Nanostructured Anti-reflection Glass for Solar Panels

Final Report
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Executive Summary

Current use of fossil fuels for energy is not sustainable due to greenhouse gas (GHG) emissions and climate change concerns. Switching to sustainable energy sources, such as solar PV, demonstrably reduces GHG emissions.

Edgehog (the "Company") is commercializing invisible solar glass that boosts energy output of panels by up to 12%. The innovative nanotexturing of the glass surface eliminates wasted energy from reflection. Edgehog previously demonstrated the enhanced energy generation performance on small solar modules, such as for space applications. In this project, the nanotexturing treatment process was scaled up for larger pieces of glass suitable for solar panels. The successful scale-up demonstrated the same unique optical properties at the large scale, including anti-reflection properties for (1) the entire usable solar spectrum and (2) at all angles, especially at wide angles. Such a transparent surface allows for up to 25% increase in energy production at the beginning and end of the day when light hits the surface at a wide angle. The continuation of this project includes the deployment of such solar modules in the field for extended testing.

Edgehog's technology will enable more rapid adoption of solar PV. Utility-scale solar PV developers in Canada will benefit from: 1) an approximate 5% decrease in their Levelized Cost of Energy; 2) enhanced energy generation during shoulder periods of the day when the value of electricity is higher; and 3) a decrease in required number of panels, saving upfront capital costs. Roof-top and other foot-print limited installations will benefit from generating more energy on the same footprint due to flexibility in panel orientation where the enhanced panel will optimally accept light from all angles of incident light.

It is estimated over 125 GW of solar power will be installed every year for the next ten years, which equates to a $5.5 billion annual market for solar panel cover glass. Edgehog is targeting 38 GW of installations within the first 5 years via partnerships.

For eluminar™-equipped panels installed within the first 5 years, GHG emissions are estimated to be reduced by 395 MtCO2e over their 25 year lifetime. Assuming Edgehog's technology becomes widely adopted, annual GHG emission reductions only by the additional energy that Edgehog creates could reach 193 MtCO2e/year by 2050.

The Project has successfully demonstrated the scale up of Edgehog's eluminar™ glass technology and processes from the previous 10 cm diameter size limit to a glass sheet of 37x47 cm size (commonly known as Gen 2 in display manufacturing). A laboratory was setup with the necessary equipment to develop the "recipes" for nanotexturing the 37x47 cm glass, performing initial durability testing of the technology, and developing a process for soda lime glass. Soda-lime is the desired material in the solar panel manufacturing industry for panel manufacturing, and facilitates the transition of the masking process from 10 cm diameter to 37x47 cm on the soda-lime substrate.

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Introduction

This report provides a final account of the project Nanostructured Anti-reflection Glass for Solar Panels undertaken by Edgehog Advanced Technologies Inc. The project took place from October 2020 to March 31, 2022.

The purpose of this project was to scale up the fabrication substrate size for Edgehog's eluminar™ glass, a unique nanostructured anti-reflection cover glass, for subsequent integration into solar PV modules.

As a result of the Project, the solar cover glass will subsequently be integrated into mini solar modules and used for extended field testing and certification under standard environmental durability testing.

The team relied on internal know-how and external partnerships to achieve these steps. Support from the Energy Innovation Program was crucial in de-risking the development of the technology for solar deployment, including the enablement of access to equipment and facilities required for the process development. In the process, Edgehog continues to develop internal expertise for achieving solar glass implementation, a key aspect of its intellectual property strategy.

Background

Edgehog had already scaled up the size of treated glass from 5 cm (original lab scale) to 10 cm wafers used in the space industry. It has simulated the impact of this technology on global solar installations using measured optical data and obtained third-party measurement validation for the enhanced solar output.

Edgehog eluminar™ glass competitive advantages include:

- <0.1% reflectance at normal incidence and maintains functionality at wide angles;
- water-repelling (super-hydrophobic) which gives it self-cleaning properties; and
- ultra-durable under extreme UV condition because unlike coatings, the textured surface does not contain any foreign material susceptible to UV degradation.

For eluminar™-equipped panels installed within the first 5 years, GHG emissions are estimated to be reduced by 395 MtCO2e over their 25 year lifetime. Assuming Edgehog's technology becomes widely adopted, total GHG emission reductions could reach over 193 MtCO2e/year by 2050. The baseline scenario is where solar panels are installed with conventional anti-reflection coatings. The emission reduction is calculated based on the displacement of grid electricity by extra solar energy generation due to Edgehog's eluminar™ surface treatment.

Objectives

The project builds on prior demonstrations enhanced solar module performance using Edgehog's nanotextured glass. This was done for space solar modules using space glass and also for fused silica glass mounted on individual terrestrial solar cells. The objectives below matures the technology to address terrestrial solar panels where one piece of glass is laminated onto and protects multiple solar cells.

The Project successfully delivered on its two primary objectives of:

1) scaling up the fabrication substrate size of the masking process for Edgehog's eluminar™ glass for subsequent etching scale-up and integration in mini solar modules used for extended field testing and certification under standard environmental durability testing; and

2) applying its technology and processes to low-iron, soda-lime glass, most typically used in the solar PV module industry. At the beginning of the project, the process was originally optimized for fused silica glass, a form of glass containing few additives, thus necessitating the need for development work to transfer the process to solar glass containing other elements that resist the nanotexturing process. Apart of this project, Edgehog has also demonstrated the transfer of the texturing process on space solar glass composed of a borosilicate glass.

Project

Approach

Light reflection off the surface of solar panel glass represents significant energy loss. Such losses are at 4-5% in the middle of the day but can be as high as 50% in the beginning and end of the day when light hits the glass surface at wide angles from normal incidence. While conventional anti-reflection coatings reduce such reflection by 1-2% for the majority of angles, it lacks the ability to compensate for the large losses at the wide angles. Edgehog utilizes a completely different anti-reflection mechanism with the unique property to increase transmission at all angles. Where conventional anti-reflection coatings add one or more layers of thin film material on the surface of the glass, Edgehog's nanotexturing approach simply creates nano-sized textures into the glass substrate itself. Edgehog's nanostructured glass approach allows energy gains of up to 25% during mornings and evenings.

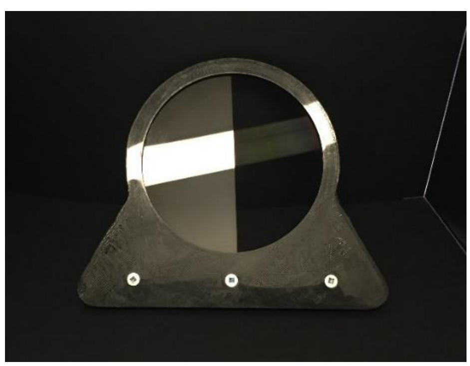

Figure 1 (left) – Glass substrate in front of a black background. Left half of glass piece is conventional glass showing reflection of the ceiling light. Right half of the glass piece is enabled with Edgehog's anti-reflection technology, and is completely clear, transmissive, and effectively invisible.

Figure 2 (right picture) – Here, the same glass substrate shown in Figure 1 is mounted on a solar cell. The left half, conventional glass, shows the reflection of the sky (wasted energy). The right half appears black appearance because all light is transmitted into the solar module and converted into electricity.

Reflection off any surface occurs because of the abrupt change in the index of refraction from one medium to another. Conventional thin-film surfaces counteract this effect by deposition layers of material in the low hundreds of nanometer range, causing a destructive interference effect at specific wavelengths of light. Many layers are required to create anti-reflection across the broad spectrum used by solar cells. Furthermore, thin-film technology does not address the issue of significant reflection at wide-angles.

For the Edgehog nanostructured approach, <100nm features are etched directly into the surface of the glass. This effectively creates a "fuzzy" layer on the surface that eliminates reflection at all angles (Figure 3). In greater detail, because the structures are much smaller than the wavelength of light, an averaging effect occurs over the cross-sectional area of the structures. One can imagine a simplified model consisting of an array of nano-size pyramids at the surface of the substrate, where the pyramids are composed of the native glass substrate. When light hits the glass, it does not "see" individual pyramids due to their small size. Instead, it "sees" an average of a large cross-sectional area composed of many pyramids. When the light hits the top layer or the tips of the pyramids, that cross-sectional area is primarily composed of air and a bit of glass (the tips of the pyramids). That top layer thus has an effective refractive index very close to that of air. As the light travels lower down the pyramids towards the base, the proportion of glass increases, thus creating a gentle increase in the index. Because there is no sudden change in the index of refraction, there is also no reflection. This gradient is observed no matter what wavelength or angle the light hits the surface, thus creating a unique anti-reflection surface that eliminates reflection for all colors of light at all angles.

Figure 3 (left graph) demonstrates superior light transmission of eluminar™ fused silica glass for all wavelengths at normal incidence compared to untreated glass and the performance of KhepriCoat® coating as documented in public reports [1]. It is calculated for light passing through the entire piece of glass (two interfaces: air to glass, and glass to air). Figure 3 (right graph) demonstrates the superior angular performance of all wavelengths of light, transmitting into the glass (single interface) for eluminar™ glass compared to KhepriCoat® porous silica AR coating [1], ISTN nanoparticle for anti-reflective surfaces [2] and idealized untreated glass using Fresnel reflection.

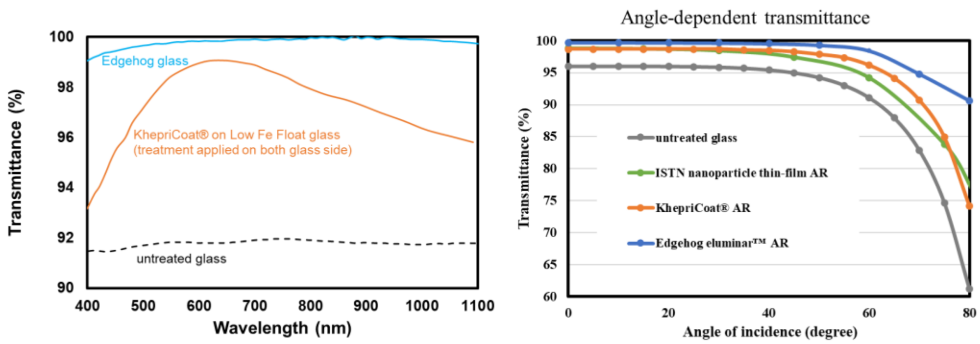

Figure 3 *– Left: light transmitting through a sheet of glass (2 interfaces: air to glass and glass to air) for untreated glass (black), glass with double-side KhepriCoat® porous silica treatment (orange), and fused silica glass with double-side treated Edgehog eluminar™ process (blue). Transmission throughout the usable solar spectrum showing near 100% transmission for eluminar™ glass. Right: Light transmitting into glass (1 interface) at various incidence angles demonstrates the omni-directional effect of Edgehog eluminar™ glass compared to available competitor data.*

Project Results

The Project has successfully demonstrated the scaled-up Edgehog's masking process for eluminar™ glass technology from the previous 10cm diameter size limit to a glass sheet of 37x47 cm size (commonly known as Gen 2 in display manufacturing). A laboratory was setup with the necessary equipment to develop the "recipes" for masking the 37x47 cm glass, subsequently etching the masked glass to create a nanotextured surface, performing initial durability testing of the technology, and developing a process applicable for low iron soda lime glass. Low iron soda-lime is the desired material in the solar panel manufacturing industry for panel manufacturing, and facilitates the transition of the masking process from 10 cm diameter to 37x47 cm on the soda-lime substrate.

As a result of the Project, the solar glass will subsequently be integrated into mini solar modules and used for extended field testing and certification under standard environmental durability testing.

Description of Benefits

Greenhouse Gas Emissions

At Edgehog, we aspire to make an impact on climate change. Our path to that impact is through improving the efficiency of solar panels. The main environmental benefit of this project sits in the energy production gain from applying the Proponent's technology on new photovoltaic solar panels. The gain from the anti-reflection property of Edgehog glass is estimated to be between 6-12% depending on the geography and installation of the solar panels. There will also likely be an additional 2-3% of annual energy gain due to the self-cleaning property of our glass. Higher energy gains will lead to further GHG reduction where solar PV electricity generation replaces fossil fuel and emitting sources.

This grant has paved the way for Edgehog to scale up the dimension of its glass manufacturing by contributing to creating the facilities required for the scale-up. This enables Edgehog to create large glass pieces that can be used as cover glass for solar panels that can be tested in the real environment. At the completion of this project, Edgehog has shown the feasibility of the scale-up and will implement the knowledge to make large glass. At the next step, we will then integrate Edgehog glass onto solar panels with our Canadian partners and test the product outdoor in Canada in our partners' facility. We estimate that we will reduce the GHG emission by 32 Mega tonnes per year by 2035.

To calculate the GHG emission reduction, we have assumed that the extra power generated on the solar panel using Edgehog technology displaces grid energy. The baseline scenario is where solar panels are installed with conventional anti-reflection coatings. The emission reduction is calculated based on the displacement of grid electricity by extra solar energy generation due to Edgehog's eluminar™ surface treatment. Grid energy is assumed to generate 0.150 tonnes GHG per MWh. For every MW solar panel installation, adding Edgehog technology onto the panel creates an additional 1,751.515 MWh each year. This results in 262.727 tonnes of GHG emission reduction per 1 MW of solar panel installed every year. Assuming a moderate adoption rate of Edgehog technology on solar panels, and considering the accelerated growth of solar panels installed per year in recent years, Edgehog would save the equivalent of over 123 Mega tonnes by the year 2035. This is equivalent to the carbon sequestered by over 2 billion tree seedlings grown over 10 years.

Overall benefits

The Project has demonstrated that a Canadian-led team could adapt its advanced processes to successfully scale up the size of its nanotexturing process by utilizing commonly used equipment in the flat panel display industry. The Project also provided critical manufacturing insights on the scale-up process, which gives Edgehog the opportunity to improve the technology and correct any weaknesses following subsequent in-field trials and testing and bring them much closer to commercialization. Cost analysis and efficiencies were also noted and analyzed for each stage of this Project. The ultimate medium to long-term benefit is acceleration of solar PV in Canada and international jurisdictions. The Company's solar manufacturing partner assisting it in integrating the larger low iron soda-lime glass in solar PV modules for environmental, performance, and durability testing may see growth opportunities for their manufacturing operations regionally and through export opportunities.

Benefits to Canada

The Project is important as it further develops Canada's capabilities to address ongoing GHG emissions reduction strategies by deploying more energy capable solar PV modules across the country, particularly in northern areas where the sunlight's angle of incidence may be sub-optimal for non-Edgehog equipped solar PV modules.

Canada would be also able to produce higher energy-generating solar PV modules to address global market needs while mitigating impacts to the environment.

After Project completion, continued development work in field testing and ultimate integration in solar PV module, the Project is also expected to create highly qualified personnel (HQP) permanent positions in Canada, specifically in STEM and other support roles.

Finally, since the technology is expected to increase energy production in the winter without the use of expensive and high-maintenance sun tracking systems, it has the potential to accelerate adoption of solar PV in Canada's northern and remote communities.

Conclusion

The primary focus of the Project was to determine the technical feasibility of transitioning the Company's existing technologies for the nanotexturing of specific glass substrates for the purpose of scaling up to glass sizes and specific glass substrates used for evaluation in the solar PV module industry.

The Project investigated and utilized technologies, cost-effective scenarios, and potential future endeavours that will likely assist in the Company in commercializing its technology. The results of the Nanostructured Anti-reflection Glass for Solar Panels Project concluded that the Company's core technologies and processes could be successfully "ported" over to "off-the-shelf" equipment capable of nanotexturing larger glass substrate sizes and the Company expects the cost of implementing the technology to be well in-line with cost expectations.

In addition to successfully demonstrating the size increase in the glass substrate, the Company has shown it can also successfully nanotexture low iron soda-lime glass that is typically used as cover glass in almost all solar PV modules. The technology readiness level did progress to TRL5 through the Project and the findings have provided valuable information to consider for future design and necessary equipment specifications.

Therefore, the Project substantially completed its stated objectives and the Company has shown its technology can scale up in size and has de-risked any issues with glass substrates used in the solar PV module industry. The Company expects to continue with next steps to integrate the scaled-up, nanotextured, low iron soda-lime glass into solar PV modules for long-term, in-field, environmental, performance, and durability testing.

Bibliography

[1] «KhepriCoat® - the best-performing anti-reflective coating for solar cover glass,» [En ligne]. Available: https://www.dsm.com/content/dam/dsm/dsm-china/zh_CN/documents/KhepriCoat%C2%AE%20brochure.pdf. [Accès le 2020].

[2] ISTN, «Low Temperature, Fast Curing Anti-reflective (AR) Coating,» [En ligne]. Available: http://www.istninc.com/ar_lowtemp.pdf. [Accès le 2020].