Distributed Intelligence using Gallium Nitride based Active Devices

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ABSTRACT

This research seeks to develop a novel branch of materials systems called Distributed Intelligent Materials Systems (DIMS) which incorporate actuation, sensing, electronics and intelligence as inherent parts of the material structure. A microcantilever optical switch is fabricated as a concept demonstrator with Gallium nitride (GaN) as host material. GaN has several material characteristics which enable it to outperform other semiconductor materials for electronic applications. It also displays exceptional chemical inertness, has a relatively high piezoelectric coefficient, good mechanical strength and toughness and is transparent to wavelengths in the visible spectrum. In this paper we develop and fabricate a GaN-based, piezoelectrically actuated microcantilever optical switch/waveguide. While the GaN-material offers the benefits mentioned above, the piezoelectric actuation and the cantilever design provide benefits of lighter weight, compactness, speed of actuation, reduced structural complexity enabling easier fabrication and low wear and tear due to minimal moving parts. The proposed design has a conventional unimorph configuration with GaN actuated in d_{31} mode. In this configuration, a laminar metal electrode and a doped n-type GaN layer are used to apply an electric field in the top layer to actuate the unimorph. The unimorph is fabricated as a micro-cantilever by using surface micromachining methods on epitaxial GaN grown on a GaN substrate. The cantilever is then etched partially using conventional semiconductor processing techniques and using a recent microfabrication technique known as photoelectrochemical (PEC) etch. PEC etching enables the fabrication of MOEMS structures that are rather difficult to create using conventional methods. Novel modifications and improvements to the current state-of-the art in PEC for GaN are presented and discussed.

Keywords: Gallium nitride, MEMS, cantilever, unimorph, optical switch, photoelectrochemical etch

1. INTRODUCTION

In the recent past, MEMS and MOEMS (or optical-MEMS) technologies have evolved tremendously, in both the academic and commercial environments. Till date, silicon has been the most popular material for these devices, but newer semiconductor materials under development suggest possibilities which are impractical or outright impossible with silicon and silicon-based systems. These possibilities include, but are not limited to, integrated on-chip optical sourcing, optical sensing and processing, better mechanical performance, thermal stability, greater power handling and biocompatibility. Additionally, some of these newer materials are piezoelectric by virtue of their lack of center of symmetry which can be utilized for actuation, sensing and energy harvesting applications. In this research we propose a novel branch of materials systems based on these materials called Distributed Intelligent Materials Systems (DIMS) which possess actuation, sensing, and electronics as inherent parts of a monolithic semiconductor and have the potential to have intelligence built-in. As a candidate device we highlight a microcantilever optical switch with Gallium nitride (GaN) as host for a DIMS device.

GaN is a wide-bandgap compound semiconductor that has several material characteristics which enable it to outperform other semiconductor materials for electronic applications[1]. GaN transistors can handle frequencies and power levels well above that of any semiconductor in use. This ability of GaN to handle high power is attributed to its high breakdown field, which in turn derives from its wide bandgap. These characteristics of GaN clearly make it well suited for applications in radar and satellite-communications, as well as electronics in engines and other harsh environments. In addition, these properties also enable smaller and more compact communications devices by tremendously improving the efficiency of current systems. Despite these beneficial properties, GaN has not seen widespread use due to limitations

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in GaN material fabrication technologies. Till date, there is no way to cheaply manufacture bulk wafers of GaN on a large scale as compared to other common semiconductor materials. This technological barrier is expected to be surmounted soon given the substantial benefits associated with GaN devices.

Aside from the material properties that make GaN attractive to the field of microelectronics, it displays exceptional chemical inertness, has a relatively high piezoelectric coefficient, and good mechanical strength and toughness. The wide bandgap also renders GaN transparent to wavelengths in the visible spectrum. This makes GaN a very serious contender for robust DIMS devices. Very little work has been done in the area of GaN based MOEMS. This is mostly due to the fact that the chemical inertness of GaN renders it relatively immune to most conventional silicon-based microfabrication techniques and that bulk single-crystal GaN is difficult and expensive to grow. Much of the research in this area has been focused on the development of material processing techniques for various structural configurations, and not on GaN-based MOEMS systems. As a first step towards realizing a DIMS device, we aim to create a GaN based optical switch. In the following sections, some basic material properties of GaN from a MOEMS standpoint are presented and device configurations are compared. The suitability of PEC etching for fabricating the proposed device and suggested enhancements are detailed. This is followed by a discussion of the results of the fabrication and future directions of research.

2. OPTICAL SWITCH DESIGN

Given the cost of semiconductor real estate and the limited variety of GaN fabrication technologies as of today, design of a simple device configuration that can successfully carry out the following key tasks is sought: act as an optical waveguide, and move or reorient itself when the guided lightwave needs to be redirected. A piezoelectric bimorph configuration is chosen to realize this device. While the GaN material system is attractive for the reasons discussed in the introduction, the piezoelectric actuation and the microcantilever form factor provide the additional benefits of lighter weight, compactness, speed of actuation, reduced structural complexity enabling ease of fabrication and lower wear and tear due to minimal moving parts as compared to other actuation technologies.

2.1 Material properties

Numerous microcantilever designs have been built and tested by researchers over the past decades, with some of the more recent ones being on the GaN platform. A key issue encountered by all the GaN based cantilevers is that of undesirable cantilever curvature upon its release from the substrate[2,3]. Such residual curvature in the microcantilever is considered to be caused due to the lattice and thermal mismatch between the GaN layers and the underlying substrate, usually a sapphire (Al_2O_3) or silicon carbide (SiC) wafer. The lattice mismatch of GaN with sapphire and SiC is 14.8% and 3.3% respectively[1]. Growth of epitaxial GaN film on such a mismatched substrate leads to a stress gradient across the thickness of the GaN layer. During cantilever fabrication, when the strained film is released from the substrate material, the differential relaxation across the thickness of the cantilever causing it to bow. The radius of the curvature depends on the thickness of the films deposited, the amount of lattice and thermal mismatch with the substrate layer and the direction depends on whether the mismatches are positive or negative. This issue is of serious concern for the optical microcantilever switch design that is proposed here. To alleviate, or to at least mitigate the issue GaN substrate wafer is chosen instead of sapphire or SiC. Such material stack was not possible until recently due to the nonexistence of free-standing single crystal GaN substrate materials.

GaN material exists in the zincblende and wurtzite crystal structures with wurtzite being the more widely used and researched form. Wurtzite GaN exhibits spontaneous polarization, with the piezoelectric coefficients d_{33} and d_{31} being in the range of 2.0pm/V to 3.7pm/V and -1.0pm/V to -1.9pm/V respectively[4], depending on the material type (bulk/thin-film, single-crystal/polycrystalline, high/low quality). Although these values do not compare favorably with PZT or other commercially piezoelectrics, GaN does offer superior integration into semiconductor devices and systems. For the wurtzite structure, the 3-direction relating to the piezoelectric coefficients refers to the crystallographic *c*-axis (see Figure 1). In other words, GaN has a single axis of polarization decided by the crystal structure. This is in contrast to most commonly used piezoelectrics which have a tetragonal structure where any of the 3 axes could be the polarization axis, determined largely by the direction chosen during poling. This reveals an important consideration pertaining to GaN and other wurtzite piezoelectrics: GaN cannot be easily poled (or poled at all) like conventional piezoelectrics. This is one of the key reasons why the piezoelectric effect in GaN has not seen much use in macroscale actuation applications. For the present application to microscale systems, this piezoelectric effect can be exploited provided we use epitaxial GaN for actuation.

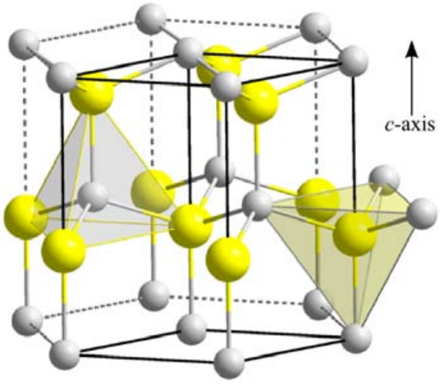


Figure 1. Wurtzite crystal structure (Larger yellow spheres represent Ga atoms and smaller grey represent N atoms)[5]

2.2 Optical waveguide design requirements

Optical MEMS (MOEMS) can be categorized into two classes based on how the light beam is manipulated: free-space systems, where light mostly travels in free space and is guided using mirrors, lenses and gratings as systems elements, and integrated systems, with light mostly confined to waveguides or optic fibers in a manner similar to electrical circuits[6]. Such integrated waveguides can have different structures[6,7] with the most common being a ridge waveguide type[8] (a waveguide core layer along the length with cladding layers above and below with refractive indices lower than the core) and a rib waveguide type[9] with semiconductor cladding on one side and air cladding on the other. Typical microscale optical waveguides have cross-sectional dimensions ranging from 0.1-8µm in height and 2-10µm width[6,8-10]. Such a waveguide cantilever switch would require a tip movement in the range of a few microns.

For the first design prototypes which we use to develop and prove the fabrication process, we choose to build a variety of waveguides with heights of about 1-2µm and widths from 5-40µm. The core waveguide layer will be GaN with air acting both the top and bottom cladding layers.

2.3 Electromechanical configuration

The unimorph/bimorph cantilever actuator, in principle, requires the ability to impose a stress gradient across the thickness of the cantilever. In conventional macroscale systems, this is most easily realized using two distinct layers of material such that both the layers can be independently subject to an induced stress. The difference in the stress along the longitudinal beam direction in the two layers sets up a bending moment to that causes the cantilever to bend up or down (in the transverse direction). In practice, this device concept manifests in the form of the device configurations[11,12] schematically shown in Figure 2. In the d_{31} configurations, the crystal polarization axis (*c*-axis) is directed transverse to the cantilever as shown with the actuating electric field directed parallel and/or antiparallel to this axis. For this reason, planar electrodes sandwiched between the GaN epilayers will ideally be needed to apply the actuating electric field. The d_{33} configuration, on the other hand, has the *c*-axis directed along the length of the cantilever. An interdigitated electrode (IDE) configuration is usually used for such device configuration[11]. Preliminary simulations using commercial multiphysics FEM software indicate that a distance of about 20µm, which is the center-to-center distance between two adjacent IDEs, is needed to maintain an electric field of at least about 10MV/m in the upper half of the cantilever. Figure 3 shows the horizontal component of electric field for a cantilever thickness of 6µm for the d_{33} configuration with the IDE. Larger spacing between the electrodes would produce lower electric fields in the cantilever, reducing the piezoelectric effect.

For a GaN based bimorph, growing epitaxial layers with the *c*-axis along the length of the cantilever is difficult as compared to growing in the transverse direction. In addition, as discussed earlier, GaN cannot be poled once it has been deposited on the substrate. Due to these reasons, the d_{33} configuration is unsuitable for the current application. Of the remaining two d_{31} configurations, the d_{31} unimorph is chosen despite its lower actuation range solely for the simplicity that stems from the application and use of the electrodes.

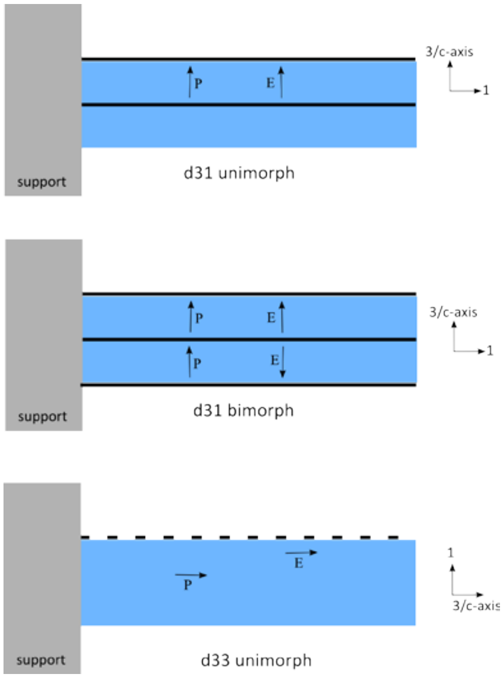


Figure 2. Practical unimorph/bimorph configurations (blue representing the active/passive layers and thick black lines indicate electrodes).

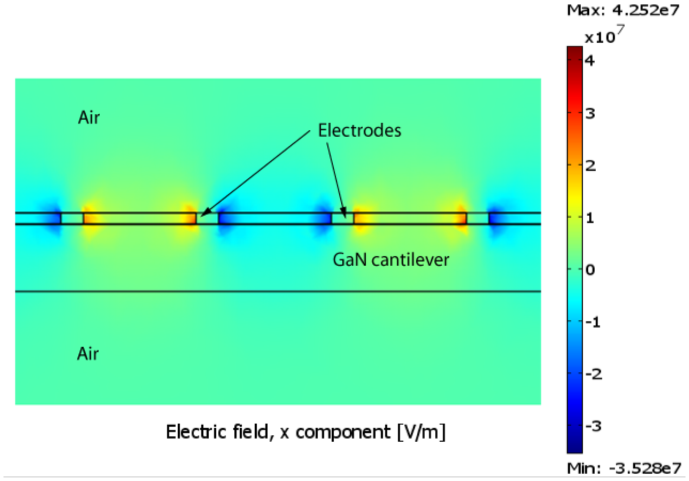


Figure 3. Electric field intensity along the length of the cantilever for d_{33} (IDE) configuration.

The maximum tip displacement of a GaN unimorph depends inversely on the beam thickness and directly on the applied electric field and the square of the beam length. The static tip displacement δ of such a unimorph cantilever can be expressed as[12,13].

$$\delta = \frac{3L^2}{2t} d_{31} E_3 \left[\frac{2AB(1+B)^2}{A^2B^4 + 2A\left(2B + 3B^2 + 2B^3\right) + 1} \right]$$

and modeling the undamped dynamics of a unimorph yields the resonant frequency of the cantilever to be[12,14,15]

$$f_r = \frac{\lambda_i^2 t}{4\pi L^2} \sqrt{\frac{E_p}{3\rho_p}} \sqrt{\frac{A^2B^4 + 2A\left(2B + 3B^2 + 2B^3\right) + 1}{(1+BC)(AB+1)(1+B)^2}}$$

where L and t are the bimorph length and total thickness, $A = E_p / E_a = s_{11}^E / s_{11}^p$ is Young's modulus ratio of the elastic (passive, subscript p) layer and the actuated (active, subscript a) layer, $B=t_p/t_a$ is the thickness ratio, $C=\rho_p/\rho_a$ is the density ratio and E_3 is the applied electric field. λ_i is an eigenvalue where i denotes the resonance mode (λ_1=1.875 and λ_2= 4.694). In the expression for tip displacement δ, the quantity within the square brackets are maximum (= 0.5) when the ratios A and B approximately equal unity[16]. For the device under consideration, a waveguide thickness t of 1-2um is chosen from optical considerations discussed in the previous subsection. Calculations using the expression for tip displacement indicate that a GaN cantilever of length ~500µm can be piezoelectrically actuated to attain modest tip displacements of about 1µm using actuation voltages of the order of 10V. The corresponding first resonant frequency is in the 100 kHz to 10MHz range.

For unimorph microcantilever beams working with air as the ambient fluid, viscous damping is the major loss mechanism. An approximate expression for the quality-factor Q associated with viscous losses for a microcantilever is[17]:

$$Q = \frac{2}{3} K \frac{\rho t w}{\left(\eta_0 / f_{res}\right) + \left(w/2\right)\sqrt{\pi \rho_0 \left(\eta_0 / f_{res}\right)}}$$

where K is a constant factor, ρ, t, w and f_{res} are the mass density, thickness, width and the resonant frequency of the microcantilever and ρ_0 and η_0 are the density and viscosity of the fluid medium surrounding the microcantilever. In simpler terms, the viscous Q diminishes with decreasing ambient pressure p as:

$$Q \sim \frac{1}{\sqrt{p}}$$

highlighting the need to test the device in a pressure controlled environment.

2.4 Semiconductor device aspects

Piezoelectric bimorphs are usually constructed using conductive metal layers sandwiched between the active/passive layers acting as the actuating electrodes. In the present context, this could pose the problem of growing epitaxial GaN layers on lattice mismatched metal layers. As discussed earlier in this section, having high-quality epitaxial layers of GaN is essential to achieving piezoelectric actuation of the device. The alternatives to metal electrodes are the use of 2-dimensional electron gas (2DEG) layers[18] or highly doped GaN layers to serve as electrodes[15] to apply the actuating field.

A 2DEG that has sufficient number of charge carriers in order for it to act as an electrical conductor requires an interface between heterogeneous semiconductors. This requires us to introduce a semiconductor layer into the microcantilever that has a different lattice constant from GaN, thereby bringing us back to the issue of lattice mismatched induced cantilever bending. Thus, the option that satisfies the need for an unstrained, homogenous unimorph is the use of heavily doped interlayers of GaN within the unimorph.

The final device design based on the discussion in this section is indicated by the schematic in Figure 5.d. In this design, the GaN unimorph microcantilever is operated in the d_{31} mode with a layer of intrinsic-GaN (undoped) acting as the active piezoelectric layer, a thin layer of Ni and a layer of n-type GaN being used to apply the actuating electric field and a layer of p-type GaN acting as the passive elastic layer of the unimorph. InGaN and another layer of n-type GaN are used as the sacrificial layers to be etched away using PEC etch to release the cantilever structure.

3. FABRICATION PROCESS DEVELOPMENT

3.1 Current state of processing technology

Conventional micromachining techniques do not often produce satisfactory results with GaN due its toughness and chemical inertness. Limitations of conventional dry etching techniques on GaN, namely, surface damage during processing and negligible lateral etch rates combined with the advantages of wet etch techniques, which include simplicity, high lateral etch rates, and high etch selectivity have driven researchers to explore **p**hoto**e**lectro**c**hemical (PEC) wet etching of GaN and related compounds[2,3,19-21]. The PEC etch technique enables greater control over the quality of microstructures, directly impacting the device performance. This technique also enables various GaN devices and structures that are not viable using conventional processing. In this section, we describe the use of PEC wet etching to fabricate the unimorph microcantilever optical switches on the GaN material platform.

3.2 PEC basics

As the name suggests, PEC is an electrochemical etch technique with light (UV radiation, in this case) as an integral component. The photons emitted by the light source serve to create electron-hole pairs within the irradiated region of the semiconductor, thereby enabling the chemical reactions that etch away those regions. Unlike many semiconductor processing/microfabrication technologies, PEC allows for an inexpensive hardware setup which is extremely easy to build, maintain and operate. The primary attraction of the PEC etch technique is its bandgap selectivity, dopant selectivity, defect selectivity and non-crystallographic etching[19].

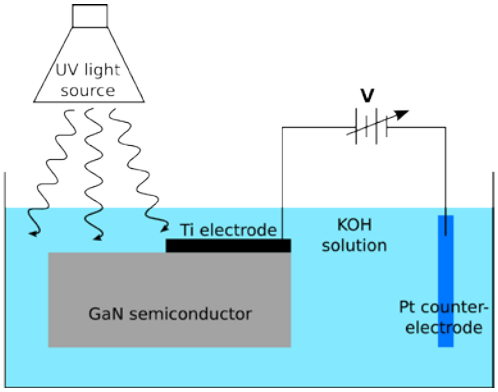


Figure 4. Schematic of the PEC etching setup.

A schematic layout of a PEC wet etching system is shown in Figure 4. The key elements of the system include the GaN semiconductor material in contact with a metal (Ti, Ni) acting as the anode in electrical contact with another metal (usually Pt) serving as the cathode, immersed in the electrolyte (KOH, H_3PO_4, etc.) and a UV light source with filter for wavelength-controlled illumination of the GaN wafer. The variable DC bias-voltage is a supplementary component used to control certain aspects of the PEC process, specifically the etch selectivity, etch rate and surface morphology. Although the PEC etch process is not yet fully understood, the distribution of electrodes, the bias voltage between the electrodes, the electrolyte concentration and the UV light intensity and wavelength are known to significantly influence the etch selectivity as well as the etch rate. These parameters are utilized to achieve a finer control over the fabrication process, while contributing to better understanding the physical phenomena behind the PEC etch. The PEC etching model is currently thought to consist of a two-step chemical reaction[20]:

$$2\mathrm{GaN} + 6\mathrm{OH}^- + 6h^+ \rightarrow \mathrm{Ga_2O_3} + 3\mathrm{H_2O} + \mathrm{N_2} \text{ (Oxide formation)}$$

$$\mathrm{Ga_2O_3} + 6\mathrm{OH}^- \rightarrow 2\mathrm{GaO_3}^- + 3\mathrm{H_2O} \text{ (Oxide dissolution)}$$

By patterning metal electrodes that act as UV masks and also as anodic contacts to the GaN, selective etch of the regions not covered by the mask can be achieved. Also, the dopant and band-gap selectivity can be utilized to selectilvely undercut specific layers of GaN.

It has been suggested based on experimental results published in the literature[19,21] that the locations and distribution of the PEC etch anodic electrodes on the GaN material has a significant impact on the PEC etch rates in the vicinity of the electrodes. For example, a reduction of about 80% was noticed in the etch rates in areas that were over 1.5mm away from the electrodes in some experiments. This is a problem for material stack under consideration, since the top actuation electrodes could unintentionally etch away the layers outside of the sacrificial layer. To get around this issue, the use of an array of anodic electrodes on the substrate material is proposed such that they are distributed close to the sacrificial layer. In addition, a negative bias (~1V relative to Pt cathode) to the top actuation electrodes and a positive bias (~1V relative to Pt cathode) to the electrodes on the substrate are simultaneously applied during the PEC etches. This novel PEC etch setup is based on the observations of Yang[20] among others who noticed dramatic variations in the etch rates with the applied bias voltages. Based on those results, it is expected that the n-GaN in the vicinity of the top actuation electrode will etch about 20 times slower than the n-GaN in the sacrificial layer (near the electrodes on the substrate). The proposed etch schematic is shown in Figure 5.b and 5.c.

Based on the above considerations the following selective etches offered by PEC etching are used for the fabrication of the proposed microcantilever device: Band-gap selective etch to remove InGaN without etching GaN using a filter to illuminate the sample with UV light with energy slightly below the GaN band-gap, dopant selective etch to remove n-type GaN without affecting either p-type or intrinsic GaN, and voltage bias-enhanced PEC to discriminate between different layers/regions of n-type GaN using an externally applied voltage bias to those layers/regions.

3.3 Proposed process flow

The optical microswitch device is fabricated using surface micromachining techniques. A novel wafer processing sequence has been developed to fabricate homogeneous, multilayered GaN unimorph/bimorph microactuators based on PEC etching technology.

The starting semiconductor material stack is composed of GaN/InGaN layers grown using N_2 plasma assisted Molecular Beam Epitaxy (Veeco Gen930) on Ga-polarity GaN/sapphire templates (Kyma Inc.) or on N-polarity free-standing GaN templates (Lumilog Inc.). Standard effusion cells for Ga, In, Si (n-type) and Mg (p-type) were used, and an Applied EPI plasma source was used for the N_2 source. The epitaxial structure is shown in Figure 5.a. The material stack used and the function of each stack in the final device are as shown in Figure 5.a. The microcantilever shapes are patterned with Ni/Au films on this stack using conventional electron-beam evaporation and liftoff techniques. Reactive Ion Etching (RIE) using a BCl_3/Cl_2 based Inductively Coupled Plasma (ICP) is then used to create a mesa structure using the Ni/Au pattern as the etch mask. Once the mesa structure is created (Figure 5.a), a band-gap selective PEC etch is used to first remove the thin layer of InGaN. A GaN wafer is used to filter and remove UV radiation with energy above the bandgap of InGaN. This etch serves to vastly increase the surface area of the sacrificial n-GaN layer in preparation for the subsequent PEC etch and also causes a preliminary release for the microcantilever (Figure 5.b). This next dopant-selective, voltage-bias-enhanced PEC etch does not use a UV filter, and makes use of two distinct selectivities to fully release the cantilever. The dopant-selectivity serves to etch the n-type GaN layers, but not the intrinsic and p-type layers and the voltage-bias-enhanced etch process discriminates between n-GaN layers based on their proximity to the bias-electrodes and the biases used (Figure 5.c)[19]. As the last step (Figure 5.d) electrical contact is established with the with the middle electrode layer using conventional wet and RIE etches and electron-beam evaporation and liftoff.

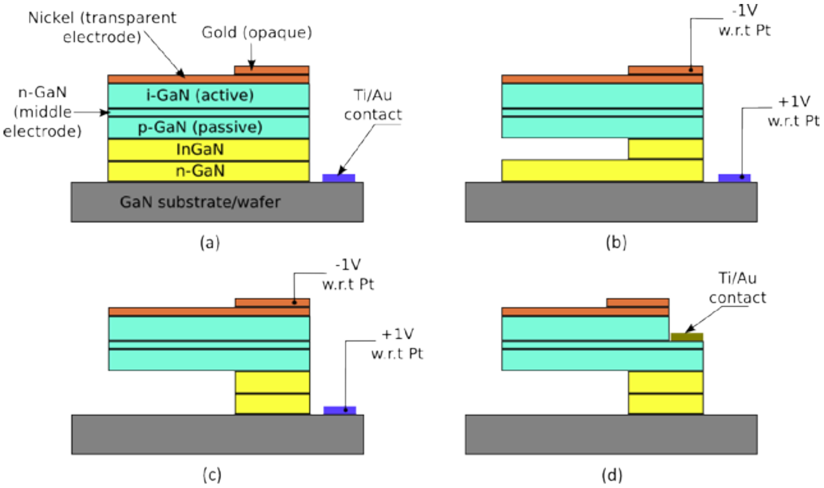


Figure 5. Fabrication process overview (not to scale). (a) is the mesa structure with the material stack details just prior to the PEC etch, (b) and (c) show wafer stack between and after the PEC etches, (d) shows the final device structure.

4. FABRICATION ISSUES AND DISCUSSION

The material stacks used to fabricate the device have been grown in-house using molecular beam epitaxy (MBE). The subsequent processing is carried out partially using processing recipes also developed in-house for GaN microelectronic devices. Two distinct wafer types, one with a Ga-face polarity and the other with an N-face polarity have been used to fabricate the devices. This is done to explore the effect of the polarity on the material stack on the device fabrication and performance. N-face epitaxial GaN is more susceptible to etching by certain acidic etchants as well as dry etch techniques, making them more complicated to process than the more inert Ga-face GaN. The rougher surface texture of N-GaN could also be the cause of adhesion issues between the electrode and metal mask layers. Although Ga-face GaN tends to have a smoother top surface, microcantilevers made using PEC tend to have a rough undercut surface. N-face

GaN on the other hand has a smoother undercut and for this reason, could be more suitable for optical waveguide applications.

Figure 6 shows SEM images of the microcantilever devices prior to the PEC etches. The shapes of the mesas at this stage of the device fabrication practically define the shape of the final devices. Overall, the mesas turned out with fairly well defined shapes as expected. In addition to the mesa structures, the figures also show the outlines of the metallizations on the flat tops of the mesa structures. During the conventional etches used to achieve the mesa structures shown, some metal delaminations and unintentional etches occurred, thereby reducing the final device yield. The device fabrication recipes need further improvements to eliminate these problems.

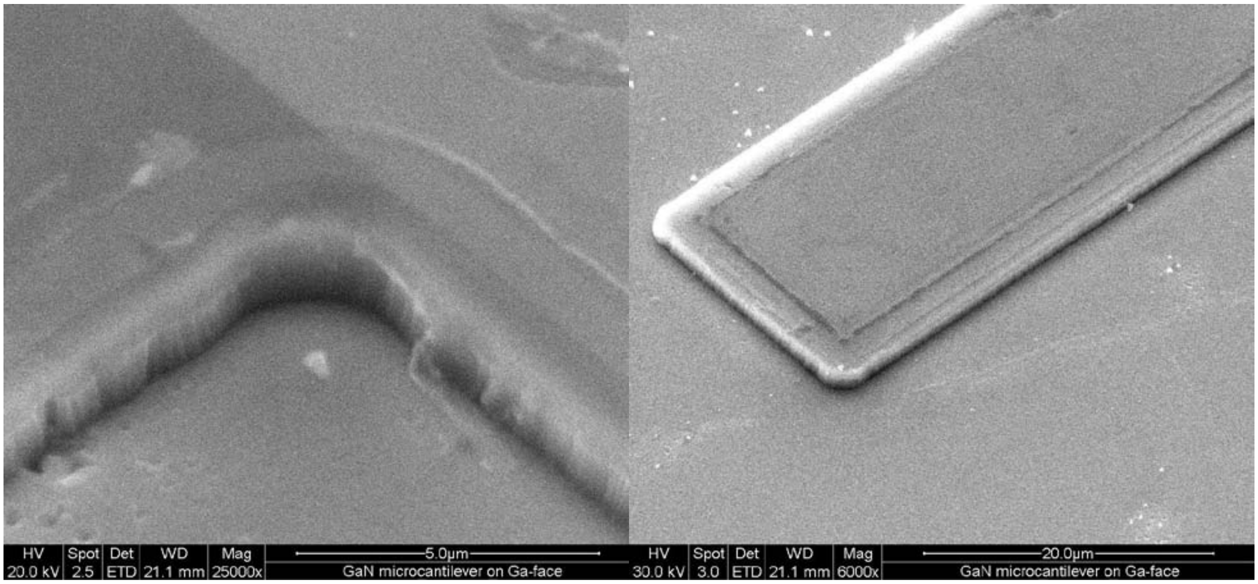
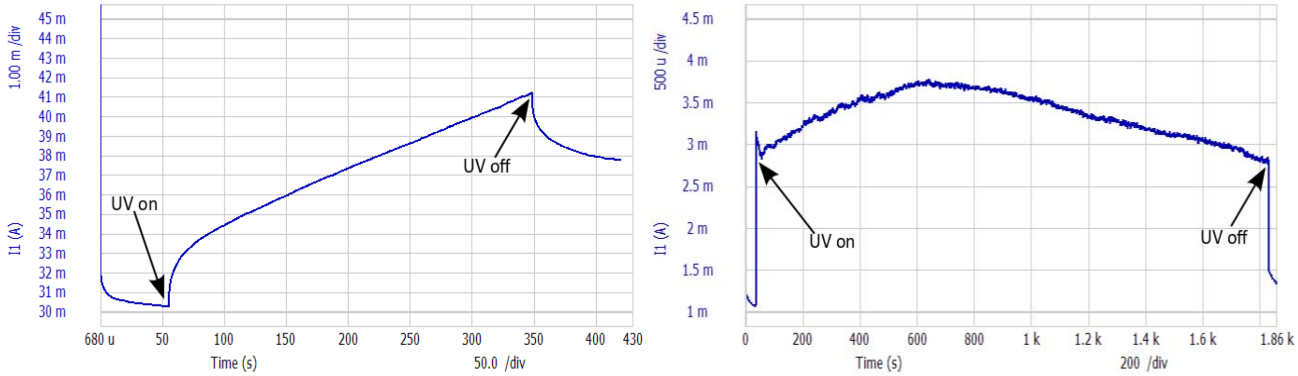


Figure 6. SEM images of the microcantilevers prior to the PEC etches.

Figure 7shows the measured current through the PEC etch setup over the duration of the two PEC etches. As expected, the PEC etch reaction rates spike (as indicated by the current spikes) at the times when the UV lamp is turned on/off. In addition, the magnitude of the currents is indicative of the actual etch rates with the currents being an order of magnitude higher for the bandgap-selective etch (Figure 7.a) than for the dopant selective etch (Figure 7.b). Taking the integral of the current-time plot could potentially be used to estimate the total material removed during an etch.



(a) (b)

Figure 7. Current variations through the PEC etch setup during the (a) band-gap selective etch and (b) dopant-selective etch. A constant bias voltage of +1V with regard to the Pt electrode was applied to the anode on the substrate. The spikes in the plots correspond to the UV light source being turned on/off.

Figures 8 and 9 are SEM images of different microcantilevers realized after the PEC etches. These images show the formation of well defined microcantilever structures that indicate the potential of this material platform. The figures also highlight a few important issues that need to be resolved. The grass-like morphology seen on the substrate arises during the PEC etching due to the depletion of holes near threading dislocation defects in the GaN layers. This hole depletion reduces the rate of the PEC reaction at these locations, leading to unetched GaN 'whiskers/grass'. A smoother morphology should result from the use of an appropriate bias voltage level coupled with a low electrolyte concentration during the PEC etch and the values for these parameters used in the present etch need to be optimized further. Also evident is some undercut beneath the masked regions of the mesa. This may be attributed to the leakage to UV radiation into these regions by reflections and scattering. This problem should be mitigated by the use of better designed enclosure for the PEC etch or other innovative techniques to limit stray UV radiations from the sides.

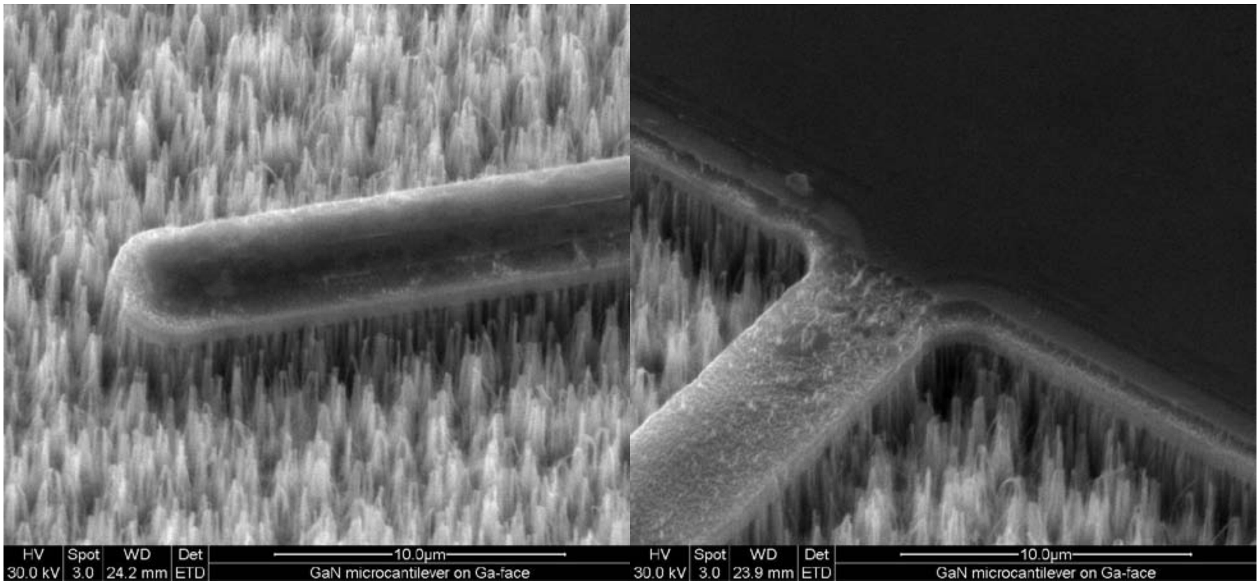


Figure 8. SEM images of the microcantilevers after the PEC etches. The dark areas on top are the Au and Ni mask/electrode layers, while the lighter shades and the grass-like morphology below corresponds to GaN.

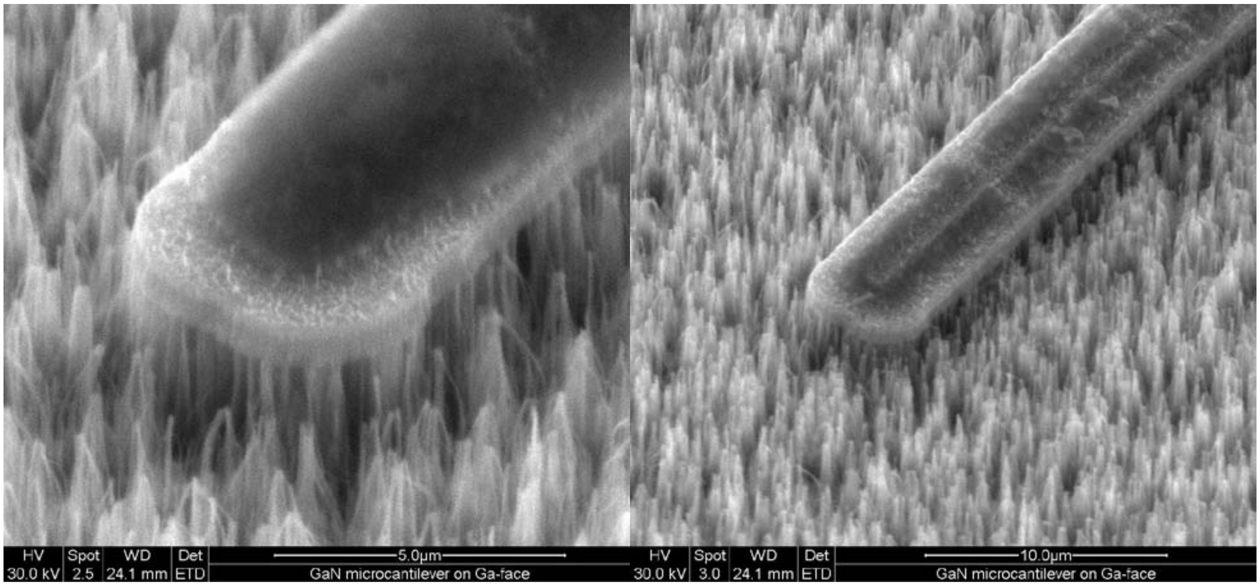


Figure 9. SEM images of the microcantilevers after the PEC etches, highlighting some fabrication issues.

5. SUMMARY AND FUTURE WORK

This paper presents the device design and fabrication of a prototype MEMS-based optical switch in the GaN material system for next-generation integrated MEMS devices. The realization of the switch involves the development of a novel semiconductor processing technology, known as the photoelectrochemical wet etch. The overall device requirements based on electromechanical, optical and semiconductor device perspectives and initial device designs based on piezoelectric bimorphs are discussed. The primary contribution of this paper is with regard to the development of the PEC etch technology: the current state of GaN etching technologies is summarized and a method of fabricating the optical switch is presented. The proposed PEC based novel etch technique involves the use of electrodes carefully distributed across the wafer and simultaneous positive and negative voltage biases to these electrodes to achieve a greater selectivity of the PEC etch process. To the authors' knowledge, this is the first time that a microscale piezoelectric unimorph/bimorph actuator has been attempted on GaN. This device is better suited for integration with GaN based optical sources, sensors and processing circuits as well as with other GaN based integrated circuits than conventional piezoelectric devices.

Work is currently underway to modify the fabrication recipes to increase the device yield and quality. Subsequent testing and characterization of the mechanical, electrical and optical performance of the device will be carried out. The data gathered from the characterization will be used to improve the mathematical models used to describe the device performance. This work is also expected to spawn further research into GaN based microsystems to exploit the unique properties of the material.

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