# 高頻應用之砷化銦鋁/砷化銦鎵

# 變異結構高電子移動率電晶體之研究

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## 摘要

本研究成功製作高頻應用之高效能砷化銦鋁/砷化銦鎵變異結構高電子移動率電晶體(MHEMTs)，並且對此元件做了深入的分析與探討。為了增進此變異結構高電子移動率電晶體之特性，在改善元件磊晶結構的同時，也研發出數種新穎的縮小閘極線寬的技術。另外，也對元件的高頻應用設計了元件的圖形佈局(Layout)與討論相關的電性量測技巧。

在論文中，研發出數種新的縮小閘極線寬的技術並且應用在MHEMT元件上。首先是使用深紫外光(DUV)微影配合特定角度乾蝕刻技術製作出具有0.15-μm的Γ型gate之MHEMT，這是第一次發表的一種降低製作成本與手續的方法。用此方法製作的MHEMT具有 680mA/mm的汲極-源極電流以及 728mS/mm的高轉導值。此元件也展現了 130GHz的高截止頻率($f_T$)與 180 GHz的最高震盪頻率($f_{max}$)。另外，研發出利用熱回流技術與使用電子束雙層光阻製作出 0.1-μm的T型閘極，並且成功的應用在MHEMT元件製作上。跟一般的兩次電子束微影的閘極製作方法相比，與原先製程相容的熱回流技術具有製程簡單並且降低成本的優點。

在線寬縮小至 100nm以下的部分，成功的在low-noise MHEMT元件上使用

介電材料sidewall方法製作出 90nm的T型閘極。此 160μm-width的MHEMT在16GHz頻率之下的雜訊指數為 0.69dB且相對應的增益(associated gain)為9.76dB。此外，具有 70nm的T型閘極與double δ-doping之power MHEMT元件也被成功的製作與研究。因具備奈米尺寸的閘極與銦含量高達 60%的通道層，此MHEMT具有 890mA/mm的飽和汲極-源極電流以及 827mS/mm的轉導值，並展現200GHz的高截止頻率($f_T$)與 300GHz的最高震盪頻率($f_{max}$)。此元件在 32GHz之Ka頻段下具有良好的特性，表現出 14.5dBm的最大輸出功率對應 11.1dBm的P1dB，以及 9.5dB的功率增益。

另外，論文中也探討Ti/Pt/Cu閘極結構對於MHEMT中的砷化鋁銦(InAlAs)蕭特基層之電性與熱穩定性。與一般的Ti/Pt/Au作比較之後發現，此種具有銅金屬的蕭特基金屬結構在經過熱處理之後仍具有良好的特性。由材料分析得知，加熱到時在InAlAs上的Ti/Pt/Cu並沒有任何擴散的現象。加熱到 400°C之後，銅金屬才開始擴散並且與下層形成$Cu_4Ti$。此結果驗證了使用Pt作為擴散阻擋層的Ti/Pt/Cu結構具有高達 350°C的良好熱穩定性，並且可以應用在MHEMT元件與單石微波積體電路(MMICs)上。

# The Study of InAlAs/InGaAs Metamorphic High Electron Mobility Transistors for High Frequency Applications

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## Abstract

High performance InAlAs/InGaAs metamorphic high electron mobility transistors (MHEMTs) have been fabricated and characterized for high frequency applicatiions. The performance of the MHEMTs was improved by optimizing the device structure and reducing the gate length using several novel gate-shrinking techniques. The epi-structure, layout design and electrical measurements of the MHEMTs were also discussed.

In this dissertation, several novel gate shrinking processes for MHEMTs fabrication were developed. For cost-effective production of submicron MHEMTs, a 0.15-μm Γ-shaped gate MHEMT technology using Deep UV lithography and a tilt dry-etching technique was developed and demonstrated for the first time. The fabricated 0.15-μm MHEMT using this novel technique shows a drain-source current of 680 mA/mm and transconductance of 728 mS/mm. The cutoff frequency $f_T$ and maximum oscillation frequency $f_{max}$ of the MHEMT are 130 GHz and 180 GHz, respectively. In addition, a 0.1 μm T-gate was achieved by thermally reflowing the bi-layer E-beam resist using hotplate and the 0.1-μm T-gate was applied to the MHEMT manufacture. Comparing with 2 step lithography of the conventional

E-Beam T-gate process, the reflowed gate process is a much simpler, relatively inexpensive and flexible process.

Under 100-nm scale, a low-noise MHEMT using 90-nm sidewall T-gate process was also successfully fabricated. The noise figure of the 160μm-width MHEMT was 0.69dB and the associated gain was 9.76dB at 16GHz. Moreover, a 70-nm $In_{0.52}Al_{0.48}As/In_{0.6}Ga_{0.4}As$ power MHEMT with double δ-doping for power application was also fabricated and evaluated. The device has a high transconductance of 827 mS/mm, high saturated drain-source current of 890 mA/mm, high $f_T$ of 200 GHz, and a high $f_{max}$ of 300 GHz was achieved due to the nanometer gate length and the high Indium content in the channel. When measured at 32 GHz, the device demonstrates a maximum output power of 14.5 dBm with P1dB of 11.1 dBm and the power gain is 9.5 dB. The excellent DC and RF performance of the 70-nm MHEMT shows a great potential for the Ka band power applications.

In addition, electrical characteristics and thermal stability of the Ti/Pt/Cu contact on InAlAs Schottky layer of the MHEMT were investigated. The Ti/Pt/Cu Schottky contact had comparable electrical properties compared to the conventional Ti/Pt/Au contact after annealing. As judged from the material analysis, the Ti/Pt/Cu on InAlAs after 350°C annealing showed no diffusion sign into the InAlAs. After 400°C annealing, the interfacial mixing of Cu and the underlying layers occurred and resulted in the formation of $Cu_4Ti$. The results show that the Ti/Pt/Cu Schottky contact using platinum as the diffusion barrier is very stable up to 350°C annealing and can be used for the InAlAs/InGaAs HEMTs and MMICs fabrication.

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