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(54)发明名称

一种基于碱性抛光凝胶的晶体硅表面精细
抛光方法

(57)摘要

本发明涉及太阳能电池生产技术领域,尤其涉及一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其包括以下步骤:将硅研磨片浸入APM溶液中,进行超声波辅助清洗,得到表面带有一层二氧化硅薄膜的预抛光片,然后在预抛光片表面涂抹一层可光固化的碱性水凝胶,经紫外光固化之后在预抛光片得到一层碱性交联水凝胶层,升温至一定温度,对预抛光片表层进行腐蚀抛光一定时间得到抛光硅片。本发明克服了现有太阳能电池技术中的抛光液在抛光过程中的液体流动会对硅片的抛光造成不良影响,导致抛光均匀性不一,工艺不稳定的缺陷,经过本发明中的精细抛光方法抛光之后的晶体硅片具有更高的抛光均匀性稳定,同时其表面反射率明显提升而表面缺陷则明显减少。



1. 一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,包括以下步骤:

(1) 预抛光:将硅研磨片浸入APM溶液中,进行超声波辅助清洗,得到表面带有一层二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在预抛光片表面涂抹一层可光固化的碱性水凝胶,经紫外光固化之后在预抛光片得到一层碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶10~20份、乙醇钠10~15份、氢氧化六甲双铵2~5份、三(丙烯酸)硼酸酯1~3份、氟化钾1~3份、羧甲基纤维素钠0.5~3份、表面活性剂0.5~1份、光引发剂0.1~0.5份以及水100份;

(3) 精细抛光:升温至一定温度,对预抛光片表层进行腐蚀抛光一定时间,然后剥离交联水凝胶层,得到抛光硅片。

2. 根据权利要求1所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述步骤(1)中的APM溶液中氨水、双氧水和水的体积比为(5~10):(1~3):100。

3. 根据权利要求1或2所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述超声波辅助清洗频率100~150kHz,功率0.1~0.5 W/cm²,时间1~5min。

4. 根据权利要求1所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述步骤(2)中表面活性剂为硬脂酰谷氨酸钠、硬脂酸钠、月桂基磺化琥珀酸单酯二钠或者月桂基磺化琥珀酸单酯二钠中的一种。

5. 根据权利要求1所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述步骤(2)中光引发剂为苯基-2,4,6-三甲基苯甲酰基膦酸锂、双(2,4,6-三甲基苯甲酰基)-苯基氧化膦或者1,1'-(亚甲基二-4,1-亚苯基)双[2-羟基-2-甲基-1-丙酮]中的一种。

6. 根据权利要求1或4或5所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述步骤(2)中涂抹碱性水凝胶时的温度为0~10℃,紫外光波段为365nm~405nm,光照时间为10~60s,碱性交联水凝胶层的厚度为5~15mm。

7. 根据权利要求1所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述步骤(3)中在碱性交联水凝胶层上下侧连接电极并通直流电,其中在靠近预抛光片端为负极。

8. 根据权利要求7所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,直流电的电压为6~12V,电流强度为0.1~0.5A。

9. 根据权利要求1或7或8所述的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,其特征在于,所述抛光温度为55~75℃,抛光时间为100~1200s,抛光结束后使用去离子水冲洗晶体硅表面。

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法

技术领域

[0001] 本发明涉及太阳能电池生产技术领域,尤其涉及一种基于碱性抛光凝胶的晶体硅表面精细抛光方法。

背景技术

[0002] 在太阳能硅片的加工过程中,会经过多次的线切割工艺,从而在硅表面形成具有一定粗糙度的损伤层。由于粗糙表面的影响,硅片背面与钝化膜及金属之间会产生接触不良的现象,因此高效太阳能电池(Topcon, IBC等电池)生产的第一步即对原硅片表面进行抛光处理,使硅片背表面更加光滑甚至达到镜面效果,抛光后硅片的背面平整,一方面可以加强对透射光的反射,减小透光率;另一方面可以有效提高背钝化镀膜的均匀性,提高钝化效果,从而有效提升成品电池的电性能及EL良率等。目前,高效太阳能电池中使用的硅片大多是N型的单晶硅片。

[0003] 现有的生产实践中,太阳能硅片的抛光主要包括化学酸腐蚀抛光和化学碱腐蚀抛光两种手段,其中使用酸腐蚀抛光的技术抛光效果差,平整度低,且抛光后会产生大量酸性污染物,这些污染物的处理成本较高,会对环境和人体的健康造成影响。而化学碱腐蚀则是通过使用含有浓碱的抛光液对晶体硅表面进行腐蚀,但是这种方式也存在抛光效果不佳的问题,尤其是由于抛光液中的液体流动会对硅片的抛光造成一定的影响,导致硅片不同位置抛光程度不均一,导致工艺不稳定,容易在硅片表面出现凹坑、波纹、色斑、橘皮涡旋、雾或者电阻率条纹等缺陷,从而导致电池少子寿命低,EL良率低等问题。

发明内容

[0004] 本发明是为了克服现有太阳能电池技术中的抛光液在抛光过程中的液体流动会对硅片的抛光造成不良影响,导致抛光均匀性不一,工艺不稳定的缺陷,因而提供了一种能够保证在抛光过程中对硅片均匀稳定刻蚀抛光的一种基于碱性抛光凝胶的晶体硅表面精细抛光方法。

[0005] 为实现上述发明目的,本发明通过以下技术方案实现:

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

(1) 预抛光:将N型单晶原硅片浸入APM溶液中,进行超声波辅助清洗,得到表面带有一层二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在预抛光片表面涂抹一层可光固化的碱性水凝胶,经紫外光固化之后在预抛光片上得到一层碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶10~20份、乙醇钠10~15份、氢氧化六甲双铵2~5份、三(丙烯酸)硼酸酯1~3份、氟化钾1~3份、羧甲基纤维素钠0.5~3份、表面活性剂0.5~1份、光引发剂0.1~0.5份以及水100份;

(3) 精细抛光:升温至一定温度,对预抛光片表层进行腐蚀抛光一定时间,然后剥离交联水凝胶层,得到抛光硅片。

[0006] 在太阳能硅片加工过程中,通常使用的是多线切割的加工方式,因此在得到的原硅片表面会形成损伤层,从而使得硅表面具有一定的粗糙度。化学抛光就是在粗糙的硅片表面上通过酸碱化学腐蚀的方式,进一步获得更光滑、平整的晶硅表面的过程。

[0007] 现有的原硅片通常其表面的粗糙度约为 $10\sim 20\mu\text{m}$,本发明的在抛光前首先通过一步预抛光步骤能够将N型单晶原硅片表面的粗糙度大幅下降至 $1\sim 3\mu\text{m}$ 。其原理在于APM溶液中的碱性成分能够对硅片进行腐蚀,而其中的双氧水能够在硅片表面形成一层二氧化硅层,在APM清洗过程中硅片表面会不断的腐蚀以及形成氧化层,使得硅表面能够不断趋于平整,配合超声辅助清洗能够使得抛光面表面凸点的腐蚀效率加快,从而使得表面的粗糙度能够大幅下降,为下一步的精细抛光提供基础。

[0008] 本发明的第二个关键点在于本发明采用了凝胶形式的抛光凝胶,其相较于传统液态的抛光液而言,其在抛光过程中不会像液体抛光剂那样流动,造成抛光均匀性不一的缺陷。

[0009] 本发明中的晶体硅抛光碱性水凝胶其包括形成凝胶体的甲基丙烯酰胺基明胶、三(丙烯酸)硼酸酯以及光引发剂,其中甲基丙烯酰胺基明胶能够在光引发剂的引发作用下发生凝胶化从而形成固体凝胶,但是这种单一由甲基丙烯酰胺基明胶形成的凝胶的机械强度较差,为了使得其具有一定的机械强度本发明在配方中引入了分子结构中含有三个丙烯酸基团的三(丙烯酸)硼酸酯作为交联剂,三(丙烯酸)硼酸酯中的丙烯酸基团能够同样在光引发的条件下与甲基丙烯酰胺基明胶聚合,从而提高了形成的明胶的交联密度,使得凝胶形成具有较高的机械力学性能。此外三(丙烯酸)硼酸酯中的含硼基能够与水中的氢产生氢键,从而进一步提升了力学性能。

[0010] 由于本发明中采用了凝胶形式,因此如果采用传统的无机碱抛光剂其与硅片之间的反应速率会有一定的下降,但是本发明中的抛光剂采用了乙醇钠与氢氧化六甲双铵的组合,其两者的碱性相较于传统的无机碱(例如氢氧化钠与氢氧化钾)而言更强,因此更强的碱性能够提升抛光剂与硅片之间的反应速率,从而能够对抛光效率进行了较大的补偿。

[0011] 本发明中的晶体硅抛光碱性水凝胶在涂抹在硅片表面时并未发生凝固,因此整个体系粘度较低,当粘度过低时,配方组合物会从硅片表面滴落,无法保证涂抹的厚度以及涂抹的均匀性。因此本发明中还添加了粘度调节剂羧甲基纤维素钠,其能够有效调节抛光凝胶的粘度,防止在未固化前凝胶组合物从硅片表面滑落以及减薄失效。

[0012] 本发明还在碱性水凝胶层中添加了氟化钾作为抛光促进剂,其对硅片具有一定的腐蚀作用,因而能够促进抛光剂对硅片的横向腐蚀作用,保证了抛光的平整性。

[0013] 此外,本发明中的抛光步骤简单,仅仅只需要在经过预抛光的预抛光片表面涂抹一层碱性水凝胶层,经过升温腐蚀一定时间之后即可对硅片进行抛光,抛光结束后仅仅只需要将硅片表层的交联水凝胶层剥离即可。

[0014] 作为优选,所述步骤(1)中的APM溶液中氨水、双氧水和水的体积比为 $(5\sim 10):(1\sim 3):100$ 。

[0015] 现有技术中的APM溶液通常其内部的氨水的浓度相较于双氧水而言会更低,但是本发明采用高浓度的氨水配合低浓度的双氧水能够提高对硅片表层的腐蚀速率,随着表层不断的腐蚀以及氧化,从而能够使得表层的粗糙度有效降低。此外,低浓度的双氧水还能够有效降低硅片表层二氧化硅层的厚度,降低了下一步中的抛光以及除二氧化硅层的难度。

[0016] 作为优选,所述超声波辅助清洗频率100~150kHz,功率0.1~0.5W/cm²,时间1~5min。

[0017] 作为优选,所述步骤(2)中表面活性剂为硬脂酰谷氨酸钠、硬脂酸钠、月桂基磺化琥珀酸单酯二钠或者月桂基磺化琥珀酸单酯二钠中的一种。

[0018] 作为优选,所述步骤(2)中光引发剂为苯基-2,4,6-三甲基苯甲酰基膦酸锂、双(2,4,6-三甲基苯甲酰基)-苯基氧化膦或者1,1'-(亚甲基二-4,1-亚苯基)双[2-羟基-2-甲基-1-丙酮]中的一种。

[0019] 作为优选,所述步骤(2)中涂抹碱性水凝胶时的温度为0~10℃,紫外光波段为365nm~405nm,光照时间为10~60s,碱性交联水凝胶层的厚度为5~15mm。

[0020] 作为优选,所述步骤(3)中在碱性交联水凝胶层上下侧连接电极并通直流电,其中在靠近预抛光片端为负极。

[0021] 作为优选,直流电的电压为6~12V,电流强度为0.1~0.5A。

[0022] 由于本发明中采用了凝胶形式,因此如果采用传统的无机碱抛光叶其与硅片之间的反应速率会有一定的下降,本发明中在抛光过程中对碱性交联水凝胶层通直流电能够在负极附近提升氢氧根的浓度,从而提升碱性,加快了对硅片的腐蚀效率。此外,在通电过程中还能够将腐蚀时产生的硅酸根从负极转移到正极处,从而使得负极处的腐蚀反应能够持续不断发生,有效提升了抛光速率。

[0023] 作为优选,所述抛光温度为55~75℃,抛光时间为100~1200s,抛光结束后使用去离子水冲洗晶体硅表面。

[0024] 因此,本发明具有以下有益效果:

- (1) 在预抛光步骤中采用具有速率差的腐蚀氧化步骤,能够有效降低原硅片表面的粗糙度;
- (2) 本发明抛光方法简单,抛光效率高;
- (3) 抛光后得到的硅片表面平整度高,表面缺陷少。

附图说明

[0025] 图1为实施例1中抛光得到的硅片的显微镜照片。

[0026] 图2为实施例4中抛光得到的硅片的显微镜照片。

[0027] 图3为对比例1中抛光得到的硅片的显微镜照片。

[0028] 图4为对比例3中抛光得到的硅片的显微镜照片。

[0029] 图5为对比例4中抛光得到的硅片的显微镜照片。

[0030] 图6为对比例6中抛光得到的硅片的显微镜照片。

具体实施方式

[0031] 下面结合说明书附图以及具体实施例对本发明做进一步描述。本领域普通技术人员在基于这些说明的情况下将能够实现本发明。此外,下述说明中涉及到的本发明的实施例通常仅是本发明一部分的实施例,而不是全部的实施例。因此,基于本发明中的实施例,本领域普通技术人员在没有做出创造性劳动的前提下所获得的所有其他实施例,都应当属于本发明保护的范围。

[0032] 实施例1

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

预抛光:将N型单晶原硅片浸入由氨水、双氧水和水的体积比为8:2:100所组成的APM溶液中,进行超声波辅助清洗,超声波辅助清洗频率125kHz,功率 $0.3\text{W}/\text{cm}^2$,时间3min,得到表面带有一层厚度为 $1\sim 2\mu\text{m}$ 的二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在 5°C 条件下,向预抛光片表面涂抹一层可光固化的碱性水凝胶,经405nm紫外光固化30s之后在预抛光片得到一层10mm厚的碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶15份、乙醇钠12份、氢氧化六甲双铵4份、三(丙烯酸)硼酸酯2份、氟化钾2份、羧甲基纤维素钠2份、表面活性剂(硬脂酰谷氨酸钠)0.8份、光引发剂(苯基-2,4,6-三甲基苯甲酰基膦酸锂)0.3份以及水100份;

精细抛光:升温至 65°C ,对预抛光片表层进行腐蚀抛光900s,然后剥离交联水凝胶层,抛光结束后使用去离子水冲洗晶体硅表面。

[0033] 图1为本实施例1中抛光后的晶体硅的显微镜照片,如图所示,经过本发明中的抛光凝胶的抛光后,硅片表面形成了均匀平滑的方块结构,单一方块结构的尺寸大致一致约在 $15\sim 16\mu\text{m}$ 左右。

[0034] 本市实施例中的抛光硅片还经过了反射光谱测试,在300-1100nm的波长范围内的积分反射率大于45%,因而具有较高的反射率。

[0035] 实施例2

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

预抛光:将N型单晶原硅片浸入由氨水、双氧水和水的体积比为10:3:100所组成的APM溶液中,进行超声波辅助清洗,超声波辅助清洗频率150kHz,功率 $0.5\text{W}/\text{cm}^2$,时间1min,得到表面带有一层厚度为 $1\sim 2\mu\text{m}$ 的二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在 $0\sim 10^\circ\text{C}$ 条件下,向预抛光片表面涂抹一层可光固化的碱性水凝胶,经405nm紫外光固化10s之后在预抛光片得到一层5mm厚的碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶20份、乙醇钠15份、氢氧化六甲双铵5份、三(丙烯酸)硼酸酯3份、氟化钾3份、羧甲基纤维素钠3份、表面活性剂(月桂基磺化琥珀酸单酯二钠)1份、光引发剂(苯基-2,4,6-三甲基苯甲酰基膦酸锂)0.5份以及水100份;

(3) 精细抛光:升温至 75°C ,对预抛光片表层进行腐蚀抛光600s,然后剥离交联水凝胶层,抛光结束后使用去离子水冲洗晶体硅表面。

[0036] 实施例3

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

预抛光:将N型单晶原硅片浸入由氨水、双氧水和水的体积比为5:1:100所组成的APM溶液中,进行超声波辅助清洗,超声波辅助清洗频率100kHz,功率 $0.1\text{W}/\text{cm}^2$,时间5min,得到表面带有一层厚度为 $1\sim 2\mu\text{m}$ 的二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在 0°C 条件下,向预抛光片表面涂抹一层可光固化的碱性水凝胶,经365nmnm紫外光固化10s之后在预抛光片得到一层5mm厚的碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶10份、乙醇钠10份、氢氧化六甲双铵2份、三(丙烯酸)硼酸酯1份、氟化钾1份、羧甲基纤维素钠0.5份、表面活性剂(硬脂酸钠)0.5份、光引发剂(双(2,4,6-三甲基苯甲酰基)-苯基氧化膦)0.1份以及水100份;

(3) 精细抛光:升温至55℃,对预抛光片表层进行腐蚀抛光1200s,然后剥离交联水凝胶层,抛光结束后使用去离子水冲洗晶体硅表面。

[0037] 实施例4

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

预抛光:将N型单晶原硅片浸入由氨水、双氧水和水的体积比为8:2:100所组成的APM溶液中,进行超声波辅助清洗,超声波辅助清洗频率125kHz,功率0.3W/cm²,时间3min,得到表面带有一层厚度为1~2μm的二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在5℃条件下,向预抛光片表面涂抹一层可光固化的碱性水凝胶,经405nm紫外光固化30s之后在预抛光片得到一层10mm厚的碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶15份、乙醇钠12份、氢氧化六甲双铵4份、三(丙烯酸)硼酸酯2份、氟化钾2份、羧甲基纤维素钠2份、表面活性剂(硬脂酰谷氨酸钠)0.8份、光引发剂(苯基-2,4,6-三甲基苯甲酰基膦酸锂)0.3份以及水100份;

(3) 精细抛光:升温至65℃,并在碱性交联水凝胶层上下侧连接电极并通电压为8V,电流强度为0.3A的直流电,其中在靠近预抛光片端为负极,对预抛光片表层进行腐蚀抛光150s,然后剥离交联水凝胶层,抛光结束后使用去离子水冲洗晶体硅表面。

[0038] 本实施例中其余步骤与对比例1相同,区别在于在精细抛光步骤中添加了通电步骤,因此其抛光时间大幅下降,观察其显微镜照片(图2),我们发现其同样也能够在表面硅片表面形成了均匀平滑的方块结构。

[0039] 实施例5

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

(1) 预抛光:将N型单晶原硅片浸入由氨水、双氧水和水的体积比为6:1.5:100所组成的APM溶液中,进行超声波辅助清洗,超声波辅助清洗频率120kHz,功率0.4W/cm²,时间4min,得到表面带有一层厚度为1~2μm的二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在8℃条件下,向预抛光片表面涂抹一层可光固化的碱性水凝胶,经365nmnm紫外光固化45s之后在预抛光片得到一层8mm厚的碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶18份、乙醇钠12份、氢氧化六甲双铵3份、三(丙烯酸)硼酸酯1份、氟化钾1份、羧甲基纤维素钠1份、表面活性剂(月桂基磺化琥珀酸单酯二钠)0.6份、光引发剂(1,1'-(亚甲基二-4,1-亚苯基)双[2-羟基-2-甲基-1-丙酮])0.4份以及水100份;

(3) 精细抛光:升温至60℃,并在碱性交联水凝胶层上下侧连接电极并通电压为12V,电流强度为0.5A的直流电,其中在靠近预抛光片端为负极,对预抛光片表层进行腐蚀抛光100s,然后剥离交联水凝胶层,抛光结束后使用去离子水冲洗晶体硅表面。

[0040] 实施例6

一种基于碱性抛光凝胶的晶体硅表面精细抛光方法,包括以下步骤:

预抛光:将N型单晶原硅片浸入由氨水、双氧水和水的体积比为9:1:100所组成的APM溶液中,进行超声波辅助清洗,超声波辅助清洗频率125kHz,功率0.1W/cm²,时间2min,得到表面带有一层厚度为1~2μm的二氧化硅薄膜的预抛光片;

(2) 表面涂胶:在2℃条件下,向预抛光片表面涂抹一层可光固化的碱性水凝胶,经405nm紫外光固化20s之后在预抛光片得到一层10mm厚的碱性交联水凝胶层;

其中碱性水凝胶层配方如下:甲基丙烯酰胺基明胶18份、乙醇钠10份、氢氧化六甲双铵3份、三(丙烯酸)硼酸酯3份、氟化钾1份、羧甲基纤维素钠0.5份、表面活性剂(硬脂酰谷氨酸钠)0.5份、光引发剂(苯基-2,4,6-三甲基苯甲酰基膦酸锂)0.1份以及水100份;

(3) 精细抛光:升温至60℃,并在碱性交联水凝胶层上下侧连接电极并通电压为6V,电流强度为0.2A的直流电,其中在靠近预抛光片端为负极,对预抛光片表层进行腐蚀抛光200s,然后剥离交联水凝胶层,抛光结束后使用去离子水冲洗晶体硅表面。

[0041] 对比例1

对比例1与实施例1的其余条件相同,区别在于:对比例1省略了预抛光步骤。

[0042] 图3为对比例1中抛光得到的硅片的显微镜照片,比较图1与图3,我们发现由于省略了与抛光步骤,对比例1中得到的晶体硅表面高低不均一,因而更加粗糙,且表面含有点状凹坑。

[0043] 对比例2

对比例1与实施例1的其余条件相同,区别在于:对比例1中使用同等质量的氢氧化钠替代了实施例1中的乙醇钠以及氢氧化六甲双铵。

[0044] 由于氢氧化钠的碱性相较于乙醇钠以及氢氧化六甲双铵较弱,因此其整体的抛光时间较长,达到相同效果时,需要将近30分钟。

[0045] 对比例3

对比例3与实施例1的其余条件相同,区别在于:对比例3中未添加三(丙烯酸)硼酸酯。

[0046] 经过比较我们发现,在不添加三(丙烯酸)硼酸酯的条件下,固化形成的交联水凝胶膜的力学性能较差,其具体表现为交联水凝胶膜在抛光结束后无法一次性从硅片表面撕下,在撕下之后硅片表面仍然会残存一定的水凝胶膜,还需要对其做进一步的处理,若不处理残留的抛光凝胶还会对硅片进一步腐蚀,导致其表面会存在较多的凹陷小坑,其电镜照片如图4所示。而实施例1中的交联水凝胶膜则能够一次性从硅片表面撕下,且没有残留,在撕下之后仅仅需要用简单的清水清洗即可,得到的硅片表面也未见明显缺陷。

[0047] 对比例4

对比例4与实施例1的其余条件相同,区别在于:对比例4中未添加抛光促进剂。

[0048] 未添加抛光促进剂的对比例4的显微镜照片如图5所示,其在晶体硅表面面形成了大面积、大量不规则的缺陷,这些缺陷引起了光散射,从而形成了照片中雾状缺陷。

[0049] 对比例5

对比例5与实施例1的其余条件相同,区别在于:对比例5中未添加抛光促进剂粘度调节剂。

[0050] 经过测定,实施例1中的抛光凝胶在未固化之前25℃时的粘度为2400泊左右,具有较高的平铺性,同时和平铺之后不会随意流动,从而形成具有一定厚度(对比例1中为10mm)的凝胶层。

[0051] 而对比例5中由于未添加粘度调节剂,其在25℃时的粘度为1400泊左右,其在平铺直后会随着时间的流逝而流动,导致相同凝胶层的厚度降低(相同凝胶使用量厚度仅为5mm),有可能会造成抛光效果的减弱。

[0052] 对比例6

对比例6采用液态的抛光液形式对硅片进行抛光,抛光液的配方如下:乙醇钠15份、氢

氧化六甲双铵3份、抛光促进剂(氟化钠)2份、表面活性剂(硬脂酰谷氨酸钠)0.6份以及水100份。

[0053] 对比例6中的有效成分与实施例1中的有效成分以及含量均相同,不同点在于对比例5中为液态,而实施例1中为凝胶态。

[0054] 其两者的工艺参数比较如下表所示:

项目	实施例1	对比例6
抛光温度	65℃	65℃
抛光时间	900s	240s
表面结构尺寸	~16μm	~7μm
表面反射率	~45%	~32%
有无缺陷	无明显缺陷	表面存在大量直径2~5μm的凹坑

通过上表中的数据以及同时结合从图6(对比例6的显微镜照片)可知,采用相同抛光剂的抛光凝胶与抛光液相比,采用本发明中的抛光凝胶除了在抛光时间上具有一定的延长之外,从图中可以看出,即使采用了相同的配方,使用液态抛光液会在硅片表面带来大量缺陷。因此,采用本发明中抛光凝胶抛光的硅片的表面反射率以及表面缺陷相较于采用抛光液的硅片而言其效果更加优异。

[0055] 综上所述,本发明中采用了基于碱性抛光凝胶的晶体硅表面精细抛光方法替代了传统使用抛光液的抛光方法,经过抛光凝胶抛光之后的晶体硅片具有更高的表面反射率以及更少的表面缺陷,能够为提高太阳能电池的光电转换效率及降低EL缺陷提供坚实基础。同时在抛光过程中通入直流电能够有效提升抛光效率,大幅降低抛光时间。

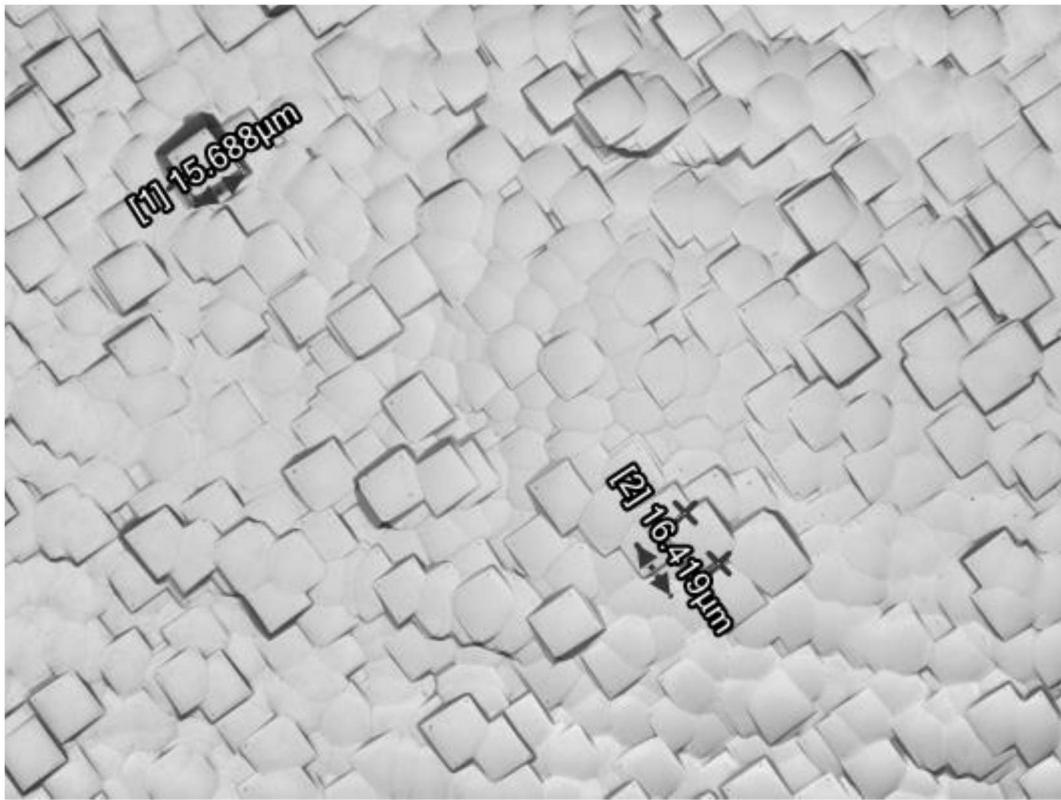


图1

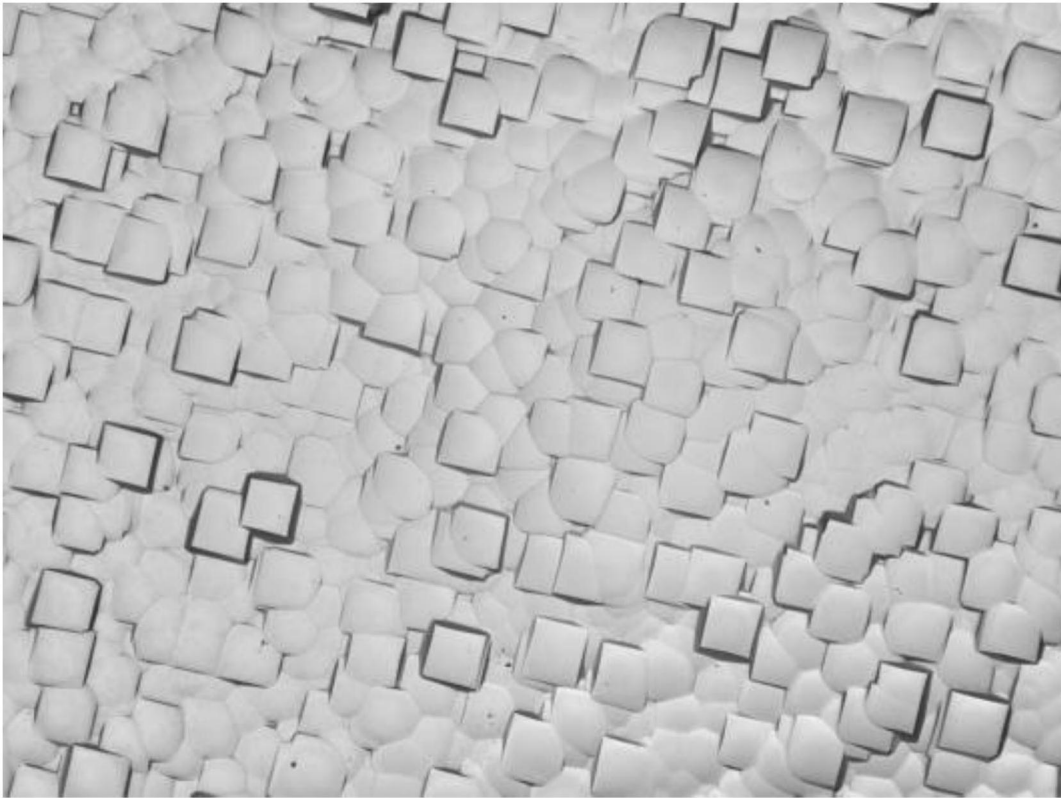


图2

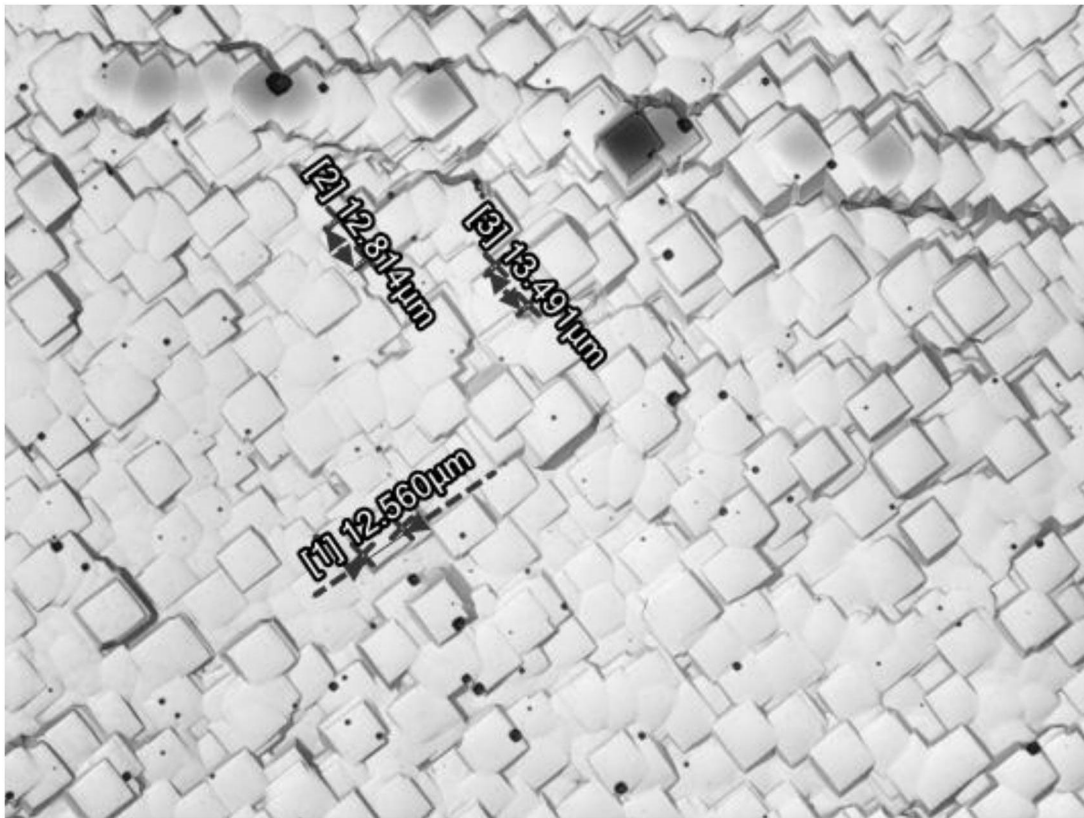


图3

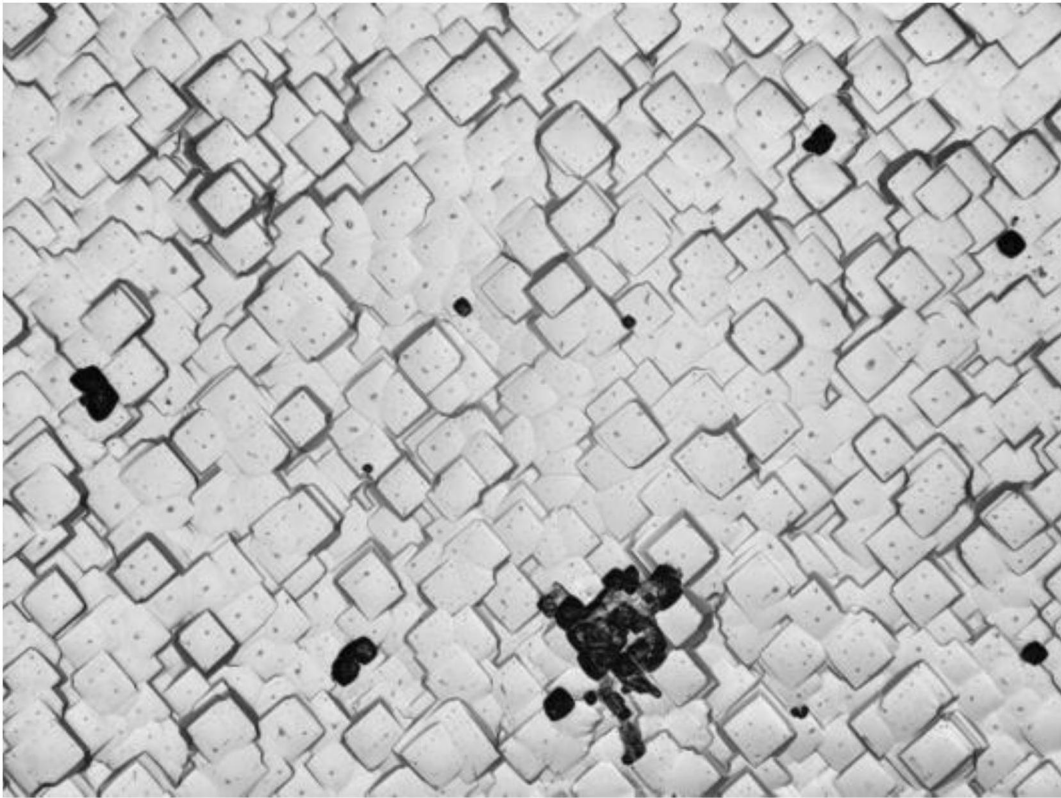


图4

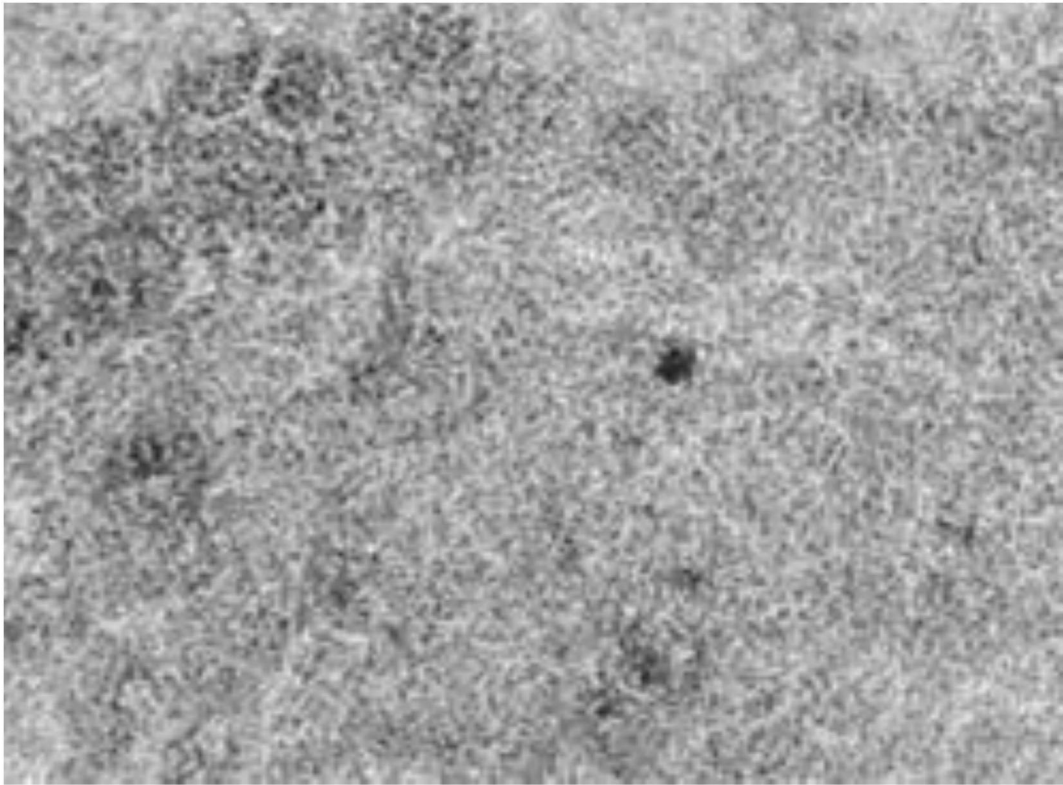


图5

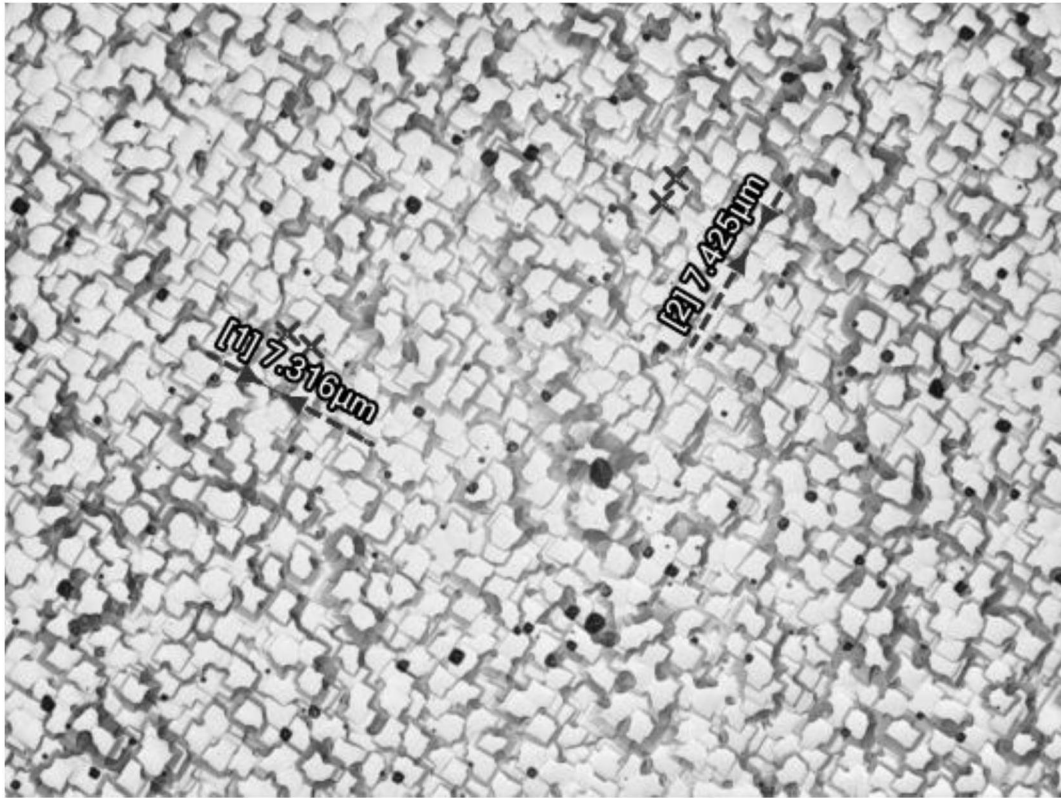


图6



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Claims (1 page)

Description (7 pages),

Drawings (6 pages)

(54) Title of Invention

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel

(57) Abstract

This invention relates to the field of solar cell manufacturing technology, and more particularly to a method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel. The method includes the following steps: immersing a silicon abrasive wafer in an APM solution for ultrasonic-assisted cleaning to obtain a pre-polished wafer with a thin silica film on its surface; then coating the surface of the pre-polished wafer with a photocurable alkaline hydrogel; curing the pre-polished wafer with ultraviolet light to obtain an alkaline cross-linked hydrogel layer; heating to a certain temperature; and etching and polishing the surface of the pre-polished wafer for a certain period to obtain a polished silicon wafer. This invention overcomes the shortcomings of existing solar cell technologies where the flow of polishing slurry during the polishing process negatively impacts the polishing of the silicon wafer, leading to inconsistent polishing uniformity and unstable processes. The crystalline silicon wafer polished using the fine polishing method of this invention exhibits higher polishing uniformity and stability, while its surface reflectivity is significantly improved and surface defects are significantly reduced.



CN 111690987 A

Exhibit B

1. A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel, characterized by comprising the following steps:

(1) Pre-polishing: The silicon abrasive wafer is immersed in APM solution and ultrasonically assisted cleaning is performed to obtain a pre-polished wafer with a silicon dioxide film on the surface.

(2) Surface coating: A layer of photocurable alkaline hydrogel is coated on the surface of the pre-polished sheet. After curing with ultraviolet light, an alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 10-20 parts of methacrylamide gelatin, 10-15 parts of sodium ethoxide, 2-5 parts of hexamethyl diammonium hydroxide, 1-3 parts of tri(acrylate)borate, 1-3 parts of potassium fluoride, 0.5-3 parts of sodium carboxymethyl cellulose, 0.5-1 part of surfactant, 0.1-0.5 parts of photoinitiator, and 100 parts of water;

(3) Fine polishing: Heat to a certain temperature, etch and polish the surface of the pre-polished wafer for a certain time, and then peel off the cross-linked hydrogel layer to obtain the polished silicon wafer.

2. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1, characterized in that the volume ratio of ammonia, hydrogen peroxide and water in the APM solution in step (1) is (5~10):(1~3):100.

3. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1 or 2, characterized in that the ultrasonic-assisted cleaning frequency is 100~150kHz, the power is 0.1~0.5W/cm², and the time is 1~5min.

4. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1, characterized in that the surfactant in step (2) is one of sodium stearyl glutamate, sodium stearate, disodium lauryl sulfonate monosuccinate, or disodium lauryl sulfonate monosuccinate.

5. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1, characterized in that the photoinitiator in step (2) is one of lithium phenyl-2,4,6-trimethylbenzoylphosphonate, bis(2,4,6-trimethylbenzoyl)-phenylphosphine oxide, or 1,1'-(methylenedi-4,1-phenylene)bis[2-hydroxy-2-methyl-1-propanone].

6. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1, 4 or 5, characterized in that the temperature when applying alkaline hydrogel in step (2) is 0~10°C, the ultraviolet light band is 365nm~405nm, the illumination time is 10~60s, and the thickness of alkaline cross-linked hydrogel layer is 5~15mm.

7. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1, characterized in that, in step (3), electrodes are connected to the upper and lower sides of the alkaline cross-linked hydrogel layer and direct current is applied, wherein the end near the pre-polished wafer is the negative electrode.

8. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 7, characterized in that the voltage of the direct current is 6~12V and the current intensity is 0.1~0.5A.

9. The method for fine polishing of crystalline silicon surface based on alkaline polishing gel according to claim 1, 7 or 8, characterized in that the polishing temperature is 55~75°C, the polishing time is 100~1200s, and the crystalline silicon surface is rinsed with deionized water after polishing.

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel

Technical Field

[0001] This invention relates to the field of solar cell manufacturing technology, and in particular to a method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel.

Background Art

[0002] During the processing of solar silicon wafers, multiple wire cutting processes are performed, resulting in a damaged layer with a certain roughness on the silicon surface. Due to the influence of the rough surface, poor contact may occur between the back of the silicon wafer and the passivation film and metal. Therefore, the first step in the production of high-efficiency solar cells (Topcon, IBC, etc.) is to polish the surface of the original silicon wafer to make the back surface of the silicon wafer smoother or even achieve a mirror effect. After polishing, the back of the silicon wafer is flat, which can enhance the reflection of transmitted light and reduce the light transmittance; on the other hand, it can effectively improve the uniformity of the back passivation coating and improve the passivation effect, thereby effectively improving the electrical performance and EL yield of the finished cell. Currently, most of the silicon wafers used in high-efficiency solar cells are N-type monocrystalline silicon wafers.

[0003] In existing production practices, the polishing of solar silicon wafers mainly includes two methods: chemical acid etching polishing and chemical alkaline etching polishing. Among them, the polishing effect of acid etching polishing is poor, the flatness is low, and a large amount of acidic pollutants are generated after polishing. The treatment cost of these pollutants is high, which will affect the environment and human health. Chemical alkaline etching is to use polishing liquid containing concentrated alkali to etch the surface of crystalline silicon. However, this method also has the problem of poor polishing effect. In particular, the flow of liquid in the polishing liquid will have a certain impact on the polishing of silicon wafers, resulting in uneven polishing degree at different positions of silicon wafers. This leads to unstable process and is prone to defects such as pits, ripples, spots, orange peel vortices, fog or resistivity stripes on the surface of silicon wafers, resulting in problems such as low minority carrier lifetime and low EL yield.

Summary of the Invention

[0004] The present invention aims to overcome the defects in existing solar cell technology where the flow of polishing slurry during the polishing process can have an adverse effect on the polishing of silicon wafers, resulting in inconsistent polishing uniformity and unstable process. Therefore, it provides a fine polishing method for crystalline silicon surfaces based on alkaline polishing gel that can ensure uniform and stable etching and polishing of silicon wafers during the polishing process.

[0005] To achieve the above-mentioned objectives, the present invention is implemented through the following technical solution:

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

(1) Pre-polishing: Immerse the N-type single crystal silicon wafer in APM solution and perform ultrasonic-assisted cleaning to obtain a pre-polished wafer with a silicon dioxide film on the surface.

(2) Surface coating: A layer of photocurable alkaline hydrogel is coated on the surface of the pre-polished sheet. After curing with ultraviolet light, an alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 10-20 parts of methacrylamide gelatin, 10-15 parts of sodium ethoxide, 2-5 parts of hexamethyl diammonium hydroxide, 1-3 parts of tri(acrylate)borate, 1-3 parts of potassium fluoride, 0.5-3 parts of sodium carboxymethyl cellulose, 0.5-1 part of surfactant, 0.1-0.5 parts of photoinitiator, and 100 parts of water;

(3) Fine polishing: Heat to a certain temperature and etch and polish the surface of the pre-polished wafer for a certain time. Then peel off the cross-linked hydrogel layer to obtain the polished silicon wafer.

[0006] In the process of solar silicon wafer processing, multi-wire cutting is usually used, which will form a damage layer on the surface of the raw silicon wafer, resulting in a certain degree of roughness on the silicon surface. Chemical polishing is a process of obtaining a smoother and flatter crystalline silicon surface by acid and alkali chemical etching on the rough silicon wafer surface.

[0007] Existing silicon wafers typically have a surface roughness of about 10-20 μm . The present invention, through a pre-polishing step before polishing, can significantly reduce the surface roughness of N-type monocrystalline silicon wafers to 1-3 μm . The principle is that the alkaline components in the APM solution can corrode the silicon wafer, while the hydrogen peroxide in it can form a silicon dioxide layer on the silicon wafer surface. During the APM cleaning process, the silicon wafer surface will be continuously corroded and an oxide layer will be formed, making the silicon surface increasingly smooth. Combined with ultrasonic-assisted cleaning, the corrosion efficiency of the bumps on the polished surface can be accelerated, thereby significantly reducing the surface roughness and providing a foundation for the next step of fine polishing.

[0008] The second key point of the present invention is that the present invention uses a polishing gel in the form of a gel, which, compared with the traditional liquid polishing liquid, does not flow like a liquid polishing agent during the polishing process, thus avoiding the defect of uneven polishing uniformity.

[0009] The crystalline silicon polishing alkaline hydrogel of the present invention comprises methacrylamide gelatin, tri(acrylate) borate, and a photoinitiator to form the gel. Methacrylamide gelatin can gel under the initiation of the photoinitiator to form a solid gel. However, the mechanical strength of this gel formed solely from methacrylamide gelatin is poor. To improve its mechanical strength, the present invention introduces tri(acrylate) borate, which contains three acrylic groups in its molecular structure, as a crosslinking agent. The acrylic groups in tri(acrylate) borate can also polymerize with methacrylamide gelatin under photoinitiation conditions, thereby increasing the crosslinking density of the formed gel and resulting in a gel with higher mechanical properties. Furthermore, the boron-containing groups in tri(acrylate) borate can form hydrogen bonds with hydrogen in water, further enhancing the mechanical properties.

[0010] Since the present invention uses a gel form, the reaction rate between the traditional inorganic alkaline polishing agent and the silicon wafer will be reduced to a certain extent. However, the polishing agent in the present invention uses a combination of sodium ethoxide and hexamethyl diammonium hydroxide, which are more alkaline than traditional inorganic alkaline agents (such as sodium hydroxide and potassium hydroxide). Therefore, the stronger alkalinity can improve the reaction rate between the polishing agent and the silicon wafer, thereby greatly compensating for the polishing efficiency.

[0011] The alkaline hydrogel for polishing crystalline silicon in this invention does not solidify when applied to the silicon wafer surface. Therefore, the viscosity of the entire system is low. When the viscosity is too low, the formulation composition will drip from the silicon wafer surface, making it impossible to guarantee the thickness and uniformity of the coating. Therefore, sodium carboxymethyl cellulose, a viscosity modifier, is also added to this invention. It can effectively adjust the viscosity of the polishing gel, preventing the gel composition from sliding off the silicon wafer surface and thinning failure before curing.

[0012] In addition, potassium fluoride was added to the alkaline hydrogel layer as a polishing promoter. It has a certain corrosive effect on silicon wafers, thus promoting the lateral corrosion of silicon wafers by the polishing agent and ensuring the smoothness of the polishing.

[0013] In addition, the polishing step in this invention is simple. It only requires applying an alkaline hydrogel layer to the surface of the pre-polished wafer, and then polishing the silicon wafer after heating and etching for a certain period of time. After polishing, it only requires peeling off the cross-linked hydrogel layer on the surface of the silicon wafer.

[0014] Preferably, the volume ratio of ammonia, hydrogen peroxide and water in the APM solution in step (1) is (5~10):(1~3):100.

[0015] In the prior art, the concentration of ammonia in APM solutions is usually lower than that of hydrogen peroxide. However, the present invention uses a high concentration of ammonia in combination with a low concentration of hydrogen peroxide to increase the corrosion rate of the silicon wafer surface. As the surface is continuously corroded and oxidized, the surface roughness can be effectively reduced. In addition, the low concentration of hydrogen peroxide can also effectively reduce the thickness of the silicon dioxide layer on the silicon wafer surface, reducing the difficulty of polishing and removing the silicon dioxide layer in the next step.

[0016] Preferably, the ultrasonic-assisted cleaning frequency is 100-150kHz, the power is 0.1-0.5W/cm², and the time is 1~5min.

[0017] Preferably, the surfactant in step (2) is one of sodium stearyl glutamate, sodium stearate, disodium lauryl sulfonate monosuccinate, or disodium lauryl sulfonate monosuccinate.

[0018] Preferably, the photoinitiator in step (2) is one of lithium phenyl-2,4,6-trimethylbenzoylphosphonate, bis(2,4,6-trimethylbenzoyl)-phenylphosphine oxide, or 1,1'-(methylenedi-4,1-phenylene)bis[2-hydroxy-2-methyl-1-propanone].

[0019] Preferably, the temperature when applying the alkaline hydrogel in step (2) is 0 to 10°C, the ultraviolet light band is 365 nm to 405 nm, the light exposure time is 10 to 60 s, and the thickness of the alkaline cross-linked hydrogel layer is 5 to 15 mm.

[0020] Preferably, in step (3), electrodes are connected to the upper and lower sides of the alkaline cross-linked hydrogel layer and direct current is applied, wherein the end near the pre-polished sheet is the negative electrode.

[0021] Preferably, the voltage of the DC power supply is 6 to 12V and the current intensity is 0.1 to 0.5A.

[0022] Because a gel form is used in this invention, the reaction rate between the traditional inorganic alkali polishing blade and the silicon wafer would decrease to some extent. In this invention, applying direct current to the alkaline cross-linked hydrogel layer during polishing can increase the concentration of hydroxide ions near the negative electrode, thereby increasing alkalinity and accelerating the corrosion efficiency of the silicon wafer. In addition, during the current application process, silicate ions generated during corrosion can be transferred from the negative electrode to the positive electrode, so that the corrosion reaction at the negative electrode can continue to occur, effectively improving the polishing rate.

[0023] Preferably, the polishing temperature is 55~75°C, the polishing time is 100~1200s, and the surface of the crystalline silicon is rinsed with deionized water after polishing.

[0024] Therefore, the present invention has the following beneficial effects:

- (1) The use of a corrosion oxidation step with a rate difference in the pre-polishing step can effectively reduce the roughness of the original silicon wafer surface.
- (2) The polishing method of the present invention is simple and has high polishing efficiency;
- (3) The silicon wafer obtained after polishing has high surface flatness and few surface defects.

Brief Description of the Drawings

[0025] Figure 1 is a microscope photograph of the silicon wafer obtained by polishing in Embodiment 1.

[0026] Figure 2 is a microscope photograph of the silicon wafer obtained by polishing in Embodiment 4.

[0027] Figure 3 is a microscope photograph of the silicon wafer obtained by polishing in Comparative Embodiment 1.

[0028] Figure 4 is a microscope photograph of the silicon wafer obtained by polishing in Comparative Embodiment 3.

[0029] Figure 5 is a microscope photograph of the silicon wafer obtained by polishing in Comparative Embodiment 4.

[0030] Figure 6 is a microscope photograph of the silicon wafer obtained by polishing in Comparative Embodiment 6.

Detailed Description of the Embodiments

[0031] The present invention will be further described below with reference to the accompanying drawings and specific embodiments. Those skilled in the art will be able to implement the present invention based on these descriptions. Furthermore, the embodiments of the present invention described below are generally only some embodiments of the present invention, and not all embodiments. Therefore, all other embodiments obtained by those skilled in the art based on the embodiments of the present invention without inventive effort should fall within the scope of protection of the present invention.

[0032] Embodiment 1

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

Pre-polishing: The N-type single crystal silicon wafer is immersed in an APM solution composed of ammonia, hydrogen peroxide and water in a volume ratio of 8:2:100 and ultrasonically assisted cleaning is performed. The ultrasonic cleaning frequency is 125kHz, the power is 0.3W/cm², and the time is 3min, resulting in a pre-polished wafer with a silicon dioxide film with a thickness of 1 to 2 μm on the surface;

(2) Surface coating: At 5°C, a layer of photocurable alkaline hydrogel is applied to the surface of the pre-polished sheet. After curing with 405nm ultraviolet light for 30s, a 10mm thick alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet;

The alkaline hydrogel layer is formulated as follows: 15 parts methacrylamide gelatin, 12 parts sodium ethoxide, 4 parts hexamethyl diammonium hydroxide, 2 parts tri(acrylate) borate, 2 parts potassium fluoride, 2 parts sodium carboxymethyl cellulose, 0.8 parts surfactant (sodium stearyl glutamate), 0.3 parts photoinitiator (lithium phenyl-2,4,6-trimethylbenzoylphosphonate), and 100 parts water;

Fine polishing: Heat to 65°C and etch and polish the surface of the pre-polished wafer for 900 seconds. Then peel off the cross-linked hydrogel layer. After polishing, rinse the crystalline silicon surface with deionized water.

[0033] Figure 1 is a microscope photograph of the polished crystalline silicon in Embodiment 1. As shown in the figure, after polishing with the polishing gel in this invention, a uniform and smooth square structure is formed on the surface of the silicon wafer. The size of a single square structure is approximately the same, about 15 to 16 μm.

[0034] The polished silicon wafer in this embodiment has also undergone a reflectance spectrum test, and the integral reflectance in the wavelength range of 300-1100nm is greater than 45%, thus having a high reflectance.

[0035] Embodiment 2

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

Pre-polishing: The N-type single crystal silicon wafer is immersed in an APM solution composed of ammonia, hydrogen peroxide and water in a volume ratio of 10:3:100 and ultrasonically assisted cleaning is performed. The ultrasonic cleaning frequency is 150kHz, the power is 0.5W/cm², and the time is 1min, resulting in a pre-polished wafer with a silicon dioxide film with a thickness of 1 to 2 μm on the surface.

(2) Surface coating: Under the conditions of 0~10°C, a layer of photocurable alkaline hydrogel is applied to the surface of the pre-polished sheet. After curing with 405nm ultraviolet light for 10s, a 5mm thick alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 20 parts methacrylamide gelatin, 15 parts sodium ethoxide, 5 parts hexamethyl diammonium hydroxide, 3 parts tri(acrylate) borate, 3 parts potassium fluoride, 3 parts sodium carboxymethyl cellulose, 1 part surfactant (disodium lauryl sulfonate monoester), 0.5 parts photoinitiator (lithium phenyl-2,4,6-trimethylbenzoylphosphonate), and 100 parts water.

(3) Fine polishing: Heat to 75°C and perform etching polishing on the surface of the pre-polished wafer for 600s. Then peel off the cross-linked hydrogel layer. After polishing, rinse the surface of the crystalline silicon with deionized water.

[0036] Embodiment 3

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

Pre-polishing: The N-type single crystal silicon wafer is immersed in an APM solution composed of ammonia, hydrogen peroxide and water in a volume ratio of 5:1:100 and ultrasonic-assisted cleaning is performed. The ultrasonic cleaning frequency is 100kHz, the power is 0.1W/cm², and the time is 5min, resulting in a pre-polished wafer with a silicon dioxide film with a thickness of 1 to 2 μm on the surface.

(2) Surface coating: Under 0°C conditions, a layer of photocurable alkaline hydrogel is applied to the surface of the pre-polished sheet. After curing with 365nm UV light for 10s, a 5mm thick alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 10 parts methacrylamide gelatin, 10 parts sodium ethoxide, 2 parts hexamethyl diammonium hydroxide, 1 part tri(acrylate) borate, 1 part potassium fluoride, 0.5 parts sodium carboxymethyl cellulose, 0.5 parts surfactant (sodium stearate), 0.1 parts photoinitiator (bis(2,4,6-trimethylbenzoyl)-phenylphosphine oxide), and 100 parts water;

(3) Fine polishing: Heat to 55°C and perform etching polishing on the surface of the pre-polished wafer for 1200s. Then peel off the cross-linked hydrogel layer. After polishing, rinse the crystalline silicon surface with deionized water.

[0037] Embodiment 4

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

Pre-polishing: The N-type single crystal silicon wafer is immersed in an APM solution composed of ammonia, hydrogen peroxide and water in a volume ratio of 8:2:100 and ultrasonically assisted cleaning is performed. The ultrasonic cleaning frequency is 125kHz, the power is 0.3W/cm², and the time is 3min, resulting in a pre-polished wafer with a silicon dioxide film with a thickness of 1 to 2 μm on the surface .

(2) Surface coating: At 5°C, a layer of photocurable alkaline hydrogel is applied to the surface of the pre-polished sheet. After curing with 405nm ultraviolet light for 30s, a 10mm thick alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 15 parts methacrylamide gelatin, 12 parts sodium ethoxide, 4 parts hexamethyl diammonium hydroxide, 2 parts tri(acrylate) borate, 2 parts potassium fluoride, 2 parts sodium carboxymethyl cellulose, 0.8 parts surfactant (sodium stearyl glutamate), 0.3 parts photoinitiator (lithium phenyl-2,4,6-trimethylbenzoylphosphonate), and 100 parts water.

(3) Fine polishing: Heat to 65°C, connect electrodes on the upper and lower sides of the alkaline cross-linked hydrogel layer and apply a DC current of 8V and 0.3A, with the end near the pre-polished wafer being the negative electrode. Etch and polish the surface of the pre-polished wafer for 150s, then peel off the cross-linked hydrogel layer. After polishing, rinse the surface of the crystalline silicon with deionized water.

[0038] The remaining steps in this embodiment are the same as those in Comparative Embodiment 1. The difference is that an electric step is added in the fine polishing step, so the polishing time is greatly reduced. Observing its microscope image (Figure 2), we found that it can also form a uniform and smooth square structure on the surface of the silicon wafer.

[0039] Embodiment 5

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

(1) Pre-polishing: The N-type single crystal silicon wafer is immersed in an APM solution composed of ammonia, hydrogen peroxide and water in a volume ratio of 6:1.5:100 and ultrasonic-assisted cleaning is performed. The ultrasonic cleaning frequency is 120kHz, the power is 0.4W/cm², and the time is 4min, resulting in a pre-polished wafer with a silicon dioxide film with a thickness of 1 to 2 μm on the surface.

(2) Surface coating: At 8°C, a layer of photocurable alkaline hydrogel is applied to the surface of the pre-polished sheet. After curing with 365nm UV light for 45s, an 8mm thick alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 18 parts methacrylamide gelatin, 12 parts sodium ethoxide, 3 parts hexamethyl diammonium hydroxide, 1 part tri(acrylate) borate, 1 part potassium fluoride, 1 part sodium carboxymethyl cellulose, 0.6 parts surfactant (disodium lauryl sulfonate monoester), and photoinitiator (1,1'-(methylenedi-4,1-phenylene)bis[2-hydroxy-2-methyl-1-propanone]), 0.4 parts and 100 parts water;

(3) Fine polishing: Heat to 60°C, connect electrodes on the upper and lower sides of the alkaline cross-linked hydrogel layer and apply a DC current of 12V and 0.5A, with the end near the pre-polished wafer being the negative electrode. Etch and polish the surface of the pre-polished wafer for 100s, then peel off the cross-linked hydrogel layer. After polishing, rinse the surface of the crystal silicon with deionized water.

[0040] Embodiment 6

A method for fine polishing of crystalline silicon surfaces based on alkaline polishing gel includes the following steps:

Pre-polishing: The N-type single crystal silicon wafer is immersed in an APM solution composed of ammonia, hydrogen peroxide and water in a volume ratio of 9:1:100 and ultrasonically assisted cleaning is performed. The ultrasonic cleaning frequency is 125kHz, the power is 0.1W/cm², and the time is 2min, resulting in a pre-polished wafer with a silicon dioxide film with a thickness of 1 to 2 μm on the surface .

(2) Surface coating: At 2°C, a layer of photocurable alkaline hydrogel is applied to the surface of the pre-polished sheet. After curing with 405nm ultraviolet light for 20s, a 10mm thick alkaline cross-linked hydrogel layer is obtained on the pre-polished sheet.

The alkaline hydrogel layer is formulated as follows: 18 parts methacrylamide gelatin, 10 parts sodium ethoxide, 3 parts hexamethyl diammonium hydroxide, 3 parts tri(acrylate) borate, 1 part potassium fluoride, 0.5 parts sodium carboxymethyl cellulose, 0.5 parts surfactant (sodium stearyl glutamate), 0.1 parts photoinitiator (lithium phenyl-2,4,6-trimethylbenzoylphosphonate), and 100 parts water;

(3) Fine polishing: Heat to 60°C, connect electrodes on the upper and lower sides of the alkaline cross-linked hydrogel layer and apply a DC current of 6V and 0.2A, with the end near the pre-polished wafer being the negative electrode. Etch and polish the surface of the pre-polished wafer for 200s, then peel off the cross-linked hydrogel layer. After polishing, rinse the surface of the crystalline silicon with deionized water.

[0041] Comparative Embodiment 1

Comparative Embodiment 1 is the same as Embodiment 1 in all other conditions, except that the pre-polishing step is omitted in Comparative Embodiment 1.

[0042] Figure 3 is a microscope photograph of the silicon wafer obtained by polishing in Comparative Embodiment 1. Comparing Figure 1 and Figure 3, we find that due to the omission of the polishing step, the surface of the crystalline silicon obtained in Comparative Embodiment 1 is uneven and therefore rougher, and the surface contains dot-shaped pits.

[0043] Comparative Embodiment 2

Comparative Embodiment 1 was the same as Embodiment 1 in all other conditions, except that sodium hydroxide of the same mass was used in Comparative Embodiment 1 instead of sodium ethoxide and hexamethyldiammonium hydroxide in Embodiment 1.

[0044] Since sodium hydroxide is less alkaline than sodium ethoxide and hexamethyldiammonium hydroxide, its overall polishing time is longer, requiring nearly 30 minutes to achieve the same effect.

[0045] Comparative Embodiment 3

Comparative Embodiment 3 was the same as Embodiment 1 under the same conditions, except that tri(acrylate)borate was not added in Comparative Embodiment 3.

[0046] Through comparison, we found that the mechanical properties of the cross-linked hydrogel film formed by curing without adding tri(acrylate) borate are poor. Specifically, the cross-linked hydrogel film cannot be peeled off from the silicon wafer surface in one go after polishing. After peeling, a certain amount of hydrogel film will remain on the silicon wafer surface, requiring further treatment. If the residual polishing gel is not treated, it will further corrode the silicon wafer, resulting in many small pits on its surface, as shown in Figure 4. In contrast, the cross-linked hydrogel film in Embodiment 1 can be peeled off from the silicon wafer surface in one go without any residue. After peeling, it only needs to be simply washed with water, and no obvious defects are observed on the surface of the silicon wafer.

[0047] Comparative Embodiment 4

Comparative Embodiment 4 was the same as Embodiment 1 under the same conditions, except that no polishing accelerator was added in Comparative Embodiment 4.

[0048] A microscopic photograph of Comparative Embodiment 4 without added polishing accelerator is shown in Figure 5. It has a large area and a large number of irregular defects on the surface of crystalline silicon. These defects cause light scattering, thus forming the hazy defects in the photograph.

[0049] Comparative Embodiment 5

Comparative Embodiment 5 was the same as Embodiment 1 in all other conditions except that no polishing accelerator or viscosity modifier was added in Comparative Embodiment 5.

[0050] According to the measurement, the viscosity of the polishing gel in Embodiment 1 at 25°C before curing is about 2400 poise, which has high spread ability. At the same time, it does not flow randomly after spreading, thus forming a gel layer with a certain thickness (10 mm in Comparative Embodiment 1).

[0051] In Comparative Embodiment 5, since no viscosity modifier was added, its viscosity at 25°C was about 1400 poise. After being laid flat, it would flow over time, resulting in a reduction in the thickness of the same gel layer (the thickness of the same amount of gel used was only 5 mm), which may lead to a weakening of the polishing effect.

[0052] Comparative Embodiment 6

Comparative Embodiment 6 uses a liquid polishing slurry to polish silicon wafers. The formula of the polishing slurry is as follows: 15 parts sodium ethoxide, 3 parts hexamethyl diammonium hydroxide, 2 parts polishing accelerator (sodium fluoride), 0.6 parts surfactant (sodium stearyl glutamate), and 100 parts water.

[0053] The effective components in Comparative Embodiment 6 are the same as those in Embodiment 1 in terms of both the effective components and their content. The difference is that Comparative Embodiment 5 is in liquid form, while Embodiment 1 is in gel form.

[0054] The process parameters of the two are compared in the following table:

Project	Embodiment 1	Comparative Embodiment 6
Polishing temperature	65°C	65°C
Polishing time	900s	240s
Surface structure dimensions	~16μm	~7μm
Surface reflectivity	~45%	~32%
Defects	No obvious defects	The surface has a large number of pits with a diameter of 2 to 5 μm.

The data in the table above, combined with the microscopic photographs in Figure 6 (Comparative Embodiment 6), show that compared to polishing slurry, polishing gel using the same polishing agent, besides extending the polishing time, also introduces numerous defects to the silicon wafer surface, as can be seen from the figure. Therefore, silicon wafers polished with the polishing gel of this invention exhibit significantly better surface reflectivity and fewer surface defects compared to silicon wafers polished with polishing slurry.

[0055] In summary, the present invention employs a fine polishing method for crystalline silicon surfaces based on alkaline polishing gel, replacing the traditional polishing method using polishing slurry. The crystalline silicon wafer polished with the polishing gel has higher surface reflectivity and fewer surface defects, providing a solid foundation for improving the photoelectric conversion efficiency of solar cells and reducing EL defects. Simultaneously, applying direct current during the polishing process can effectively improve polishing efficiency and significantly reduce polishing time.

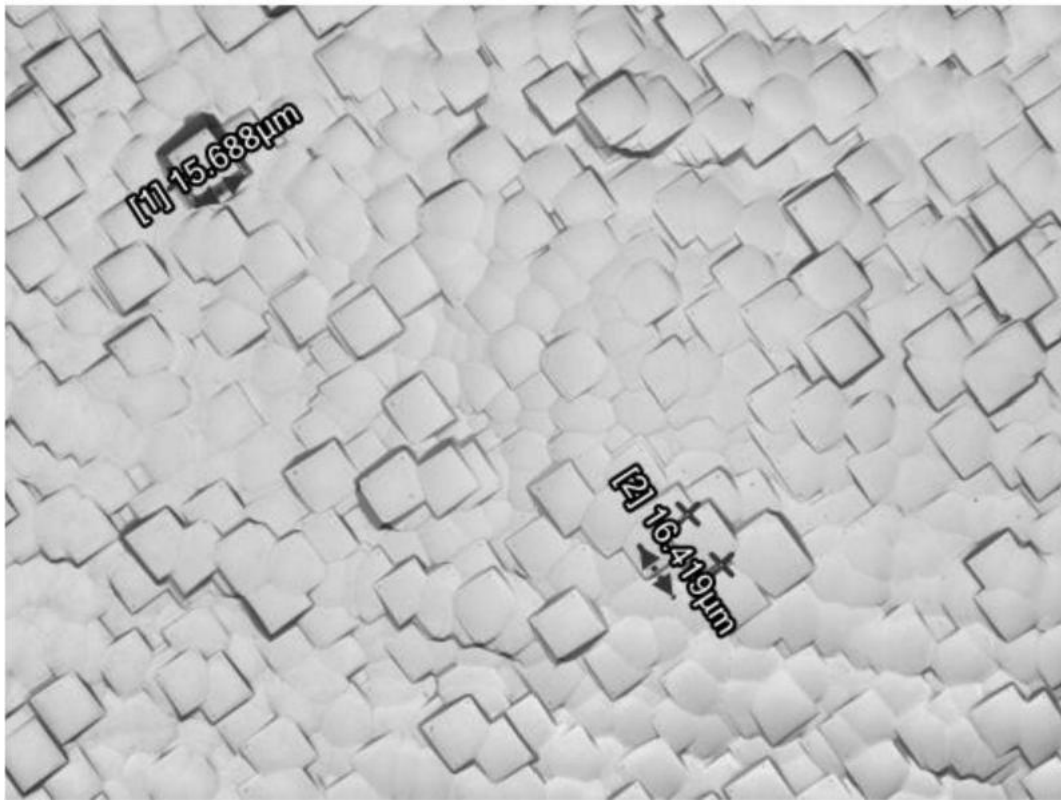


Figure 1

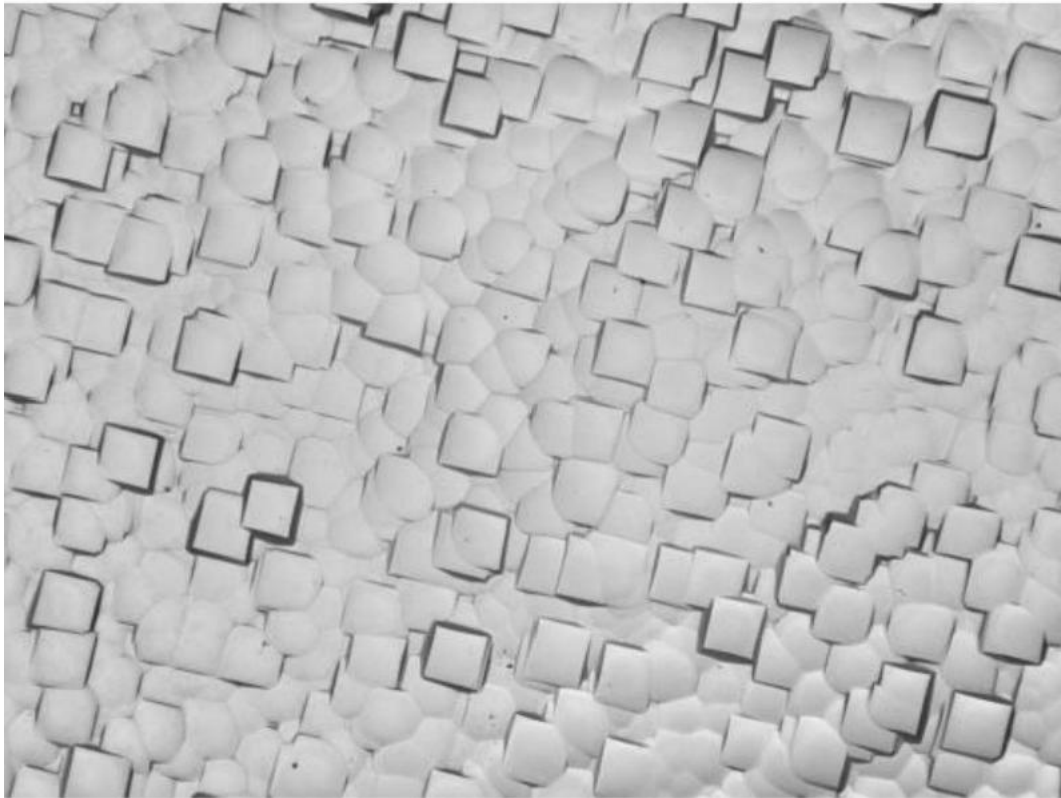


Figure 2



Figure 3

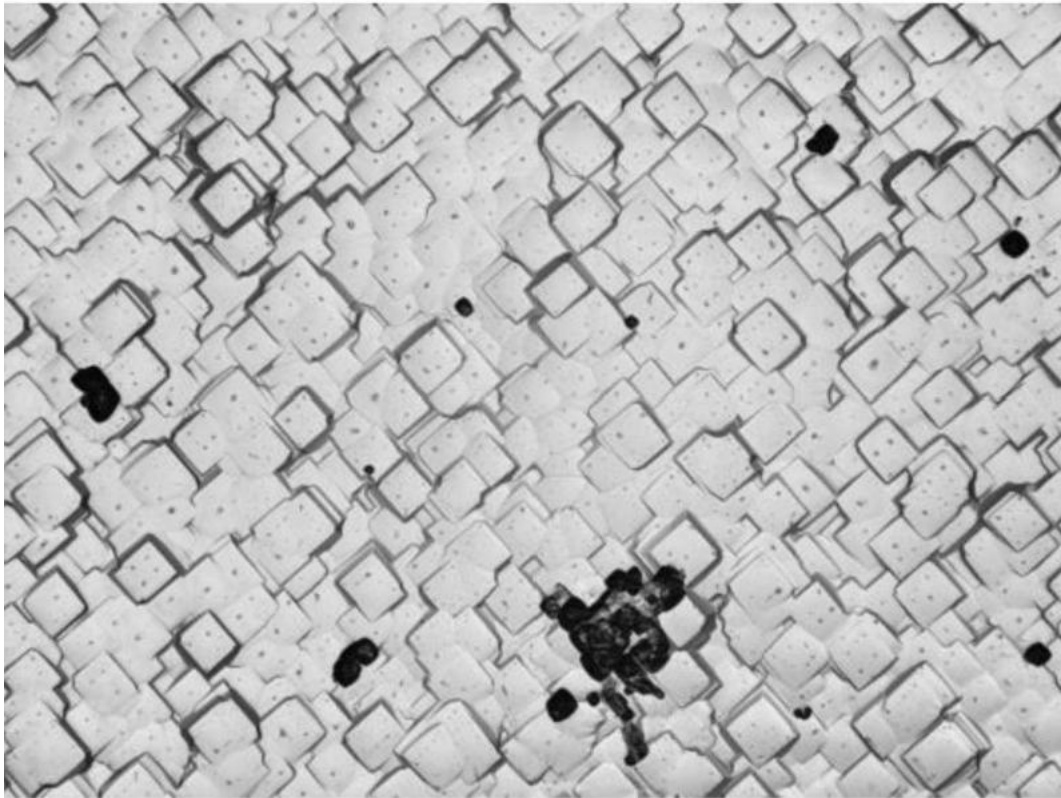


Figure 4

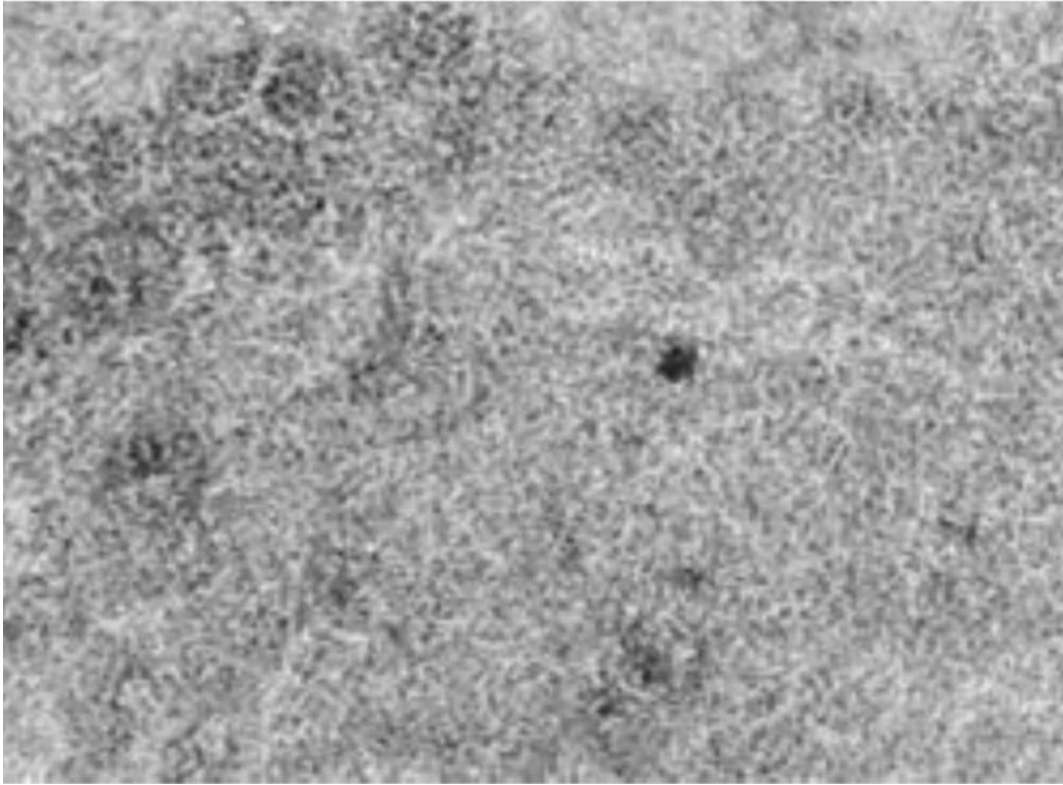


Figure 5

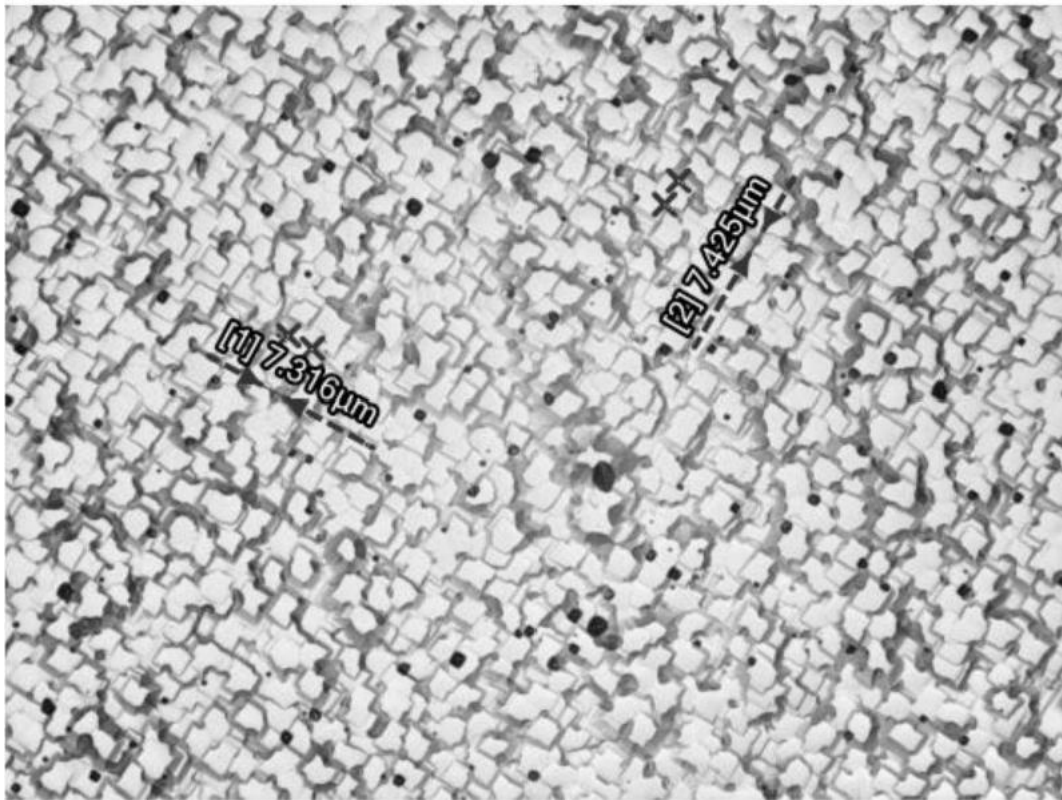


Figure 6

CERTIFICATE OF ACCURACY

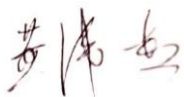
Attached as Ex A is the original document identified as patent application number CN111690987A and attached as Ex B is the translation of the original document from Chinese to English.

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

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)

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

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