

氮摻雜高熵Ba(Ti,Zr,Mo,Hf,Ta)O₃介電層 與ZNSNO通道之透明柔性薄膜電晶體研究

ELECTRICAL AND UV-SENSING PERFORMANCE OF N-DOPED HIGH-ENTROPY BA(TI,ZR,MO,HF,TA)O₃ DIELECTRIC AND ZNSNO-CHANNEL FLEXIBLE TFTS

研究動機與背景 MOTIVATION & BACKGROUND

隨著透明顯示與穿戴式裝置發展，電子元件需兼具高效能、低功耗、透明與柔性。但傳統SiO₂或HfO₂介電層介電常數低，限制電壓縮小與高溫穩定性。高熵氧化物具高介電常數、低漏電與優異熱穩定性，ZNSNO則兼具透明性與高遷移率，是無銻透明電子的理想通道材料。本研究結合氮摻雜高熵氧化物與ZNSNO，開發高效能透明柔性TFT。

WITH THE RISE OF TRANSPARENT DISPLAYS AND WEARABLES, DEVICES MUST OFFER HIGH PERFORMANCE, LOW POWER, TRANSPARENCY, AND FLEXIBILITY. CONVENTIONAL DIELECTRICS LIKE SiO₂ OR HfO₂ HAVE LOW DIELECTRIC CONSTANTS, LIMITING VOLTAGE SCALING AND STABILITY. HIGH-ENTROPY OXIDES PROVIDE HIGH PERMITTIVITY, LOW LEAKAGE, AND THERMAL STABILITY, WHILE ZNSNO IS TRANSPARENT, INDIUM-FREE, AND OFFERS GOOD MOBILITY. THIS STUDY COMBINES N-DOPED HIGH-ENTROPY OXIDES WITH ZNSNO TO DEVELOP HIGH-PERFORMANCE, TRANSPARENT, AND FLEXIBLE TFTS.

摘要 INTRODUCTION

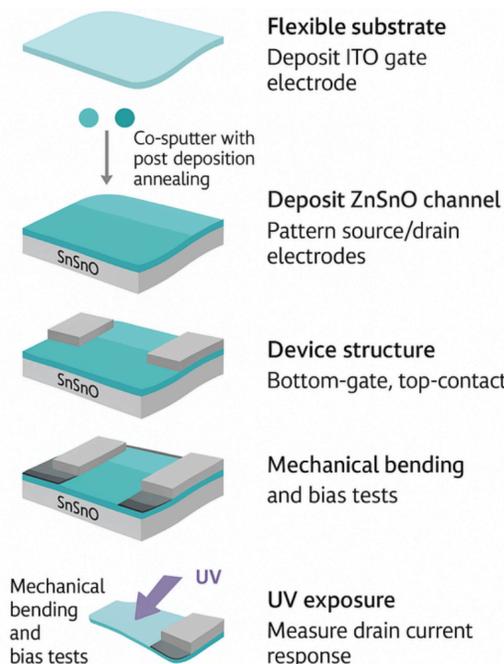
本研究利用氮摻雜高熵Ba(Ti,Zr,Mo,Hf,Ta)O₃作為高介電常數閘極層，搭配ZNSNO通道，成功製備出透明柔性薄膜電晶體。元件展現極佳的電性表現，包括高達10⁸的開關電流比、76 cm²/V·s的載子遷移率，以及0.062 V/DEC的次臨界擺幅。進一步測試顯示其具備長期穩定性與耐高溫操作能力。此外，在紫外光(253 nm)照射下，元件展現靈敏度約2×10⁶與響應度1171.9 A/W，並於彎曲狀態下仍能維持性能穩定，顯示其於透明電子與光感測應用具高度潛力。

THIS WORK DEMONSTRATES TRANSPARENT FLEXIBLE TFTS BASED ON AN N-DOPED HIGH-ENTROPY BA(TI,ZR,MO,HF,TA)O₃ DIELECTRIC LAYER AND A ZNSNO CHANNEL. THE DEVICES ACHIEVE EXCELLENT ELECTRICAL PROPERTIES, INCLUDING AN ON/OFF CURRENT RATIO OF 10⁸, A MOBILITY OF 76 CM²/V·S, AND AN ULTRA-LOW SUBTHRESHOLD SWING OF 0.062 V/DEC. THEY ALSO SHOW LONG-TERM STABILITY AND RELIABLE OPERATION UNDER HIGH TEMPERATURE. UNDER UV ILLUMINATION (253 NM), THE TFTS EXHIBIT REMARKABLE SENSITIVITY (~2×10⁶) AND RESPONSIVITY (1171.9 A/W), WHILE MAINTAINING PERFORMANCE UNDER MECHANICAL BENDING. THESE RESULTS HIGHLIGHT THEIR STRONG POTENTIAL FOR TRANSPARENT ELECTRONICS AND UV SENSING APPLICATIONS.

研究方法 RESEARCH METHODS

- 在柔性塑膠基板上沉積下閘極電極（如ITO透明電極）。
- 以共濺鍍方式沉積含氮源的高熵Ba(Ti,Zr,Mo,Hf,Ta)O₃介電層。
- 經適當熱處理，使介電層呈現無定形結構並具高介電性。
- 濺鍍沉積薄的非晶質ZnSnO作為有源通道。
- 製作源/汲極電極（若使用ITO，可確保元件全透明）。
- 完成底閘極、頂接觸結構之TFT製程，全程溫度控制於300℃以下以兼容塑膠基板。
- 進行多次機械彎折與偏壓穩定性測試，評估電性表現。
- 在紫外光照射下量測汲極電流響應，以分析UV感測性能。

- DEPOSIT A GATE ELECTRODE (E.G., ITO FOR TRANSPARENCY) ON A FLEXIBLE PLASTIC SUBSTRATE.
- CO-SPUTTER AN N-DOPED HIGH-ENTROPY BA(TI,ZR,MO,HF,TA)O₃ DIELECTRIC LAYER WITH A NITROGEN-CONTAINING ATMOSPHERE.
- PERFORM POST-DEPOSITION ANNEALING TO OBTAIN AN AMORPHOUS HIGH-κ STRUCTURE.
- SPUTTER A THIN AMORPHOUS ZNSNO LAYER AS THE ACTIVE CHANNEL.
- PATTERN SOURCE/DRAIN ELECTRODES (ITO USED FOR FULL TRANSPARENCY IF REQUIRED).
- FABRICATE A BOTTOM-GATE, TOP-CONTACT TFT STRUCTURE WITH ALL PROCESSING TEMPERATURES KEPT BELOW ~300 °C TO ENSURE SUBSTRATE COMPATIBILITY.
- CONDUCT MECHANICAL BENDING AND BIAS STRESS TESTS TO EVALUATE ELECTRICAL STABILITY.
- UNDER UV ILLUMINATION, MEASURE THE DRAIN CURRENT RESPONSE TO CHARACTERIZE UV SENSING PERFORMANCE.



研究成果與數據亮點

Results & Data Highlights

電學性能 Electrical Performance

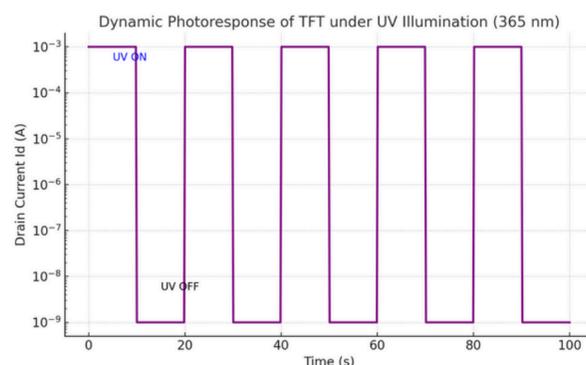
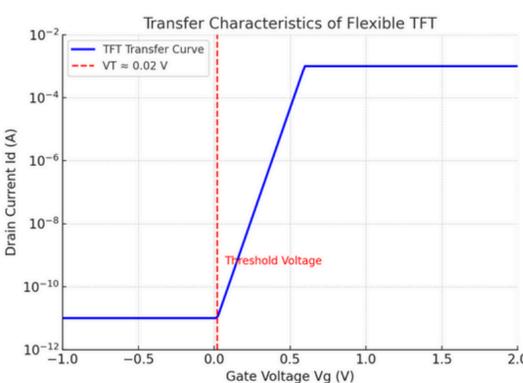
TFT展現優異性能：超高介電常數 (~322)、低漏電 (10⁻¹¹ A/cm²)、接近零的閘極電壓 (0.02 V)、次臨界擺幅僅0.072 V/dec。載子遷移率高達196 cm²/V·s，開/關比約10⁸。長時間偏壓下僅有微小漂移，顯示出極佳穩定性。

THE TFTS EXHIBIT EXCELLENT PERFORMANCE, WITH AN ULTRAHIGH DIELECTRIC CONSTANT (~322), LOW LEAKAGE (10⁻¹¹ A/CM²), NEAR-ZERO THRESHOLD VOLTAGE (0.02 V), AND A SUBTHRESHOLD SWING OF 0.072 V/DEC. THE FIELD-EFFECT MOBILITY REACHES 196 CM²/V·S WITH AN ON/OFF RATIO OF ~10⁸. MINIMAL DRIFT UNDER PROLONGED BIAS STRESS CONFIRMS OUTSTANDING STABILITY.

紫外光感測 UV Sensing

在365 nm紫外光下，器件靈敏度達10⁶，響應度1171.9 A/W，能在微弱UV下產生明顯電流變化。反覆光循環測試下表現穩定，且對可見光不敏感，可實現高選擇性UV偵測。

UNDER 365 NM UV ILLUMINATION, THE DEVICES ACHIEVE A SENSITIVITY OF 10⁶ AND A RESPONSIVITY OF 1171.9 A/W, WITH A STRONG RESPONSE EVEN UNDER WEAK UV. THE PERFORMANCE IS STABLE ACROSS REPEATED CYCLES AND INSENSITIVE TO VISIBLE LIGHT, ENABLING HIGHLY SELECTIVE UV DETECTION.



應用前景 APPLICATION PROSPECTS

- 低功耗透明電子：** 適合用於透明顯示與驅動電路，降低功耗並保持高透明度。
- 紫外光感測：** 可作為UV感測器，用於火焰偵測、環境監測或穿戴式UV監控。
- 高溫與太空電子：** 在高溫下仍具穩定性，適合汽車、工業與太空環境應用。

LOW-POWER TRANSPARENT ELECTRONICS: SUITABLE FOR TRANSPARENT DISPLAYS AND DRIVER CIRCUITS, REDUCING POWER WHILE MAINTAINING OPTICAL TRANSPARENCY.

UV SENSING: CAN FUNCTION AS A UV DETECTOR FOR FLAME DETECTION, ENVIRONMENTAL MONITORING, OR WEARABLE UV SENSORS.

HIGH-TEMPERATURE AND SPACE ELECTRONICS: REMAINS STABLE AT ELEVATED TEMPERATURES, IDEAL FOR AUTOMOTIVE, INDUSTRIAL, AND AEROSPACE APPLICATIONS.

結論 CONCLUSION

本研究成功結合氮摻雜高熵Ba(Ti,Zr,Mo,Hf,Ta)O₃介電層與ZnSnO通道，製備出透明柔性薄膜電晶體。元件展現高達10⁸的開關比、76 cm²/V·s的載子遷移率與極低的次臨界擺幅，並具備長期穩定性與高溫耐受性。此外，在紫外光下展現優異的靈敏度與響應度，即使在彎曲狀態下亦能維持性能。此成果顯示該元件在低功耗透明電子、紫外光感測以及柔性應用領域具有廣大潛力。

THIS STUDY SUCCESSFULLY COMBINES N-DOPED HIGH-ENTROPY BA(TI,ZR,MO,HF,TA)O₃ DIELECTRICS WITH ZNSNO CHANNELS TO FABRICATE TRANSPARENT FLEXIBLE TFTS. THE DEVICES DEMONSTRATED AN ON/OFF RATIO OF 10⁸, A MOBILITY OF 76 CM²/V·S, AND AN ULTRA-LOW SUBTHRESHOLD SWING, WITH LONG-TERM STABILITY AND HIGH-TEMPERATURE RELIABILITY. UNDER UV ILLUMINATION, THEY SHOWED EXCELLENT SENSITIVITY AND RESPONSIVITY, WHILE MAINTAINING PERFORMANCE UNDER MECHANICAL BENDING. THESE RESULTS HIGHLIGHT THE GREAT POTENTIAL OF THIS APPROACH FOR LOW-POWER TRANSPARENT ELECTRONICS, UV SENSING, AND FLEXIBLE DEVICE APPLICATIONS.

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