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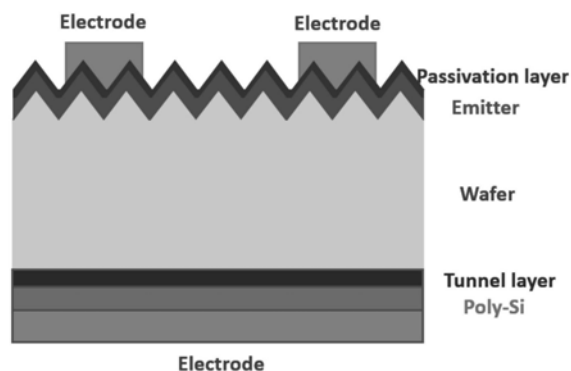
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(54) 发明名称

一种叠层薄膜钝化接触结构的制备方法及其应用

(57) 摘要

本发明提供一种叠层薄膜钝化接触结构的制备方法及其应用,制备方法包括以下步骤:首先在硅片表面生长一层氧化硅层,然后在所述氧化硅层表面上沉积一层本征或掺杂的碳硅薄膜,最后在所述碳硅薄膜表面再沉积至少一层掺杂的非晶硅薄膜层,并进行780-1100°C的高温晶化处理,形成隧穿氧化硅钝化接触结构;本发明避免了硅薄膜破裂现象,保持了钝化性能,能够确保进行后继丝印烧结;保持了较低的方块电阻,有利于保持金属接触和载流子的横向输运,结构完全兼容现有PECVD技术,无需增加设备,可拓展性强。



1. 一种叠层薄膜钝化接触结构的制备方法, 其特征在于: 包括以下步骤: 首先在硅片表面生长一层氧化硅层, 然后在所述氧化硅层表面上沉积一层本征或掺杂的碳硅薄膜, 最后在所述碳硅薄膜表面再沉积至少一层掺杂的非晶硅薄膜层, 并进行780-1100°C的高温晶化处理, 形成隧穿氧化硅钝化接触结构。

2. 根据权利要求1所述的叠层薄膜钝化接触结构的制备方法, 其特征在于: 所述硅薄膜层的掺杂浓度为 $1 \times 10^{19} \text{cm}^{-3}$ - $1 \times 10^{21} \text{cm}^{-3}$ 。

3. 根据权利要求1所述的叠层薄膜钝化接触结构的制备方法, 其特征在于: 所述氧化硅层的厚度为1.0-3.5 nm。

4. 根据权利要求1所述的叠层薄膜钝化接触结构的制备方法, 其特征在于: 所述碳硅薄膜厚度3-50nm。

5. 根据权利要求1所述的叠层薄膜钝化接触结构的制备方法, 其特征在于: 所述碳硅薄膜厚度为10-20nm。

6. 根据权利要求1所述的叠层薄膜钝化接触结构的制备方法, 其特征在于: 所述碳硅薄膜中碳在碳硅薄膜中的原子浓度 $>5\text{at}\%$ 。

7. 根据权利要求1所述的叠层薄膜钝化接触结构的制备方法, 其特征在于: 所述碳硅薄膜为掺杂薄膜, 其掺杂原子可以是提供电子的氮、磷、砷或提供空穴的硼、铝、镓。

8. 一种权利要求1-7中任一项所述的叠层薄膜钝化接触结构的应用, 其特征在于: 用于隧穿氧化硅钝化接触晶硅太阳能电池中。

一种叠层薄膜钝化接触结构的制备方法及其应用

技术领域

[0001] 本发明涉及太阳能电池技术领域,具体讲是一种一种叠层薄膜钝化接触结构的制备方法及其应用。

背景技术

[0002] 钝化接触也叫载流子选择性收集,是近年来硅太阳能电池的热点研究方向。钝化接触结构能够在硅表面形成显著的能带弯曲,使一种载流子通过而另一种载流子无法通过,形成很好的载流子收集,同时又能抑制载流子在界面的复合。因此,钝化接触结构可以实现高效钝化和载流子收集,消除硅与金属的直接接触,因而能够提高钝化效果,使太阳能电池获得很高的开路电压。

[0003] 隧穿氧化硅钝化接触晶硅太阳能电池是一种典型的钝化接触电池,英文也称TOPCon,其典型的器件结构如图1所示。需要说明的是,其他一些技术如POL0、monoPoly、PERPoly等也是基于氧化硅/掺杂多晶硅的结构,只是名称有所不同而已。TOPCon技术具有结构简单、钝化效果好、可承受高温工艺、兼容现有产线、可有效提升电池效率等优点,因此被产业界和学术界关注。

[0004] 常规的TOPCon晶硅太阳能电池的主要特征功能层由两部分组成:氧化硅钝化隧穿层、多晶硅载流子收集层。目前,隧穿氧化硅钝化结构可以实现非常优异的钝化效果。隐含开路电压(iV_{oc})和单面饱和暗电流(J_0)是表征钝化效果的两个关键指标,其中 iV_{oc} 越高越好、 J_0 则越低越好。通常而言,钝化效果好的n型TOPCon,其 $iV_{oc}>730\text{mV}$, $J_0<7\text{fA}/\text{cm}^2$,其接触电阻率均可以低于 $20\text{m}\Omega\text{cm}^2$,满足全背面接触高效电池所需的接触电阻率需求。

[0005] 目前,各大光伏制造厂商已经开始研究TOPCon结构的商用化进程。基于掺杂多晶硅的TOPCon结构已经成为一种重要的下一代高效光伏技术,具有重大的应用前景。

[0006] TOPCon技术在制备掺杂多晶硅方面存在两大技术路线:一是采用低压化学气相沉积(LPCVD)路线,另一种则是等离子体增强化学气相沉积法(PECVD)路线。相比于LPCVD路线,PECVD路线可以实现高速的原位掺杂薄膜沉积、且不产生绕镀,被认为是更适合于工业生产的技术路线。

[0007] PECVD技术路线的具体实现方式是:首先在硅片表面制备一层氧化硅,接着采用PECVD沉积一层掺杂非晶硅,然后进行高温晶化处理,使非晶硅形成多晶硅,从而制备TOPCon结构。

[0008] 然而,PECVD路线存在一个问题,为了降低多晶硅薄膜层的方块电阻,必须增加PECVD沉积非晶硅薄膜的厚度,不过高厚度的非晶硅在高温晶化过程中易产生剥落。非晶硅薄膜剥落的原因并不清楚,通常认为是PECVD长的非晶硅薄膜中氢含量过高,退火过程中氢会溢出,破坏界面硅薄膜与氧化硅的粘附,使得硅薄膜剥落,导致TOPCon结构的钝化性能显著下降,且不再适合后继的丝印烧结处理。

[0009] 解决硅薄膜晶化过程剥落问题是PECVD技术路线存在的重大挑战。

发明内容

[0010] 本发明所要解决的技术问题是,克服以上现有技术的缺点:提供一种硅薄膜不易剥落、钝化效果好的叠层薄膜钝化接触结构的制备方法及其应用。

[0011] 本发明的技术解决方案如下:一种叠层薄膜钝化接触结构的制备方法,包括以下步骤:首先在硅片表面生长一层氧化硅层,然后在所述氧化硅层表面上沉积一层本征或掺杂的碳硅薄膜,最后在所述碳硅薄膜表面再沉积至少一层掺杂的非晶硅薄膜层,并进行780-1100℃的高温晶化处理,形成隧穿氧化硅钝化接触结构。

[0012] 作为优选,所述硅薄膜层的掺杂浓度为 $1 \times 10^{19} \text{cm}^{-3}$ - $1 \times 10^{21} \text{cm}^{-3}$ 。

[0013] 作为优选,所述氧化硅层的厚度为1.0-3.5nm。

[0014] 作为优选,所述碳硅薄膜厚度3-50nm。

[0015] 作为最优选,所述碳硅薄膜厚度为10-20nm。

[0016] 作为优选,所述碳硅薄膜中碳在碳硅薄膜中的原子浓度 $>5\text{at}\%$ 。

[0017] 所述掺杂的碳硅薄膜为掺杂的薄膜,其掺杂原子可以是提供电子的氮、磷、砷或提供空穴的硼、铝、镓。

[0018] 本发明提供一种叠层薄膜钝化接触结构的应用,用于隧穿氧化硅钝化接触晶硅太阳能电池中。

[0019] 本发明叠层薄膜钝化接触结构的优点在于:1)避免了硅薄膜破裂现象,保持了钝化性能,能够确保进行后继丝印烧结。2)保持了较低的方块电阻,有利于保持金属接触和载流子的横向输运。3)结构完全兼容现有PECVD技术,无需增加设备,可拓展性强。

[0020] 叠层薄膜能够同时实现上述目标的原因在于:碳硅薄膜与氧化硅具有较好的粘附力,同时碳硅薄膜也具有较高强度。因此,在高温晶化处理过程中,碳硅薄膜不易发生剥落。同时,碳硅薄膜中的碳含量可以根据灵活调节,增加碳含量可以提升薄膜的粘附性和强度。由于碳的引入会增加碳硅薄膜的电阻率。如果采用掺杂的碳硅薄膜完全取代掺杂非晶硅薄膜,则会导致薄膜整体方块电阻过高(通常会 $>200 \Omega/\text{sq}$),不利于载流子的横向传输。为了实现低的薄膜方块电阻,本发明采用了叠层结构解决方案,即在底层碳硅薄膜上面再覆盖重掺杂的非晶硅薄膜,非晶硅薄膜的电阻率低,可以将方块电阻降低到目标值,从而保持了载流子的横向传输性能。碳硅薄膜对杂质的扩散阻挡能力较强,有利于保持器件的稳定性。

[0021] 本发明的有益效果是:本发明具有以下优点:

[0022] 1) 采用叠层薄膜取代单层硅薄膜,其中与氧化硅接触的底层薄膜为碳硅薄膜,由于碳硅薄膜有很强粘附力和强度,有利于避免传统单层硅薄膜在高温退火过程中出现的剥落现象,从而保持优异的钝化效果,有利于电池获得高的开路电压、短路电流和填充因子。

[0023] 2) 在底层碳硅薄膜之上制备具有合适厚度重掺杂的多晶硅薄膜,利用多晶硅薄膜低的电阻率,实现适合于电池用的背面薄膜方阻,从而减低串联电阻,有利于电池获得高的填充因子。

[0024] 3) 叠层薄膜的结构组合可以根据电池设计而灵活调整,可以全部在PECVD中制备,具有高度灵活性,有利于实现不同的器件性能。碳硅薄膜对杂质的扩散阻挡能力较强,有利于保持器件的稳定。

附图说明

[0025] 图1为现有技术中的TOPCon器件结构。

[0026] 图2为非晶硅薄膜剥落的光学显微镜照片。

[0027] 图3为碳硅薄膜-硅薄膜叠层没有爆膜的光学显微镜照片。

具体实施方式

[0028] 下面用具体实施例对本发明做进一步详细说明,但本发明不仅局限于以下具体实施例。

[0029] 为了使本发明的目的、技术方案及优点更加清楚明白,以下结合实施例对本发明进行进一步详细说明。应当理解,此处所描述的具体实施例仅用以解释本发明,并不用于限定本发明。

[0030] 本发明所用n型硅片为180 μ m的太阳能级直拉单晶硅片,双面碱抛光,电阻率为1-7 $\Omega \cdot \text{cm}$ 。

[0031] 本发明实施例中钝化片的制备方法:采用500-700 $^{\circ}\text{C}$ 热氧化法制备表面氧化硅层;接着放入PECVD腔室,以硅烷、磷烷、甲烷(或氨气)、氢气为反应气体,沉积一层不同厚度的磷掺杂的碳硅薄膜;然后再以硅烷、磷烷、氢气为反应气体,沉积一层或多层厚度为80-200nm的磷掺杂的非晶硅薄膜;接着放入管式退火炉中进行800-1000 $^{\circ}\text{C}$ 高温处理30min;最后测试钝化性能和接触性能。

[0032] 对比例中钝化片的制备方法:采用了掺磷的非晶硅薄膜制备TOPCon结构,其制备方法:采用500-700 $^{\circ}\text{C}$ 热氧化法制备表面氧化硅层;接着放入PECVD腔室,以硅烷、磷烷、氢气为反应气体,沉积一层厚度为80-200nm的磷掺杂的非晶硅薄膜;接着放入管式退火炉中进行800-1000 $^{\circ}\text{C}$ 高温处理30min;最后测试钝化性能和接触性能。

[0033] 实施例1磷掺杂多叠层碳硅/硅薄膜的钝化效果和薄膜方阻

[0034] 分别制备了不同结构的叠层结构的薄膜,进行880 $^{\circ}\text{C}$ 退火30min处理,获得如下钝化和接触性能。

[0035]	对比例样品结构	$i V_{oc}$ (mV)	Rsh (Ω/sq)
	c-Si/SiO _x / n ⁺ poly-Si (10nm)	728	>200
	c-Si/SiO _x / n ⁺ poly-Si (150nm)	680	32
	实施例样品结构	$i V_{oc}$ (mV)	R _{sh} (Ω/sq)
	c-Si/SiO _x / n ⁺ poly-SiC _x (5nm)/ n ⁺ polySi (40 nm)	722	>200
	c-Si/SiO _x /i-poly-SiC _x (5 nm)/ n ⁺ -poly-SiC _x (5 nm)/ n ⁺ polySi (40 nm)	734	>200

[0036]

c-Si/SiO _x / i-poly-SiCx (5 nm) / n ⁺ -poly-SiCx (5 nm) / n ⁺ polySi (80nm)	732	75
c-Si/SiO _x / i-poly-SiCx (5 nm) / n ⁺ -poly-SiCx (5 nm) / n ⁺ polySi (120nm)	731	34
c-Si/SiO _x / i-poly-SiCx (5 nm) / n ⁺ -poly-SiCx (15 nm) / n ⁺ polySi (150nm)	736	25

[0037] 实施例2磷掺杂多叠层碳硅/硅薄膜用于太阳能电池

[0038] 电池结构依然如图1所示,首先对n型硅片前表面进行扩硼处理,形成p⁺发射极;进行背面碱抛光处理;接着按照上述方法,采用热氧化法在背面制备一层氧化层;采用PECVD法分别沉积不同结构的碳硅薄膜,并在880℃下退火30min;接着制备前表面Al₂O₃/SiN和背表面的SiN钝化层,采用丝网印刷法烧结前后电极。最后采用Newport Oriel,SoliA测试电池效率。

[0039]

背面结构	编号	V _{oc} (mV)	J _{sc} (mA/cm ²)	FF (%)	Eff. (%)
c-Si/SiO _x /n ⁺ poly-Si (120nm)	1	653	39.45	67.4	17.36
	2	650	39.36	69.3	17.72
c-Si/SiO _x / n ⁺ polySiCx (5nm) / n ⁺ polySi (40 nm)	1	645	38.89	70.3	17.62
	2	640	38.65	70.8	17.51
c-Si/SiO _x / i-poly-SiCx (5 nm) /n ⁺ -poly-SiCx (5 nm) /	1	676	40.03	81.4	22.03
	2	679	40.10	81.8	22.27

[0040]

n ⁺ polySi (120nm)					
c-Si/SiO _x /	1	680	40.78	82.0	22.74
i-poly-SiC _x (5 nm)/	2	681	40.83	82.1	22.82
n ⁺ -poly-SiC _x (15 nm)/					
n ⁺ polySi (150nm)					

[0041] 以上仅是本发明的特征实施范例,对本发明保护范围不构成任何限制。凡采用同等交换或者等效替换而形成的技术方案,均落在本发明权利保护范围之内。

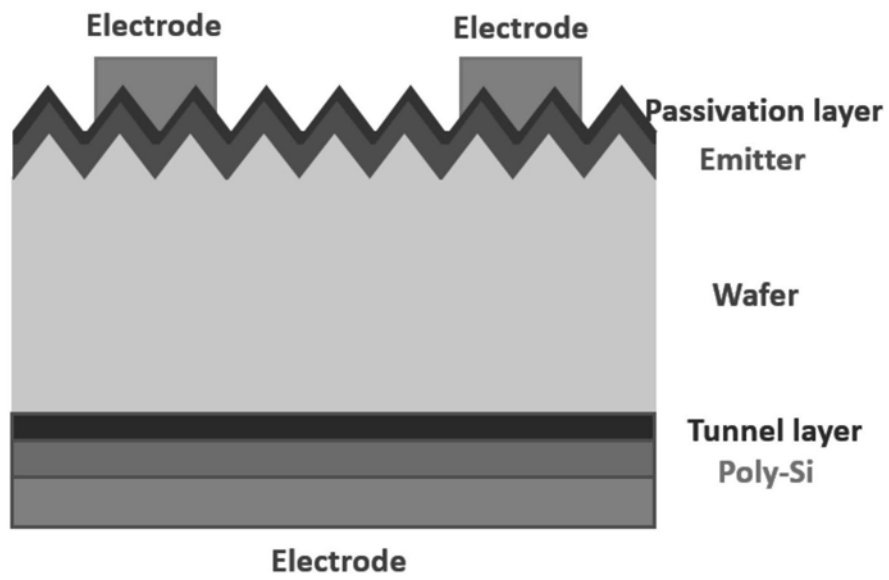


图1

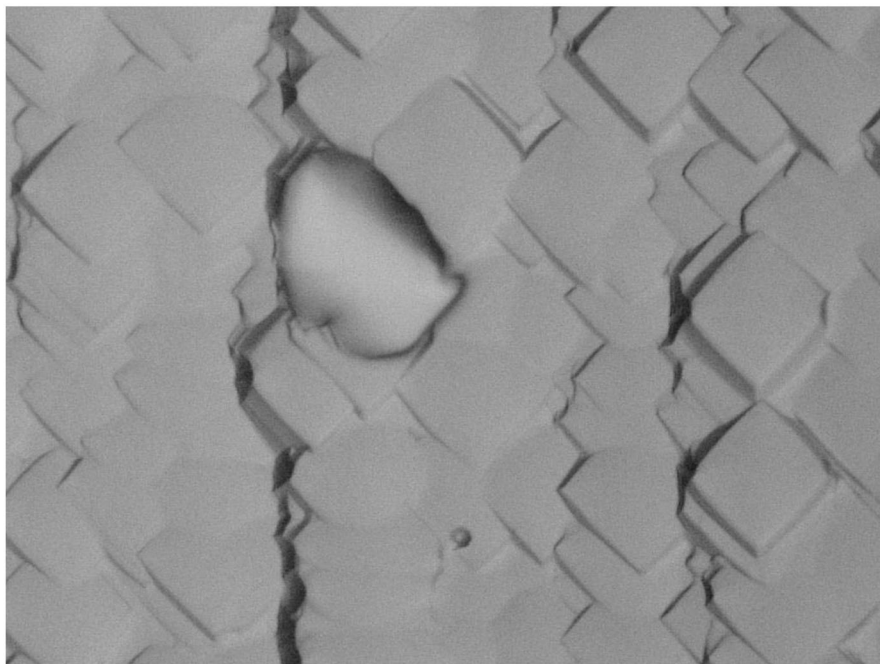


图2

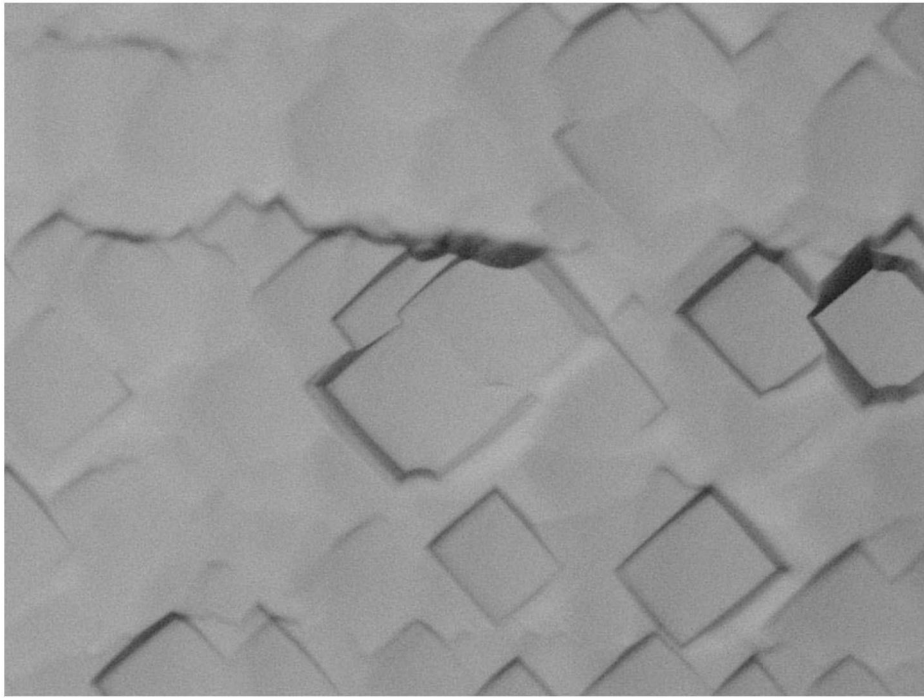


图3



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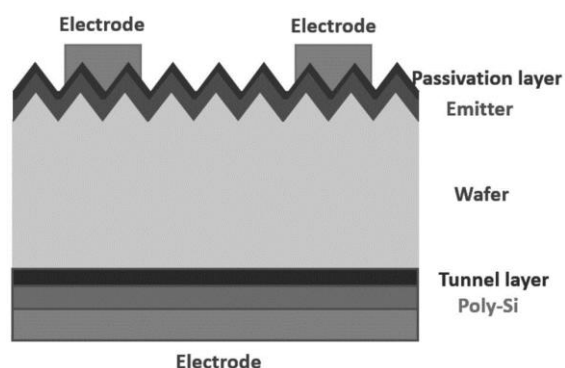
Claims: 1 page; Description: 5 pages; Drawings: 2 pages

(54) Title of Invention

Preparation method and application of laminated film
passivation contact structure

(57) Abstract

The present invention provides a method for preparing a laminated thin-film passivated contact structure and applications thereof. The preparation method comprises the following steps: first, growing a silicon oxide layer on the surface of a silicon wafer; then depositing an intrinsic or doped silicon-carbon thin film on the surface of the silicon oxide layer; and finally depositing at least one doped amorphous silicon thin-film layer on the surface of the silicon-carbon thin film, followed by high-temperature crystallization treatment at 780–1100 °C to form a tunnel-oxide passivated contact structure. The present invention avoids silicon thin-film cracking or delamination while maintaining passivation performance, thereby ensuring subsequent screen-printing and firing processes. It also maintains a relatively low sheet resistance, which is beneficial for metal contacting and lateral carrier transport. Moreover, the structure is fully compatible with existing PECVD technology, requires no additional equipment, and offers strong scalability.



1. A method for preparing a laminated thin-film passivated contact structure, characterized in that it comprises the following steps: first, growing a silicon oxide layer on the surface of a silicon wafer; then depositing an intrinsic or doped silicon-carbon thin film on the surface of the silicon oxide layer; and finally depositing at least one doped amorphous silicon thin-film layer on the surface of the silicon-carbon thin film, followed by high-temperature crystallization treatment at 780–1100 °C to form a tunnel-oxide passivated contact structure.
2. The method for preparing a laminated thin-film passivated contact structure according to claim 1, characterized in that the dopant concentration of the silicon thin-film layer is $1 \times 10^{19} \text{ cm}^{-3}$ to $1 \times 10^{21} \text{ cm}^{-3}$.
3. The method for preparing a laminated thin-film passivated contact structure according to claim 1, characterized in that the thickness of the silicon oxide layer is 1.0–3.5 nm.
4. The method for preparing a laminated thin-film passivated contact structure according to claim 1, characterized in that the thickness of the silicon-carbon thin film is 3–50 nm.
5. The method for preparing a laminated thin-film passivated contact structure according to claim 1, characterized in that the thickness of the silicon-carbon thin film is 10–20 nm.
6. The method for preparing a laminated thin-film passivated contact structure according to claim 1, characterized in that the atomic concentration of carbon in the silicon-carbon thin film is greater than 5 at%.
7. The method for preparing a laminated thin-film passivated contact structure according to claim 1, characterized in that the silicon-carbon thin film is a doped thin film, wherein the dopant atoms may be electron-donating elements such as nitrogen, phosphorus, or arsenic, or hole-donating elements such as boron, aluminium, or gallium.
- 8 An application of the laminated thin-film passivated contact structure according to any one of claims 1–7, characterized in that it is used in tunnel-oxide passivated contact crystalline silicon solar cells.

Preparation method and application of laminated film passivation contact structure

Technical Field

[0001] The present invention relates to the technical field of solar cells, and more specifically to a method for preparing a laminated thin-film passivated contact structure and applications thereof.

Background Art

[0002] Passivated contacts, also known as carrier-selective contacts, have become a major research focus in silicon solar cells in recent years. A passivated contact structure can induce significant band bending at the silicon surface, allowing one type of charge carrier to pass while blocking the other, thereby enabling effective carrier collection while suppressing carrier recombination at the interface. Consequently, passivated contact structures can achieve highly efficient surface passivation and carrier collection, eliminate direct contact between silicon and metal, and thus enhance the passivation effect, enabling solar cells to obtain a very high open-circuit voltage.

[0003] Tunnel-oxide passivated contact crystalline silicon solar cells are a typical type of passivated contact solar cell, also referred to in English as TOPCon. A typical device structure thereof is shown in FIG. 1. It should be noted that other technologies, such as POLO, monoPoly, and PERPoly, are also based on silicon oxide/doped polysilicon structures, differing mainly in name. TOPCon technology has attracted considerable attention from both industry and academia due to its simple structure, excellent passivation performance, tolerance to high-temperature processes, compatibility with existing production lines, and its ability to effectively improve cell efficiency.

[0004] The main functional layers of a conventional TOPCon crystalline silicon solar cell consist of two parts: a silicon oxide passivating tunneling layer and a polysilicon carrier-collection layer. At present, tunnel-oxide passivated structures can achieve excellent passivation performance. The implied open-circuit voltage (iV_{oc}) and the single-sided saturation dark current density (J_0) are two key indicators for evaluating passivation performance, where a higher iV_{oc} and a lower J_0 are preferred. Generally, for n-type TOPCon cells with good passivation performance, $iV_{oc} > 730$ mV and $J_0 < 7$ fA/cm² can be achieved, and the contact resistivity can be lower than 20 mΩ·cm², satisfying the contact resistivity requirements for high-efficiency full rear-contact solar cells.

[0005] At present, major photovoltaic manufacturers have begun to explore the commercialization of TOPCon structures. TOPCon structures based on doped polysilicon have become an important next-generation high-efficiency photovoltaic technology with significant application prospects.

[0006] In the preparation of doped polysilicon, TOPCon technology mainly follows two technical routes: one is the low-pressure chemical vapor deposition (LPCVD) route, and the other is the plasma-enhanced chemical vapor deposition (PECVD) route. Compared with the LPCVD route, the PECVD route enables high-rate in-situ doped thin-film deposition without wrap-around deposition, and is therefore considered more suitable for industrial production.

[0007] The PECVD technical route is implemented as follows: first, a silicon oxide layer is formed on the surface of a silicon wafer; then, a doped amorphous silicon layer is deposited by PECVD; subsequently, a high-temperature crystallization process is performed to convert the amorphous silicon into polysilicon, thereby forming a TOPCon structure.

[0008] However, the PECVD route has a drawback: in order to reduce the sheet resistance of the polysilicon thin-film layer, the thickness of the PECVD-deposited amorphous silicon film must be increased. Excessively thick amorphous silicon films are prone to delamination during high-temperature crystallization. The cause of amorphous silicon film delamination is not fully understood, but it is generally believed that PECVD-grown amorphous silicon films contain a high hydrogen content. During annealing, hydrogen out-diffusion may occur, which damages the adhesion between the silicon film and the silicon oxide interface, causing film delamination. This leads to a significant deterioration in the passivation performance of the TOPCon structure and renders it unsuitable for subsequent screen-printing and firing processes.

[0009] Solving the delamination problem during silicon thin-film crystallization remains a major challenge in the PECVD technical route.

Disclosure of Invention

[0010] The technical problem to be solved by the present invention is to overcome the deficiencies of the prior art described above by providing a method for preparing a laminated thin-film passivated contact structure that is resistant to silicon thin-film delamination and exhibits excellent passivation performance, as well as applications thereof.

[0011] The technical solution of the present invention is as follows: a method for preparing a laminated thin-film passivated contact structure, comprising the following steps: first growing a silicon oxide layer on the surface of a silicon wafer; then depositing an intrinsic or doped silicon-carbon thin film on the surface of the silicon oxide layer; and finally depositing at least one doped amorphous silicon thin-film layer on the surface of the silicon-carbon thin film, followed by a high-temperature crystallization treatment at 780–1100 °C to form a tunnel-oxide passivated contact structure.

[0012] Preferably, the dopant concentration of the silicon thin-film layer is $1 \times 10^{19} \text{ cm}^{-3}$ to $1 \times 10^{21} \text{ cm}^{-3}$.

[0013] Preferably, the thickness of the silicon oxide layer is 1.0–3.5 nm.

[0014] Preferably, the thickness of the silicon-carbon thin film is 3–50 nm.

[0015] Most preferably, the thickness of the silicon-carbon thin film is 10–20 nm.

[0016] Preferably, the atomic concentration of carbon in the silicon-carbon thin film is greater than 5 at%.

[0017] The doped silicon-carbon thin film is a doped thin film, wherein the dopant atoms may be electron-donating elements such as nitrogen, phosphorus, or arsenic, or hole-donating elements such as boron, aluminum, or gallium.

[0018] The present invention further provides an application of the laminated thin-film passivated contact structure in tunnel-oxide passivated contact crystalline silicon solar cells.

[0019] The advantages of the laminated thin-film passivated contact structure of the present invention are as follows: 1) Silicon thin-film cracking or delamination is avoided, passivation performance is maintained, and subsequent screen-printing and firing processes can be reliably performed. 2) A relatively low sheet resistance is maintained, which is beneficial for metal contacting and lateral carrier transport. 3) The structure is fully compatible with existing PECVD technology, requires no additional equipment, and offers strong scalability.

[0020] The reasons why the laminated thin-film structure can achieve the above objectives are as follows: the silicon-carbon thin film has good adhesion to silicon oxide and also exhibits high mechanical strength. Therefore, during high-temperature crystallization, the silicon-carbon thin film is less prone to delamination. Meanwhile, the carbon content in the silicon-carbon thin film can be flexibly adjusted; increasing the carbon content enhances the adhesion and strength of the film. However, the introduction of carbon increases the resistivity of the silicon-carbon thin film. If a doped silicon-carbon thin film were to completely replace a doped amorphous silicon thin film, the overall sheet resistance of the film would become excessively high (typically $>200 \text{ } \Omega/\text{sq}$), which is unfavorable for lateral carrier transport. To achieve low sheet resistance, the present invention adopts a laminated structure solution, in which a heavily doped amorphous silicon thin film is deposited on top of the underlying silicon-carbon thin film. The amorphous silicon thin film has low resistivity and can reduce the sheet resistance to a target value, thereby maintaining good lateral carrier transport performance. In addition, the silicon-carbon thin film has strong impurity diffusion barrier capability, which is beneficial for maintaining device stability.

[0021] The beneficial effects of the present invention are as follows:

[0022] 1) A laminated thin film is used instead of a single-layer silicon thin film, wherein the bottom thin film in contact with the silicon oxide is a silicon-carbon thin film. Due to the strong adhesion and mechanical strength of the silicon-carbon thin film, delamination that typically occurs in conventional single-layer silicon thin films during high-temperature annealing is effectively avoided, thereby maintaining excellent passivation performance and enabling solar cells to achieve high open-circuit voltage, short-circuit current, and fill factor.

[0023] 2) A heavily doped polysilicon thin film of appropriate thickness is formed on top of the underlying silicon-carbon thin film. By utilizing the low resistivity of the polysilicon thin film, a suitable rear-side film sheet resistance for solar cells is achieved, thereby reducing series resistance and enabling a high fill factor.

[0024] 3) The structural combination of the laminated thin film can be flexibly adjusted according to solar cell design requirements, and the entire structure can be fabricated using PECVD, providing high flexibility and facilitating the realization of different device performances. Moreover, the silicon-carbon thin film has strong impurity diffusion barrier capability, which is beneficial for maintaining device stability.

Drawings

[0025] FIG. 1 shows a TOPCon device structure in the prior art.

[0026] FIG. 2 is an optical microscope image of delamination of an amorphous silicon thin film.

[0027] FIG. 3 is an optical microscope image showing a silicon–carbon thin film/silicon thin-film laminated structure without film blistering or delamination.

Detailed Description

[0028] The present invention is further described in detail below with reference to specific embodiments; however, the present invention is not limited to the following embodiments.

[0029] In order to make the objectives, technical solutions, and advantages of the present invention more clearly understood, the present invention is further described in detail below in conjunction with the embodiments. It should be understood that the specific embodiments described herein are merely for explaining the present invention and are not intended to limit the present invention.

[0030] The n-type silicon wafers used in the present invention are 180 μm -thick solar-grade Czochralski-grown monocrystalline silicon wafers, subjected to double-sided alkaline polishing, with a resistivity of 1–7 $\Omega\cdot\text{cm}$.

[0031] In the embodiments of the present invention, the preparation method of passivated samples is as follows: a surface silicon oxide layer is formed by thermal oxidation at 500–700 $^{\circ}\text{C}$; the wafers are then placed into a PECVD chamber, where a phosphorus-doped silicon–carbon thin film of varying thickness is deposited using silane, phosphine, methane (or ammonia), and hydrogen as reaction gases; thereafter, one or more phosphorus-doped amorphous silicon thin-film layers with a thickness of 80–200 nm are deposited using silane, phosphine, and hydrogen as reaction gases; the wafers are then placed into a tube furnace and subjected to high-temperature treatment at 800–1000 $^{\circ}\text{C}$ for 30 minutes; finally, the passivation performance and contact performance are tested.

[0032] In the comparative examples, the preparation method of passivated samples adopts a TOPCon structure formed using phosphorus-doped amorphous silicon thin films. The preparation method is as follows: a surface silicon oxide layer is formed by thermal oxidation at 500–700 $^{\circ}\text{C}$; the wafers are then placed into a PECVD chamber, where a phosphorus-doped amorphous silicon thin film with a thickness of 80–200 nm is deposited using silane, phosphine, and hydrogen as reaction gases; the wafers are subsequently placed into a tube furnace and subjected to high-temperature treatment at 800–1000 $^{\circ}\text{C}$ for 30 minutes; finally, the passivation performance and contact performance are tested.

[0033] Embodiment 1: Passivation performance and film sheet resistance of phosphorus-doped multilayer silicon–carbon/silicon thin films

[0034] Laminated thin films with different structures were prepared and subjected to annealing at 880 $^{\circ}\text{C}$ for 30 minutes, and the following passivation and contact performance results were obtained.

[0035]

Comparative Example Sample Structure	iV_{oc} (mV)	Rsh (Ω/sq)
c-Si / SiO_x / n^+ poly-Si (10 nm)	728	>200
c-Si / SiO_x / n^+ poly-Si (150 nm)	680	32
Embodiment Sample Structure	iV_{oc} (mV)	Rsh (Ω/sq)
c-Si / SiO_x / n^+ poly-SiCx (5 nm) / n^+ poly-Si (40 nm)	722	>200
c-Si / SiO_x / i-poly-SiCx (5 nm) / n^+ poly-SiCx (5 nm) / n^+ poly-Si (40 nm)	734	>200

[0036]

c-Si / SiO _x / i-poly-SiC _x (5 nm) / n ⁺ -poly-SiC _x (5 nm) / n ⁺ poly-Si (80 nm)	732	75
c-Si / SiO _x / i-poly-SiC _x (5 nm) / n ⁺ -poly-SiC _x (5 nm) / n ⁺ poly-Si (120 nm)	731	34
c-Si / SiO _x / i-poly-SiC _x (5 nm) / n ⁺ -poly-SiC _x (15 nm) / n ⁺ poly-Si (150 nm)	736	25

[0037] Embodiment 2: Application of Phosphorus-Doped Multilayer Silicon–Carbon/Silicon Thin Films in Solar Cells

[0038] The solar cell structure is still as shown in FIG. 1. First, boron diffusion is performed on the front surface of an n-type silicon wafer to form a p⁺ emitter; then backside alkaline polishing is carried out. Subsequently, a silicon oxide layer is formed on the rear surface by thermal oxidation according to the method described above. Silicon–carbon thin films with different structures are then deposited by PECVD and annealed at 880 °C for 30 minutes. Thereafter, Al₂O₃/SiN passivation layers are formed on the front surface, and a SiN passivation layer is formed on the rear surface. Front and rear electrodes are formed by screen printing followed by firing. Finally, the solar cell efficiency is measured using a Newport Oriel SoliA solar simulator.

[0039]

Rear-Side Structure	No.	V _{oc} (mV)	J _{sc} (mA/cm ²)	FF (%)	Eff. (%)
c-Si / SiO _x / n ⁺ poly-Si (120 nm)	1	653	39.45	67.4	17.36
	2	650	39.36	69.3	17.72
c-Si / SiO _x / n ⁺ poly-SiC _x (5 nm) / n ⁺ poly-Si (40 nm)	1	645	38.89	70.3	17.62
	2	640	38.65	70.8	17.51
c-Si / SiO _x / i-poly-SiC _x (5 nm) / n ⁺ poly-SiC _x (5 nm) /	1	676	40.03	81.4	22.03
	2	679	40.10	81.8	22.27

[0040]

n ⁺ poly-Si(120nm)					
c-Si / SiO _x / i-poly-SiCx (5 nm) / n ⁺ poly-SiCx (15 nm) / n ⁺ poly-Si (150 nm)	1	680	40.78	82.0	22.74
	2	681	40.83	82.1	22.82

[0041] The foregoing embodiments are merely exemplary implementations of the present invention and do not impose any limitation on the scope of protection of the present invention. Any technical solutions formed by equivalent exchange or equivalent substitution shall fall within the scope of protection of the present invention.

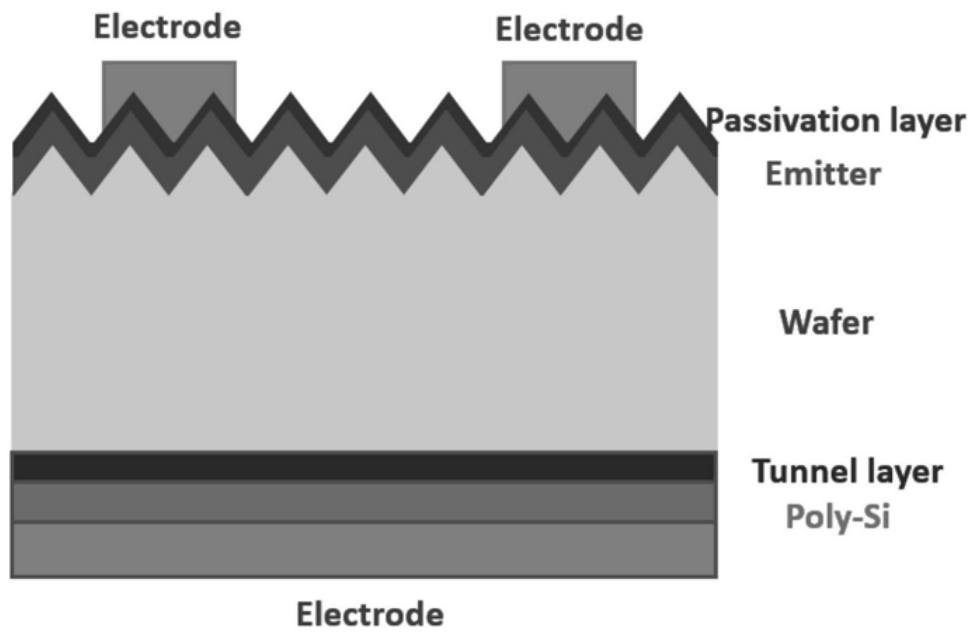


Figure 1

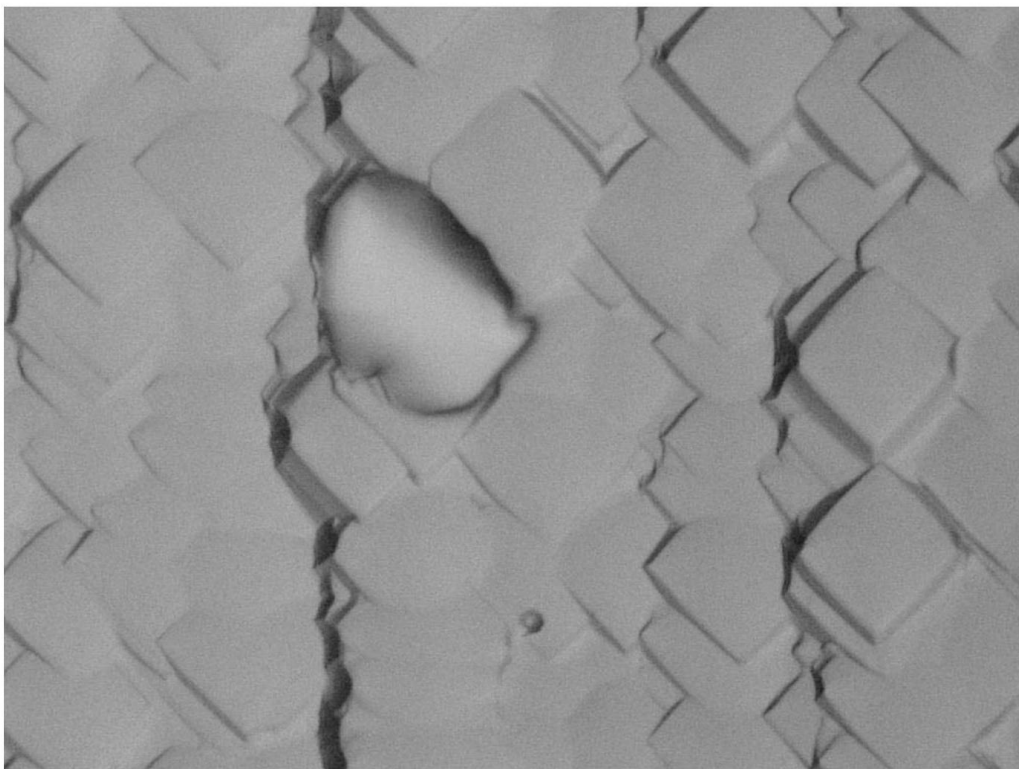


Figure 2

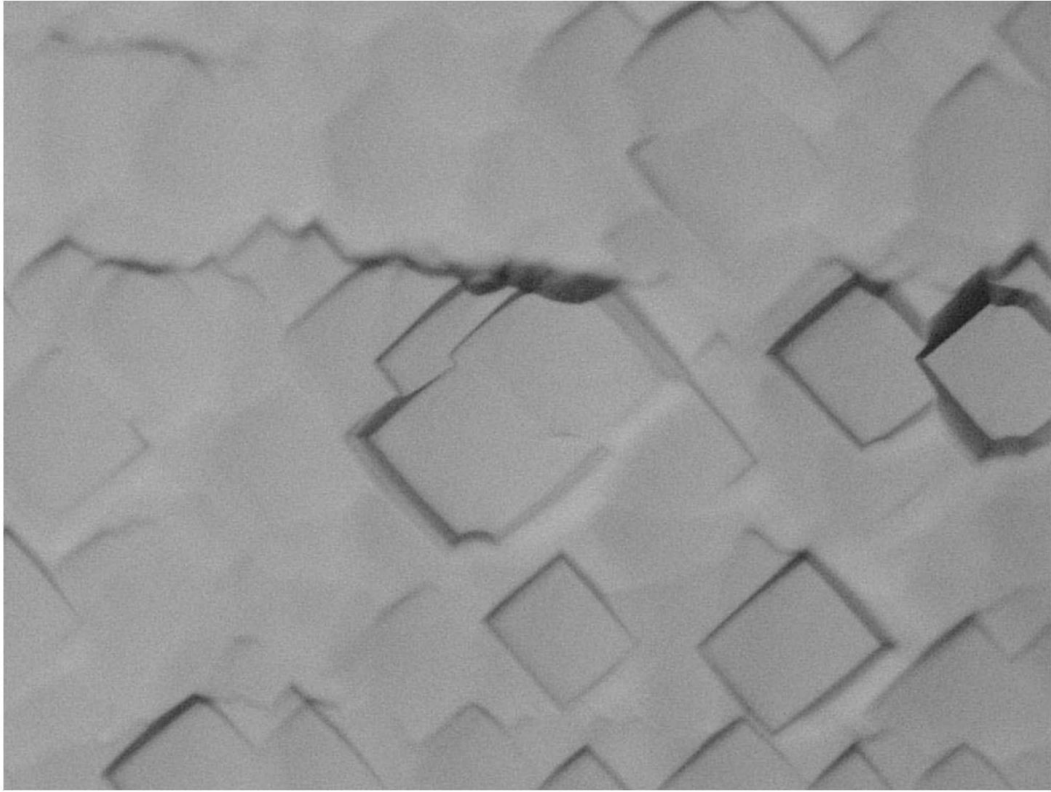


Figure 3

CERTIFICATE OF ACCURACY

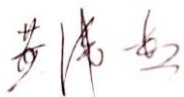
Attached as Ex A is the original document identified as patent application number CN112259614A and attached as Ex B is the translation of the original document from Chinese to English.

This is to certify under penalty of perjury that I, Weijie Huang, translated the document attached as Exhibit B and it is a true, accurate, and complete translation of Exhibit A.

I am thoroughly familiar with and competent in both Chinese and English languages. I have over 15 years of experience in translating Chinese to English and hold a Bachelor's degree in Linguistics from Beijing Language and Culture University. Attached as Exhibit C is a copy of my current CV.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 01/19/2026



Weijie Huang
Chinese > English Linguist

Your
legal
translation
partner 

Weijie Huang

Highlights

15 years in translation between Chinese and English in multiple domains with a focus on litigation.

Experience

Translator | Mar 2008 – Present

- Extensive experience translating litigation and dispute-related documents, including court pleadings, judgments, affidavits, witness statements, evidentiary materials, and legal correspondence for use in cross-border litigation and arbitration.
- Proven expertise in financial and corporate translation, covering annual reports, audited financial statements, investment agreements, shareholder agreements, trust deeds, compliance materials, and internal governance documents.
- Specialized experience in patent and IP translation, including patent specifications, claims, abstracts, office actions, prosecution history, prior art references, and related technical-legal documentation, with strict adherence to jurisdiction-specific terminology and formatting requirements.

Partial list of subject matter experience:

Telecommunications

- 4G/LTE, 5G NR, and 6G Standards
- Network Architecture and Protocols (TCP/IP, RAN, NFV)
- Wireless and Mobile Communication
- Signal Processing and Data Encoding
- Internet of Things (IoT) and M2M
- Satellite and Microwave Communication
- Cybersecurity and Encryption Protocols

Pharmaceuticals

- Drug Delivery
- Biologics and Monoclonal Antibodies (mAbs)
- Gene and Cell Therapy (CRISPR, mRNA)
- Small Molecule Synthesis and API Manufacturing
- Pharmacokinetics and Pharmacodynamics (ADME)
- Clinical Trial Protocols and Regulatory Documentation
- Immunology and Vaccine Development
- Medicinal Chemistry

Mechanical Engineering

- Automotive Engineering (EV Drivetrains, Autonomous Systems)
- Robotics and Industrial Automation
- Thermodynamics and Heat Exchange Systems
- Fluid Dynamics and Hydraulic/Pneumatic Systems
- Aerospace and Aeronautical Engineering
- Manufacturing and Tooling (CNC, Additive Manufacturing)

Chemistry

- Polymer and Materials Science
- Organic and Inorganic Synthesis
- Electrochemistry (Batteries, Fuel Cells)
- Heterogeneous and Homogeneous Catalysis
- Nanotechnology and Nanomaterials
- Petrochemicals and Refining Processes
- Analytical Chemistry and Spectroscopic Methods
- Biochemistry and Enzymology

- Regularly handles high-stakes legal translations submitted to courts, regulators, arbitration panels, and government authorities, ensuring precision, consistency, and defensibility of terminology.
- Deep familiarity with common law and civil law systems, enabling accurate rendering of legal concepts across jurisdictions without distortion of legal effect or procedural meaning.
- Experienced in translating complex, multi-entity and multi-jurisdictional matters, including materials involving offshore structures, trusts, cross-border investments, and regulatory filings.
- Skilled in maintaining terminology consistency across large-volume projects through glossaries, style guides, and parallel reference materials, particularly in long-running litigation or patent portfolios.
- Experienced in producing certified and court-ready translations, including Certificates of Accuracy where required, and working under tight litigation and regulatory deadlines.
- Comfortable collaborating with law firms, in-house legal teams, IP professionals, financial advisors, and compliance teams, responding to revision requests and clarification queries with precision and professionalism.
- Strong attention to detail, formatting fidelity, and document structure, ensuring translated documents mirror the original legal and technical layout for seamless reference and submission.

Education and Training

Bachelor of English Language and Literature, Beijing Language & Culture University (BLCU) (2004-2008)
Master of Professional Studies, Informatics with Concentration in Data Analytics, Northeastern University, (2022-2024)

Skills & Language Abilities

Bilingual (English-Mandarin) with fluency in Cantonese and basic French