

# Selective laser melting of metal foils for ultrathin patterned contacts in silicon solar cells

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# Selective Laser Melting of Metal Foils for Ultrathin Patterned Contacts in Silicon Solar Cells

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**Abstract.** The vast majority of today's solar modules are produced using screen printing of silver pastes, which places a heavy burden on the supply of this increasingly expensive metal. The expected growth in photovoltaic electricity generation requires alternative metallisation techniques that minimise or eliminate the use of silver, which today accounts for up to one quarter of the non-silicon cost of cell production. To address this pressing need this work describes a novel way of producing silicon-metal interfaces via selective laser melting of foils. We apply the recent innovations of laser assisted additive manufacturing of metals to the production of finger contacts in silicon solar cells. We demonstrate that fingers as thin as 15  $\mu\text{m}$  can be laser melted and contacted to the surface of a textured and oxidised silicon surface, directly from a metal foil. We perform scanning electron microscopy and energy-dispersive X-ray spectroscopy measurements of these contacts to demonstrate the potential of this new technique. The process described here uses readily available metal foils, and low-cost, high-throughput laser equipment, which can be easily integrated into the manufacture of PERC-like device architectures. The implementation of this metal printing technique could lead to an extremely promising new method of manufacturing ultrathin and high aspect ratio contacts for silicon solar cells.

## INTRODUCTION

The solar industry currently consumes a large portion of the global silver production. The expected growth in silicon photovoltaics cannot be sustained with the current levels of silver usage, or the dependence on market price fluctuations of such expensive metals. Metallization pastes using both silver and aluminium remain one of the most expensive materials used in the production of silicon solar panels [1]. Researchers and manufacturers are continuously looking to reduce cost without compromising cell efficiency, and current trends already estimate the need to reduce the amount of silver well below today's 90 mg/cell figure. Furthermore, as bifacial solar cells become prevalent efficient metallisation both on the front and rear of the cell may lead to even more Ag usage. This points towards the need for novel metallisation technologies that can reduce or eliminate such expensive paste consumption and reliance.

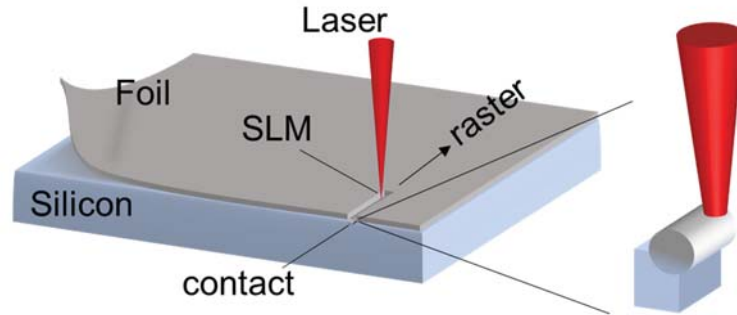
Copper has been often highlighted as a potential replacement candidate, primarily due to the cost and low resistance advantages [2]. Cu metallisation has had a long history in PV manufacturing, starting with the well-known laser-grooved buried contact cells from BP over two decades ago [3]. Most recently Cu plated contacts were also used in the production of Suntech's Pluto cell [4], or at the rear of SunPower's IBC cells [5]. Despite such developments Cu has not yet gained substantial traction as several hurdles remain: defects and recombination in Si, adhesion and reliability, and the cost-effective processing using plating equipment [6].

Recent advances in additive manufacturing and 3D printing of metals have opened new possibilities for the development of solar cell metallisation. In fact, a laser method of micromachining contacts for silicon cells via laser sintering was reported a decade ago [7]. However, it did not seem to gain interest presumably as it used silver powders similar to those in screen printing. In recent years, fast advancements have occurred in the development of laser technology, affordable optical components, computer vision, and positioning and tracking machinery. Such progress has contributed to an explosion in the applications of 3D printing of all types of materials. Selective laser melting (SLM) is just one of the available methods for additive manufacturing of metals. It involves the use of a high-power laser heat source which is directed and focused to a metal powder to melt it and fuse it to a substrate surface. This

SLM process facilitates the production of complex structures simply by programming the 3D coordinates that the laser must raster to melt and sinter the metal. In this work we leverage such advancements in metal additive manufacturing to demonstrate a potential new way of producing surface finger metallization for silicon photovoltaic devices.

## SELECTIVE LASER MELTING OF METAL FOILS

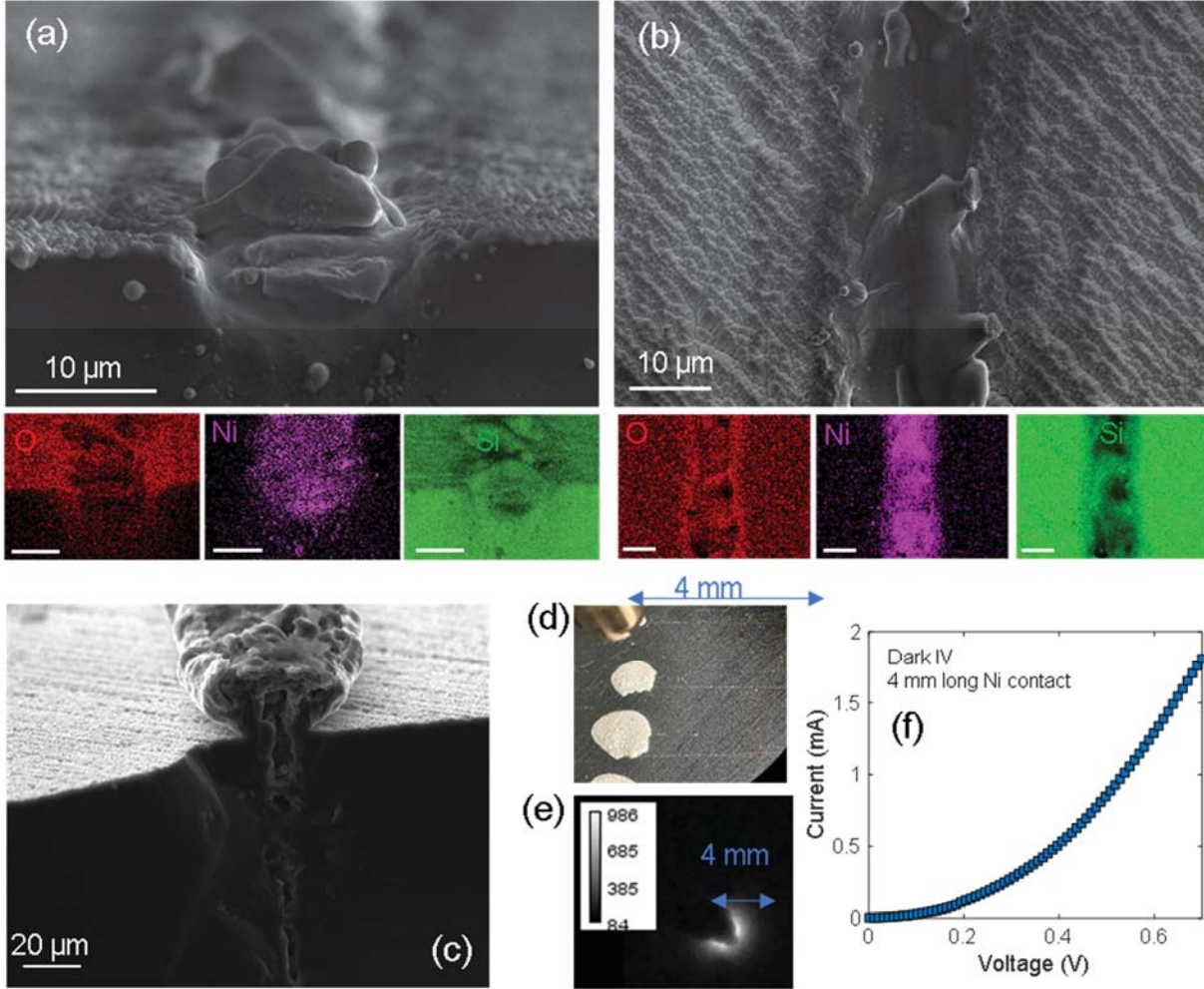
Here we have designed a SLM system that considers the complex interaction between the laser energy source, the metal melting, and the interface between a foil and a textured silicon surface. Key aspects of the system include the laser absorption and reflection from the metal surface, the interaction with silicon underneath, and the energy absorption distribution across the structure. Fig. 1 illustrates the experimental set up used to produce SLM of foils on top of a silicon solar cell precursor. Aluminum and nickel foils have been tested here, and a variety of laser parameters (power, repetition frequency, scanning speed, defocus) were tested to achieve the optimal melting and transfer onto the surface. It is to note that nickel, chromium, aluminium, and copper foils are all readily available and mass produced by industry at a competitive price, versus that of silver. Ag pastes often include an added price for the cost of developing the right formulation for firing, while metal foils are widely produced around the world. The design in Fig. 1 leverages the use of a foil form.



**FIGURE 1.** Schematic of selective laser melting of foils on the surface of a silicon solar cell.

## TOPOGRAPHY AND COMPOSITION OF METAL-SILICON CONTACTS

Metal fingers were produced on the top of a silicon cell precursor using SLM of nickel and aluminium foils. Fig. 2 illustrates the surface morphology and chemical composition of the SLM contacts fabricated. Fig. 2.a and 2.b illustrate cross section and plan view micrographs, respectively. At the bottom we have included an energy-dispersive X-ray spectroscopy (EDS) analysis of the chemical composition of the metal-silicon interface. Here it is evident that SLM of a Ni foil can produce contacts as thin as 15  $\mu\text{m}$ , readily producing a nickel silicide required as a copper barrier, and without generating laser damage. When the SLM optimal conditions are difficult to meet, for example in the use of Al foils, the process can induce substantial damage as illustrated in Fig. 2.c. Despite this damage Fig 2.c indicates the possibility of producing high aspect ratio structures when the foil-laser dynamics are optimised. The Ni contacts were then deposited with Ag paste contacts on top of the oxidised silicon surface, to facilitate a probe connection as shown in Fig. 2.d. These 4 mm long, 15  $\mu\text{m}$  wide contacts were tested using electro-luminescence as shown in Fig. 2.e, and IV measurements in the dark, Fig. 2.f. These tests indicate that the nickel finger is providing an effective contact to the phosphorous emitter underneath, as seen from the diode-like IV behaviour and *pn* junction luminescence under a forward bias current. Overall, this work demonstrates the exciting potential of this new technique for the production of metallisation in current and future production of silicon photovoltaics.



**FIGURE 2.** SEM micrograph in (a) cross-section and (b) plan view of a silicon surface including a SLM nickel metal contact of width  $\sim 15 \mu\text{m}$ , including EDS analysis of the oxygen, nickel and silicon detected. (c) SEM cross sectional micrograph of an SLM aluminium contact showing subsurface laser damage. (d) Optical microscopy photo of Ag contact dots on top of SLM Ni contact lines used for IV characterisation. (e) Electroluminescence photo of the region around the probe for a 100 mA forward current, colour bar shows the detector counts (f) Current-voltage characteristic of a single 4 mm Ni line contact.

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