Ion implantation in silicon solar cell research

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Silicon solar cell technology has advanced dramatically over recent decades. Since the year 2000, the cost of photovoltaic modules has decreased by a factor of 50, while their efficiency has increased from around 12% to up to 24% - approaching the theoretical limit of 29% for single-junction Si cells [1]. As a result of these continuing trends, many forecasts predict photovoltaics will become the single largest source of primary energy production globally by 2050, making it a crucial technology for the energy transition.

One of the most important enablers for modern solar cell performance has been a dramatic improvement in the electronic quality of the Si material itself. Unwanted metallic impurities, such as Fe, Cu, Ni and Cr, are very detrimental to Si solar cells. The concentrations of these impurities has been dramatically reduced over the past 20 years, to the point that today's industrial Czochralski-grown Si ingots have Fe concentrations below 10^{11} atoms/cm^{-3}, or less than 1 Fe atom for every 10^{11} Si atoms! [2].

Courtesy of its unique ability to introduce very well controlled, but extremely low concentrations of select impurities into Si wafers, the ion implantation facilities at ANU have played a critical role in developing the methods that are now routinely used to measure such miniscule concentrations of Fe in Si [3].

However, even at concentrations as low as 10^{11} cm^{-3}, Fe can still negatively impact solar cell performance. Fortunately, the formation of heavily-doped regions on the surface of a solar cell, which is required to form the p-n junction, also provides a very strong 'gettering' effect, in which trace impurities are segregated into the heavily doped regions. This causes a further reduction of the Fe concentration by another 1-2 orders of magnitude – enough to be largely harmless to cell performance [4].

Our understanding of these critical gettering effects has been enabled by the extensive use of ion implantation at ANU over the past decade. The ion implanters continue to help us to understand the impact of other important metallic impurities in modern solar cells, such as Cu and Ni, which are expected to soon replace the more expensive silver in industrial solar cell metallization.

[1] International Technology Roadmap for Photovoltaic (ITRPV), 14th Edition, April 2023.
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[4] AY Liu, D Yan, SP Phang, A Cuevas, D Macdonald, "Effective impurity gettering by phosphorus-and boron-diffused polysilicon passivating contacts for silicon solar cells", Solar Energy Materials and Solar Cells, **179,** 136-41, 2018.