Community Service Project Extension Request:
P-GaN/AlGAN/GaN E-mode HEMT

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Request for Extension

The community service project "P-GaN/AlGAN/GaN E-mode HEMT" was proposed on 2019. 04. 05., and we have continued on this project since then. Our initial plan, as suggested in the proposal from, was to finish the project by 2019. 06. 28. However, according to the technical problems we encountered regarding the growth of the material, the whole progress was delayed and here we request for the extension of the project.

Description of the Problem

The fabrication of lateral gallium nitride(GaN) devices usually follows the following macroscopic steps: (i) choosing and cleaning the substrate, (ii) growth of the buffer layes and main GaN layer stack, (iii) post-growth steps of etching and metal deposition. The second step, the growth or materials, can be done using MBE and MOCVD, and currently most Stanford lab-members are using the MOCVD tool aix-ccs for this step.

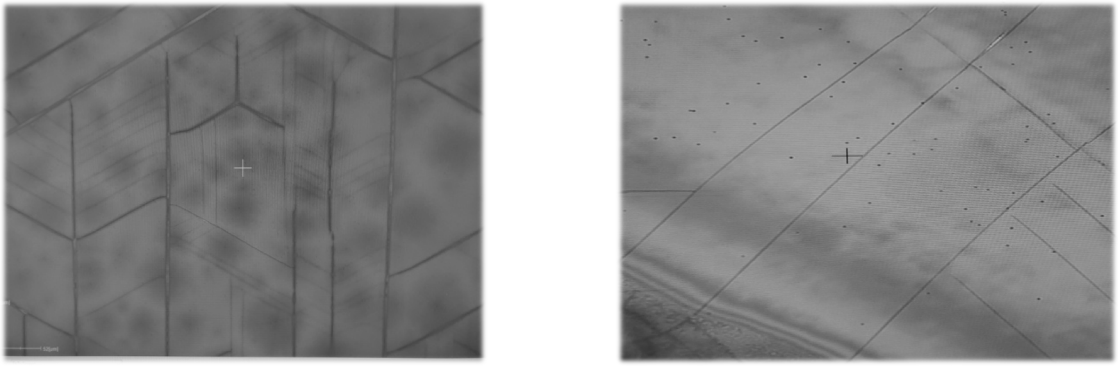

Figure 1. Cracks seen on the surface of gallium nitride samples after the MOCVD growth using Stanford aix-ccs.

However, when we actually grew $Al_xGa_{1-x}N$ buffer layer stacks on Si(111) wafers, we saw lots of cracks along the crystal planes of GaN, which were not seen for years. Since $Al_xGa_{1-x}N$ has different lattice constants depending on the mole faction x, we have to carefully control the thickness and growth condition of AlN, $Al_{0.8}Ga_{0.2}N$, $Al_{0.5}Ga_{0.5}N$, $Al_{0.2}Ga_{0.8}N$, and GaN. If we fail to do so, the layers cannot stand the tensile strain are vulnerable to cracking problems, as seen in the Figure 1.

Status

With the assumption that the long-time use of the aix-ccs susceptor(especially with lots of Mg-dopant contamination over years), we replaced the graphite susceptor, quartz liner with new ones, along with other major maintenances. Since a slight change in the growth condition requires the change of other parameters as well, we had to fine-tune the growth parameters including the temperature zone and thickness of the layers. (Previously working recipes could not be used anymore.) There are other alleged problems as well and corresponding measures we have taken, as summarized in table 1.

Alleged Cause of the Crack Problem	Our Solution
SiO_2 formation of Si(111) wafer (buffer growth)	Newly cleaned Si(111)/ sapphire wafers
	Increased initial baking steps
Ga_2O_3 on template GaN samples (device stack growth, post-buffer device stack)	Inclusion of 80°C HCl cleaning step
Mg-dopant contamination of the graphite susceptor & quartz liner (growth in general)	Replacement of the susceptor & liner
GaN layer strain problem due to new susceptor (after replacement)	Modification of thermal zone
	Change of stack layer thickness

Table 1. The possible causes of the crack problem and the measures we took to solve them.

With lots of short-loop experiments, we managed to find out recipes for stable growth of depletion mode GaN stack as well as enhancement mode GaN stack for GaN electronics on Si(111) wafers. However, this took a lot of time and money. Since the project started in the April of 2019, we did not get the working wafer for the actual PGaN/AlGaN/GaN e-mode samples until the end of June, which was when we planned to finish the project. We spent about 2.5 months just solving this tool-specific technical problem.

	SNF Expense($)	MOCVD Expense($)	nSiL Expense($)
Proposed	4590	3200	1800
Spent	3318	7475	1946
Spent During Troubleshooting Period (April-June)	2093	5501	854
Remaining Budget (approximate)	3365	1226	708

Table 2. Budget spent during the project period.

It can be seen from the table 2 above that most of the research budget was spent absurdly on MOCVD, as the remedy for the cracking problem took us a large amount of our resources. A large portion of SNF expense was also spent on the treatment of those short-loop samples. Though those numbers are somewhat approximate, as even during the troubleshooting period not all budget was spent for the crack issue, we are very sure that by excluding this we are still within the original budget limit we proposed. Therefore, we are eager to finish this project by getting an extension.

Revised Plan & Deliverable

Originally proposed deliverables ar as in the table below.

Proposed Deliverable	**Status**
Ox-35 Nonselective AlGaN/GaN etching recipe and data	Achieved
Ox-35 Selective (P) GaN etching recipe and data	Achieved
aix-ccs Mg-doped GaN growth recipe and data	Partially achieved & Changes needed
Process-runsheet for e-mode GaN HEMT	Achieved
Threshold voltage control method of GaN HEMT	Not achieved yet
High-temperature data of GaN HEMT	Partially achieved & Changes needed

Table 3. Proposed deliverables.

In terms of the etching processes, we have achieved all we expected. The problems lied within the growth. The crack problem, which was not in our original plan, is successfully solved. However, the PGaN growth, though we managed to grow p-type gallium nitride layer, but it turned out that we might need major changes in terms of the doping level. Our devices show much improved V_{th}, but it is not indeed enhancement-mode yet. Our short-loops for PGaN doping level as well as layer thickness and the gate metal are the key to the full V_{th} control.

Below are the items to be finished during this quarter.

- Short-loop investigation of PGaN Mg doping level.
- Short-loop investigation of PGaN Mg layer thickness.
- (If time allows) Short-loop investigation of gate metals.
- Use TCAD model to find out final device configuration.
- Fabrication of final device optimized based on the previous data.
- Room-temperature & high-temperature characterization of the device.
- Documentation of the full recipes

We expect to finish the fabrication side of the project by the end of the 2019 Fall quarter, which is 2019. 12. 22.