LPCVD doped polysilicon with in-situ tunnel oxide

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LPCVD polysilicon at ANU

- Furnace retrofit in 2015: collaborative project between ANU-Tempress-ARENA.
- Includes Silane, and Oxygen.
- Enabling low pressure in-situ oxidation for the Poly-Ox deposition.
**Fabrication Process**

**Diffused LPCVD Poly-Ox fabrication sequence**

- **Tunnel oxide**
  - LPCVD Chamber
  - Low Pressure (600mTorr)
  - 700-800 °C, 10 minutes

- **Polysilicon deposition**
  - LPCVD chamber
  - Silane SiH$_4$
  - 250 mTorr
  - 520 °C

- **Dopant diffusion**
  - Ex-situ process
  - Boron from BBr
  - Phosphorus from POCI

- **SiO$_2$**
  - ~1nm

- **Poly-Si**
  - ~20-40nm
  - Poly-Si diffusion

- **In-situ process**
TEM of Poly-Ox layer

TEM of Phosphorus difused Poly-Ox structure (after 900°C anneal)

- Oxide ~ 1 nm
  Appears fuzzy on both sides, with no clear boundary.
- Poly-Si appears crystalline with numerous grains of varying crystal orientation

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FZ Si

~1nm SiO₂

Phos doped Polysilicon

Differing Polycrystalline grains
Best passivation of $\sim 0.3$ fA cm$^{-2}$ is measured, with implied $V_{OC}$ of 735mV.

Oxidation temperature is the key parameter.

Temp: 600-800 °C, 10mins,

- $\text{SiO}_2 \rightarrow 1\text{-}1.2\text{nm}$
- $J_0 \rightarrow \sim 350\text{fA} \text{–} 0.3\text{fA}$

Will be apparent from diffusion profile.

Diffusion Profiles

Diffusion profile is extremely sensitive to oxide growth condition

Ox Temp: 600-800 °C
- SiO$_2$ → 1-1.2nm
- $J_0$ → ~350fA – 0.3fA
- $R_{\text{sheet}}$ → 23 $\Omega/\square$ to 1530 $\Omega/\square$

To achieve <1fAcm$^2$, there must be only a small amount of dopant penetration to the wafer bulk, so as to avoid massive Auger recombinations.

This highlights the importance of excellent control in oxide growth conditions.

Bulk lifetime

Using High-res n-type:

- High effective lifetimes above 70ms can be achieved.
- 735mV i-Voc
Modified Cox & Strack circular dot structure

- Using the lifetime sample, we evaporate metal dots, and etch surrounding poly-Ox
- This allows the use of the same wafer for lifetime & contact measurement.
- $I-V$ curve is measured & $\rho_c$ is calculated via iterative fitting to 3D ohmic model, assuming symmetrical front & rear $\rho_c$

Test structure (cross section)

Test structure (cross section)

3D model

Excellent contact resistance below 1 mΩ cm² is measured for a wide range of conditions.

Large error bars:
- Bulk resistance limits the accuracy of the method to ~ 1 mΩ cm².

Comparing to literature, we are on par if not better than the best reported values:

**Phosphorus diffused Poly-Ox**

$J_0 \sim 1 \text{ fA cm}^{-2}$  
$\rho_c \sim 1 \text{ mOhm cm}^{-2}$

**Boron diffused Poly-Ox**

$J_0 \sim 7.5 \text{ fA cm}^{-2}$  
$\rho_c \sim 10 \text{ mOhm cm}^{-2}$

Conclusion

This work:

• Demonstrated $J_0 < 1 \text{ fA cm}^{-2}$, $\rho_c < 1 \text{ m}Ω \text{ cm}^2$ with phosphorus diffused LPCVD Poly-Ox

• Key novelty of in-situ process for Poly-Ox & low pressure oxidation step. Providing excellent process control.

• High bulk lifetimes ~ 70ms, with $iV_{oc}$ ~735mV.

Future:

• Boron doped LPCVD Poly-Ox

• Application to cells, PERL, IBC, Bifacials

• Open to collaborations (Cell fabrication, tandem devices, etc)
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Specific ACAP contributions to this work:
- ACAP PP1: Silicon Solar Cells
- ACAP PP6.32: Optical Properties of Passivated Contacts
- ACAP Fellowship: Transparent Doped LPCVD Polysilicon Passivated Contacts

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