

# Fabrication of inverted GaAs solar cells on silicon substrates

陳勵璋、蕭宏彬

E-mail: 322112@mail.dyu.edu.tw

## ABSTRACT

This study is to investigate the fabrication of inverted GaAs solar cells on silicon substrates by wafer bonding and epitaxial lift-off technique. Conventional InGaP/GaAs/Ge-based triple junction solar cells with high conversion efficiency have been demonstrated. However, Ge junction contributes only 270 mV to open circuit voltage due to 0.66 eV of bandgap energy for Ge. By switching to InGaAs, the bandgap energy of this junction increases to 1.03 eV. Typical voltages of 550~650 mV can be generated, which enables it to be joined to InGaP/GaAs junctions without limiting the cell's current. This approach involves growing InGaP and GaAs junctions that are lattice matched to a Ge or GaAs substrate in an inverted manner. Any dislocations are then confined to the InGaAs junction, which is deposited on top of the InGaP/GaAs dual junctions. Moreover, GaAs substrates removed by epitaxial lift-off technique are recyclable to save resource and prevent form waste. In this study, wafer bonding technique was applied to connect inverted GaAs solar cells and Si substrates by Au/Ag/Au and Au/Sn/Au. Then GaAs substrates were separated from inverted GaAs solar cells by epitaxial lift-off technique. Finally, the fabrication of inverted GaAs solar cells without any antireflection coating (ARC) was finished by photolithography. The measured open circuit voltage (Voc), short circuit current density (Jsc), fill factor (F.F.) and conversion efficiency ( ) of the thin film GaAs solar cells on silicon substrates were 0.85V, 20.58mA/cm<sup>2</sup>, 0.74 and 12.8% respectively.

Keywords : GaAs solar cells、Inverted metamorphic structure、Wafer bonding、Epitaxial lift-off

## Table of Contents

目錄 封面內頁 簽名頁 授權書 . . . . .	iii
中文摘要 . . . . .	iv
英文摘要 . . . . .	v
誌謝 . . . . .	vi
目錄 . . . . .	vii
圖目錄 . . . . .	ix
表目錄 . . . . .	xi
第一章 序論 1.1 前言 . . . . .	1
1.2 研究背景與動機 . . . . .	2
第二章 理論介紹 2.1 太陽光光譜 . . . . .	6
2.2 太陽能電池原理 . . . . .	9
2.2.1 太陽能電池參數介紹 . . . . .	11
2.2.2 太陽能電池等效電路 . . . . .	13
2.3 反向結構砷化鎵太陽電池 . . . . .	15
2.4 晶圓接合 . . . . .	19
2.4.1 晶圓接合的種類 . . . . .	19
2.4.2 晶圓接合的品質 . . . . .	21
2.4.3 晶圓接合的夾具設計 . . . . .	23
2.5 磊晶層剝離技術 . . . . .	25
第三章 傳統與反向結構太陽能電池製程 3.1 元件結構介紹 . . . . .	27
3.1.1 傳統結構砷化鎵太陽電池 . . . . .	27
3.1.2 反向結構砷化鎵太陽電池 . . . . .	28
3.2 傳統結構薄膜砷化鎵太陽電池製作流程 . . . . .	29
3.3 反向結構薄膜砷化鎵太陽電池製作流程 . . . . .	32
第四章 實驗結果與討論 4.1 簡介 . . . . .	37
4.2 晶圓接合分析 . . . . .	37
4.2.1 傳統結構薄膜太陽電池晶圓接合分析 . . . . .	37
4.2.2 反向結構薄膜太陽電池晶圓接合分析 . . . . .	38
4.3 薄膜太陽電池電壓電流量測 . . . . .	43
4.3.1 傳統結構太陽電池電壓電流特性 . . . . .	43
4.3.2 反向結構太陽電池電壓電流特性 . . . . .	45
4.3.3 傳統結構與反向結構太陽電池對照 . . . . .	46
第五章 結論 . . . . .	48
參考文獻 . . . . .	49
圖目錄 圖1.1 理論轉換效率與材料能隙關係圖 . . . . .	3
圖1.2 半導體對光之吸收係數圖 . . . . .	4
圖2.1 太陽光光譜圖 . . . . .	6
圖2.2 在地球表面測得的太陽光光譜谷狀分佈 . . . . .	7
圖2.3 AM0,AM1與AM(sec )定義圖 . . . . .	8
圖2.4 太陽能電池運作原理 . . . . .	10
圖2.5 太陽能電池I-V特性曲線圖 . . . . .	11
圖2.6 太陽電池之等效電路圖 . . . . .	14
圖2.7 InGaP/GaAs/Ge三界面太陽能電池結構圖 . . . . .	15
圖2.8 吸收不同波長太陽光譜的材料示意圖 . . . . .	16
圖2.9 (a)傳統三界面太陽電池結構 (b)反向變異結構 示意圖 . . . . .	18
圖2.10 微小粒子對晶圓接合介面影響示意圖 . . . . .	22
圖2.11 晶圓接合夾具設計示意圖 . . . . .	24
圖2.12 磊晶層剝離示意圖 . . . . .	25
圖2.13 (a) - 族太陽電池製程 (b) - 族薄膜太陽電池製程 . . . . .	26
圖3.1 傳統結構太陽電池示意圖 . . . . .	28
圖3.2 反向結構太陽電池示意圖 . . . . .	29
圖3.3 傳統結構薄膜砷化鎵太陽電池製作流程圖 . . . . .	32
圖3.4 . . . . .	

夾具實物圖 . . . . .	34	圖3.5 反向結構薄膜砷化鎵太陽電池製作流程圖 . . . . .	
. 36 圖4.1 銀膠在(a)120 與(b)100 磊晶層剝離後的俯視圖 . . . . .	38	圖4.2 砷化鎵與矽基板以金銀金接合介面剖面圖 . . . . .	
. . . . .	40	圖4.3 退火350 時間0.5、1小時的薄膜砷化鎵俯視圖 . . . . .	40
圖4.3 退火350 時間0.5、1小時的薄膜砷化鎵俯視圖 . . . . .	40	圖4.4 退火350 時間2、4小時的薄膜砷化鎵俯視圖 . . . . .	41
圖4.5砷化鎵與矽基板以金錫金接合介面剖面圖 . . . . .	42	圖4.6 退火280 、310 在0.5小時的薄膜砷化鎵俯視圖 . . . . .	42
圖4.7 退火280 、310 在4小時的薄膜砷化鎵俯視圖 . . . . .	43	圖4.8 傳統結構太陽電池照光電壓電流曲線圖 . . . . .	44
圖4.9 反向結構太陽電池照光電壓電流曲線圖 . . . . .	45	圖4.10 傳統正向結構與反向結構電壓電流曲線圖 . . . . .	47
表目錄 表2.1 不同空氣質量數定義的太陽光入射功率表 . . . . .	9	表2.2 各材料之熱膨脹係數表 . . . . .	24
表4.1 退火溫度與時間對應接合結果 . . . . .		表4.2 傳統結構砷化鎵太陽電池各參數表 . . . . .	44
表4.3 反向結構砷化鎵太陽電池各參數表 . . . . .		表4.4傳統結構與反向結構太陽電池參數對照表 . . . . .	47

## REFERENCES

- [1]莊嘉琛, " 太陽能工程(太陽電池篇), " 全華科技圖書股份有限公司, (2001).
- [2]W. Hoagland, "Solar energy," Sci. Amer. Sept. 1995. vol. 273, pp. 170-173.
- [3]Jianhua Zhao, Aihua Wang, and Martin A. Green, "19.8% efficient " honeycomb " textured multicrystalline and 24.4% monocrystalline silicon solar cells," Appl. 1998, 73, pp. 1991-1993.
- [4]R. R. King, D. C. Law, K. M. Edmondson, et al., " 40% efficient metamorphic GaInP/GaInAs/Ge multijunction solar cells " , Appl. Phys. Lett., vol. 90, 3, 2007.
- [5]P. Sharps, A. Cornfeld, M. Wanlass, "Inverting the triple junction improves efficiency and flexibility." Compound Semiconductor. Oct. 2007, pp. 25-28.
- [6]M.A. Steiner, J.F. Geisz, R.C. Reedy, and S. Kurtz, "A direct comparison of inverted and non-inverted growths of GaInP solar cells," 33rd IEEE Photovoltaic Specialist Conference, May. 2008, pp. 11 – 16 [7]J.F. Geisz et al., "High-efficiency GaInP / GaAs / InGaAs triple-junction solar cells grown inverted with a metamorphic bottom junction," Appl. Phys. Lett. 91, 2007, pp. 023502.
- [8]A. van Geelen, P. R. Hageman, G. J. Bauhuis, P. C. van Rijnsingen, P. Schmidt, and L. J. Giling, "Epitaxial Lift-off GaAs Solar Cell from a Reusable GaAs Substrate," Mat'ls. Sci. and Eng'g. B45, (1997) pp. 162-171.
- [9]Brenton Burnett, "The Basic Physics and Design of III-V Multijunction Solar Cells," 2002, pp. 10-11.
- [10]M. P. Thekackra, "The Solar Cell Constant and Solar Spectrum Measurement from a Research Aircraft," NASA Technical Report No. R-351, 1970, pp. 15-20.
- [11]C. Riordan and R. Hulstrom, "what is an air mass 1.5 spectrum?" , Conference Record of the IEEE Photovoltaic Specialists Conference, vol. 2, 1990, pp. 1085-1088.
- [12]施敏, "Semiconductor Device Physics abd Technology," 2002. p348.
- [13]Richard C. Neville, "Solar Energy Conversion:THE SOLAR CELL", Second edition, ELSEVIER, 1995.
- [14]M. A. Green, "Solar Cells Operating Principles, Technology, and System Application," 1982, P85-96.
- [15]C. M. Fetzer, R.R. King, P.C. Colter, K.M. Edmondson et al., "High-efficiency metamorphic GaInP/GaInAs/Ge solar cells grown by MOVPE", J. Crystal. Growth, vol. 261, 341, 2004. pp. 341-348.
- [16]M. Stan, D. Aiken, B. Cho, A. Cornfeld, J. Diaz, V. Ley, A. Korostyshevsky, P. Patel, P. Sharps, T. Varghese, "Very high efficiency triple junction solar cells grown by MOVPE" J. Crystal Growth 310 (2008) pp. 5204 – 5208.
- [17]J.F. Geisz, et al., "Inverted GaInP / (In)GaAs / InGaAs Triple-Junction Solar Cells with Low-Stress Metamorphic Bottom Junctions." 33rd. IEEE Photovoltaic Specialists Conference, May, 2008, pp. 11-16.
- [18]T. Soga, M. Kawai, K. Otsuka, T. Jimbo, M. Umeno, "Proceedings of the Second World Conference on Photovoltaic Solar Energy Conversion," 1998, pp. 3737.
- [19]T. Suni, K. Henttinen, I. Suni, and J. Ma"kinen, "Effects of Plasma Activation on Hydrophilic Bonding of Si and SiO<sub>2</sub>", J. Electrochem. Soc., 149, June 2002., pp. G348-G351.
- [20]C. L. Chang, Y. C. Chuang, and C. Y. Liu, "Ag/Au Diffusion Wafer Bonding for Thin-GaN LED Fabrication", Electrochemical and Solid-State Letters, 10 (11), 2007, H344-H346.
- [21]G. R. Dohle, J. J. Callahan, K. P. Martin, and T. J. Drabik , "Bonding of Epitaxial Lift Off (ELO) Devices with AuSn," in Tech. Dig., 45th ECTC, 1995, pp. 423 – 427.
- [22]H. C. Lin, K. L. Chang, G. W. Pickrell, K. C. Hsieh, and K. Y. Cheng, "Low temperature wafer bonding by spin on glass", J. Vac. Sci. Technol. B, 20, March 2002, pp. 752-754.
- [23]K. Hjort, "Transfer of InP epilayers by wafer bonding", J. Crystal Growth, 268, August 2004, pp. 346-358.
- [24]M. Shimbo, K. Furukawa, K. Kukuda, and K. Tanzawa. "Silicon-to-Silicon Direct Bonding Method", J. Appl. Phys. 60, (1986) pp. 2987.
- [25]P. Demeester, I. Pollentier, P. De Dobbelaere, C. Brys and P. Van Daele, "Epitaxial lift-off and its applications", Semicond. Sci. Technol. 8

(1993), pp. 1124-1135.

[26]Y. Yazawa, J. Minemura, K. Tamura, S. Watahiki, T. Kitatani, T. Warabisako, "Process damage free thin-film GaAs solar cells by epitaxial lift off with GaInP window layer," *Sol. Energy Mater. Sol. Cells*, vol. 50, (1998) pp. 163-168.

[27]J.J. Schermer, G.J. Bauhuis, P. Mulder, E.J. Haverkamp, J. van Deelen, A.T.J. van Niftrik, P.K. Larsen, "Photon confinement in high-efficiency, thin-film III—V solar cells obtained by epitaxial lift-off," *Thin Solid Films* 511 – 512 (2006), pp. 645 – 653.