GaN RF Power Electronics
The technology of choice for 5G applications

Unique Patent Purchase Opportunity
With 5G implementation coming, the GaN RF market is developing fast.

The GaN RF market will grow from $380M in 2017 to $1.3B by 2023 (Yole Report, RF GaN Market, 2018).

GaN has become the technology of choice for base transceiver stations, radar and satellite communications. It is increasingly used in wireless charging devices and self-driving cars.

High-frequency, high-bandwidth, high-power, high-efficiency applications are where GaN differentiates itself from other materials.
Sensor Electronic Technology, Inc. (SETi) was founded by two Rensselaer Polytechnic Institute (RPI) professors in 2000.

SETi was at the forefront of GaN device development for high-power RF electronic and LED UV technologies.

After being acquired by Seoul Viosys, a subsidiary of Seoul Semiconductor, SETi decided to focus on LED UV technologies and now sells this GaN RF patent portfolio.
PATENT PORTFOLIO OVERVIEW

- 80 assets
- 60 issued patents
- 20 patent applications

- Issued patents:
  - 60 patents
  - 2 TW patents
  - 3 JP patents
  - 1 CN patent

- Patent applications:
  - 20 applications
  - 1 CN patent application

- KR patent applications:
  - 19 applications
RF POWER TECHNOLOGY

- A high-electron-mobility transistor (HEMT or HFET) is a field-effect transistor incorporating a junction between two materials with different band gaps as the channel.

- Gallium nitride (GaN) has the advantage of a high breakdown field, which allows GaN HEMTs to operate at much higher voltages than other semiconductor devices, which makes them ideal for high-power applications.

GaN HEMT

Current flows through the channel from the source to the drain electrode.

The current can be modified by applying a voltage to the gate electrode.

Because the power required to control the channel is much smaller than the power the transistor can deliver to a load, the HEMT can amplify a radio frequency (RF) signal.
## OVERVIEW: EXEMPLARY PATENTS

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Name</th>
<th>Priority Date</th>
<th>Estimated Expiration Date</th>
<th>Exemplary Applications</th>
</tr>
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<tbody>
<tr>
<td>US 7674666</td>
<td>Fabrication Of Semiconductor Device Having Composite Contact</td>
<td>2/23/2007</td>
<td>1/10/2028</td>
<td>Amplifiers, mixers, oscillators, THz devices</td>
</tr>
<tr>
<td>US 7795672</td>
<td>Profiled Gate Field Effect Transistor With Enhanced High Harmonic Gain</td>
<td>12/26/2006</td>
<td>12/16/2028</td>
<td>Power amplifiers</td>
</tr>
<tr>
<td>US 8299835</td>
<td>Radio-Frequency Switch Circuit With Separately Controlled Shunt Switching Device</td>
<td>2/1/2008</td>
<td>5/20/2031</td>
<td>High voltage switching regulators, 5G microwave switches, automotive switch products</td>
</tr>
<tr>
<td>US 8552562</td>
<td>Profiled Contact For Semiconductor Device</td>
<td>6/1/2009</td>
<td>6/8/2031</td>
<td>HEMTs</td>
</tr>
<tr>
<td>US 9219137</td>
<td>Vertical gallium nitride transistors and methods of fabricating the same</td>
<td>02/12/2013</td>
<td>02/11/2034</td>
<td>HEMTs</td>
</tr>
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</table>
METAL OXIDE SEMICONDUCTOR HETEROSTRUCTURE FIELD EFFECT TRANSISTOR

Summary of the Invention
“The current invention provides a method and structure for controlling reverse current leakage in semiconductor devices by providing nitride based heterostructures having a silicon dioxide dielectric layer.”
(US6690042, column 1, line 48)
METAL OXIDE SEMICONDUCTOR HETEROSTRUCTURE FIELD EFFECT TRANSISTOR

**Highlights**

This patent has been licensed to the Ballistic Missile Defense Organization of the United States Department of Defense, confirming its value proposition: “The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of DR9A90100001 awarded by the U.S. Army BMDO/SMDC.”

(US6690042, Certificate of Correction, page 1)

A newer Samsung patent application refers to silicon dioxide in HFETs: “The HFET of claim 1, wherein a protection layer comprising at least one selected from the group consisting of silicon nitride (SixN), silicon oxide (SiOx), and aluminum oxide (Al2O3) is formed . . .”

(US20120280233A1, claim 7)

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**Patent Number**  
US6690042

**Priority Date**  
September 27, 2000

**Date of Patent**  
February 10, 2004

**Estimated Expiration Date**  
September 27, 2021

**Patent Family Members**  
US6878593

**Exemplary Applications**  
Switches, amplifiers, photodetectors

**Potential Buyers**  
Furukawa Electric, Toyota, Samco, TI, Infineon, Cree, Qorvo, MACOM, Navitas, GaN Systems, EPC, Boeing, Northrop Grumman, Teledyne, Raytheon, Lockheed
Summary of the Invention
“The invention provides an improved semiconductor sensing device. Specifically, under the present invention, a semiconductor device includes a sensing layer incorporated below a contact.”
(US7382004, column 1, line 57)

Exemplary Claim
6. A semiconductor device configured to sense a property of a medium, the device comprising:
   - an electrical contact; and
   - a gallium nitride (GaN) sensing layer disposed below the contact, wherein the sensing layer is exposed to the medium in an area below the contact by at least one perforation in at least one of the contact and a second layer disposed between the sensing layer and the contact.
**Highlights**

“A future iPhone or Apple Watch could determine its general location by gases,” Apple has proposed, with the use of miniature sensors inspecting the air to determine if the user is inside or outdoors, and potentially even narrowing down to a specific room, without relying on GPS or signals from communication networks.”


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**Patent Number**  
US7382004

**Priority Date**  
November 25, 2003

**Date of Patent**  
June 3, 2008

**Estimated Expiration Date**  
June 3, 2025

**Patent Family Members**  
US7868399

**Exemplary Applications**  
Gas sensors, pH sensors

**Potential Buyers**  
am AG, KST, Microlyne, GE, Siemens, Apple, Samsung, Huawei
Summary of the Invention
“The composite contact is formed by forming a direct current (DC) conducting electrode attached to a semiconductor layer in a semiconductor structure and forming a capacitive electrode that is partially over the DC conducting electrode and extends beyond the DC conducting electrode. The composite contact provides a combined resistive-capacitive coupling to the semiconductor layer. As a result, a contact impedance is reduced when the corresponding semiconductor device is operated at high frequencies.”

(US7674666 column 2, line 21)
FABRICATION OF SEMICONDUCTOR DEVICE HAVING COMPOSITE CONTACT

**Highlights**
Related patents US8587028 and US9349848 in the portfolio are licensed to the U.S. Air Force, confirming the value of these patents: “The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of contract awarded by the United States Air Force (USAF)/Air Force Material Command (AFMC).” (US8587028 column 1, line 14 & US9349848, column 1, line 16)

<table>
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<tr>
<th>Patent Number</th>
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<td>Priority Date</td>
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<td>March 9, 2010</td>
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<td>US7655962, US8461631, TWI362754</td>
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<tr>
<td>Exemplary Applications</td>
<td>Amplifiers, mixers, oscillators, THz devices (see US8338871)</td>
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<td>Potential Buyers</td>
<td>NXP, Nexgen, Cree</td>
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### Summary of the Invention

“Aspects of the invention provide a field effect transistor that can be operated as a low voltage Class FN radio frequency (RF) amplifier with harmonic tuning.” (US7795672, column 1, line 61)

### Exemplary Claim

1. A field effect transistor comprising:
   a common electrode;
   a single gate having
   a plurality of gate sections, each section comprising a different gate length within the plurality of gate sections; and
   a plurality of separate electrodes, each separate electrode corresponding to one of the plurality of gate sections.
PROFILENAME GATE FIELD EFFECT TRANSISTOR WITH ENHANCED HIGH HARMONIC GAIN

Highlights
Countless devices have now a plurality of gate sections and a plurality of electrodes corresponding to them.

<table>
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<tr>
<th>Patent Number</th>
<th>US7795672</th>
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<td>Priority Date</td>
<td>December 26, 2006</td>
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<td>Date of Patent</td>
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<td>US7560985</td>
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<tr>
<td>Exemplary Applications</td>
<td>Power amplifiers</td>
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<td>Potential Buyers</td>
<td>Any manufacturer of power amplifiers</td>
</tr>
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</table>
Summary of the Invention

“Aspects of the invention provide a switch circuit that includes at least one main switching device and at least one shunt switching device. Each main switching device is connected in series with a conductor that carries an RF signal between an input circuit and an output circuit. Each shunt switching device is connected between a controlling terminal of the main switching device and a high frequency ground. The switch circuit can provide substantially improved OFF state isolation over other approaches.”  

(US8299835 column 2, line 21)
RADIO-FREQUENCY SWITCH CIRCUIT WITH SEPARATELY CONTROLLED SHUNT SWITCHING DEVICE

**Highlights**
This switch has value for high power products and RF products.

<table>
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<tr>
<th>Patent Number</th>
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<tr>
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<td>Date of Patent</td>
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<td>May 20, 2031</td>
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<td>Exemplary Applications</td>
<td>High voltage switching regulators, 5G microwave switches, automotive switch products</td>
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<td>Potential Buyers</td>
<td>TI, Infineon, Cree, Navitas, GaN Systems, EPC, Dialog, pSemi Corp</td>
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</table>
Summary of the Invention

“(T)he impedance of the driving/control circuit must be much lower than the gate-to-channel impedance of the HFET at high frequencies. Therefore, it is often important for each of the HFET’s gates to be connected to the control signal supplies through a low-pass filter, which for robustness and cost efficiency can be monolithically integrated with each HFET.”

(US8339163 column 1, line 48)

Exemplary Claim

14. A device comprising: a field effect transistor (FET) comprising a gate; and a circuit element monolithically integrated with the gate of the FET, wherein a low-pass filter is formed using the monolithically integrated circuit element, wherein the monolithically integrated circuit element includes a contact for electrically connecting the gate to a gate control circuit, and wherein the device is a discrete component for inclusion in a circuit.
**Highlights**

This widely used “RF switch circuit can provide low loss, high isolation, and high power operating characteristics as compared to similar prior art switch circuits.”

US8339163 column 3, line 67

<table>
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<tr>
<th>Patent Number</th>
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<td>Exemplary Applications</td>
<td>High voltage switching regulators, 5G microwave switches, automotive switch products</td>
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<td>Potential Buyers</td>
<td>TI, ON Semiconductor, EPC, Navitas, GaN Systems</td>
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</table>
PROFILES CONTACT FOR SEMICONDUCTOR DEVICE

Summary of the Invention
“A profiled contact for a device, such as a high power semiconductor device is provided. The contact is profiled in both a direction substantially parallel to a surface of a semiconductor structure of the device and a direction substantially perpendicular to the surface of the semiconductor structure. The profiling can limit the peak electric field between two electrodes to approximately the same as the average electrical field between the electrodes, as well as limit the electric field perpendicular to the semiconductor structure both within and outside the semiconductor structure.”
(US8552562 abstract)

Exemplary Claim
1. A device comprising:
   a semiconductor structure; and
   a first contact located on a surface of the semiconductor structure, wherein the first contact comprises at least two contact corners having a substantially lateral direction with respect to a surface of the semiconductor structure and a substantially perpendicular direction with respect to the surface of the semiconductor structure, wherein the at least two contact corners have a lateral profiled shape along the substantially lateral direction and at least one edge having a perpendicular profiled shape along the substantially perpendicular direction, wherein the lateral profiled shape of each of the at least two contact corners provides a gradual transition between a first edge and a second edge forming the corresponding contact corner and the perpendicular profiled shape provides a non-planar transition from the surface of the semiconductor structure to a top surface of the first contact.
<table>
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<tr>
<th><strong>Highlights</strong></th>
<th>The profiled contact is easy to detect from a top level photo and a cross sectional analysis.</th>
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<tr>
<td><strong>Patent Number</strong></td>
<td>US8552562</td>
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<td><strong>Potential Buyers</strong></td>
<td>Vishay, Infineon, Fuji Electric</td>
</tr>
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</table>
VERTICAL GALLIUM NITRIDE TRANSISTORS
AND METHODS OF FABRICATING THE SAME

Exemplary Claim
1. A vertical gallium nitride transistor, comprising:
   
   a drain electrode, wherein the second semiconductor layer is disposed on a first surface of the drain electrode; and
   
a current blocking layer disposed between the drain electrode and the second semiconductor layer, the current blocking layer comprising a lower surface in direct contact with the drain electrode and an upper surface that is in direct contact with the second semiconductor layer,
   
   wherein the first semiconductor layer, the third semiconductor layer, and the second semiconductor layer comprise a semiconductor structure.

Patent Number          US 9219137
Priority Date          February 12, 2013
Date of Patent         December 22, 2015
Estimated Expiration Date        February 12, 2034
Patent Family Members          KR10-2013-0014873, 
                                KR10-2013-0070692, 
                                KR10-2013-0081623
Exemplary Applications      HEMTs
Potential Buyers          Toyota, Nexgen, Toyoda Gosei, Qorvo
EXTENDING BREAKDOWN VOLTAGE

In power semiconductor devices, achieving the highest breakdown voltage simultaneously with minimal on-resistance is one of the most important performance characteristics. The patent portfolio includes three solutions to overcome this problem.

Semiconductor device with multiple space-charge control electrodes (US8878154)

Semiconductor device with breakdown preventing layer (US9190510)

Lateral/vertical Semiconductor device with Embedded isolator (US9601611)
## LICENSES

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<th>Licenses</th>
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<td>Encumbrances</td>
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<td>Seller</td>
<td>Seller will retain customary, non-exclusive license.</td>
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<tr>
<td>US6690042</td>
<td>The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of DR9A90100001 awarded by the U.S. Army BMDO/SMDC.</td>
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