immobilization layer 3-aminopropyltriethoxysilane (APTES) commonly used to functionalize surfaces for bacteria attachment. Figure 1 depicts this APTES layer in the context of the HEMT device. Deposition and characterization of APTES will contribute to understanding the functionalization of GaN and may allow for construction of a HEMT radiation detector.

Fabrication Procedure:

We performed the following fabrication procedure on GaN samples and on silicon samples, using the silicon samples as references. Figure 2 depicts the fabrication procedure, which began with exposing the samples to 3:1 piranha solution (3:1 sulfuric acid: hydrogen peroxide) for two ten-minute sessions to clean the surface of organic molecules and activate hydroxyl groups on the surface. These hydroxyl groups add to the native oxide of the surface and ensure chemical functionalization of this surface for APTES [7].

Next, we used photolithography to pattern the surface to optimize for the gate size and shape of the HEMT device concept. This photolithography step consisted of depositing hexamethyldisilazane, depositing 1 μm of photoresist (Shipley 3612), exposing the samples to UV light, and developing in MF-26A. We then deposited APTES by molecular layer deposition to promote a conformal monolayer of APTES, and we performed liftoff in acetone. This left a surface patterned with APTES.

Characterization and Results:

To confirm deposition of this immobilization layer, the samples were characterized before and after the deposition step using goniometry and ellipsometry. Goniometry, a commonly used method for detecting changes in surface morphology, measures the wettability of the surface by surface water contact angle (SWCA) measurements. Table 1 shows a significant change in contact angle, indicating deposition of APTES. We used ellipsometry to further confirm the deposition of APTES. Ellipsometry calculates film thicknesses by measuring the change in light polarization and then fitting this experimental data to a model based on refractive index. APTES has a similar refractive index as oxide and therefore can be modeled as an oxide [8]. Table 1 shows a significant change in oxide thickness, indicating deposition of APTES.

	Pre-APTES	Post-APTES	Difference
Goniometry data			
Patterned GaN:	53°	43°	-10°
Patterned Si:	52°	29°	-23°
Bare GaN:	< 5°	27°	+27°
Bare Si:	< 5°	15°	+15°
Ellipsometry data			
Bare GaN:	7.1 Å	8.7 Å	1.6 Å
Bare Si:	17.1 Å	23.4 Å	6.3 Å

Table 1: Goniometry and ellipsometry characterization. Patterned samples underwent hydroxylation and photolithography before deposition. Bare samples only underwent hydroxylation before deposition and were used as reference samples.

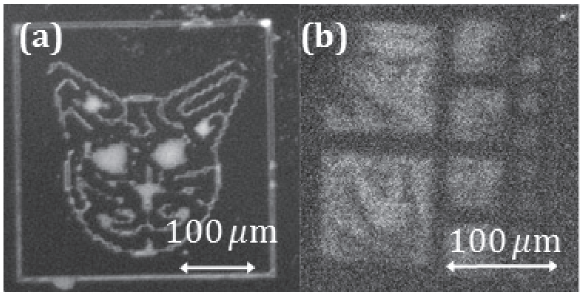

Figure 3: Fluorescence microscopy images of (a) cat and (b) square family on silicon. (See full-color version on inside cover.)

To verify patterning of the samples with APTES, the samples were characterized by fluorescence microscopy after liftoff. The samples were dyed with fluorescein isothiocyanate, which covalently binds with APTES and fluoresces at 510 nm (green light) when excited by 488 nm light (blue light). Figure 3 shows the fluorescently labeled samples, confirming patterning of the APTES.

Conclusions and Future Work:

Deposition and patterning of APTES on GaN were performed and characterized to support the development of a HEMT radiation detector. Future work includes investigating the attachment of *D. radiodurans* to APTES, and investigating the effectiveness of a *D. radiodurans* and GaN-based HEMT device for radiation detection.

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