レーザーを用いた落氷雪事故防止技術に関する研究

Snow and Ice Accretion Fall Accident Prevention using Laser Technology

近年積雪寒冷地では、冬期間に案内標識、道路情報板、橋梁等に着氷雪が成長し、それらが落下することにより車両などに被害を及ぼす事例が発生しています。落雪を防ぐための着氷雪除去は、主に人力で行っているため作業の手間など、大変な作業です。そのため、着氷雪防止や効率的な着氷雪除去技術の開発を行っています。

Recently, road accidents have been occurring in cold, snowy regions due to accreted snow falling from road infrastructure such as road guide signs, information signs, and bridges. Snow accretions grow and fall, causing damage to vehicles passing on the road beneath. The removal of accretions has been done mainly by road maintenance personnel, requiring time and hard work. To improve the situation, we have been developing technologies for the prevention and effective removal of snow accretion from road infrastructure.

着雪事例
An example of snow accretion on a road structure

雪落とし作業
Maintenance personnel removing accreted snow

着雪とは
Snow accretion

雪が物体に付着する現象、あるいは付着した雪のことです。送電線、アンテナ、航空機、鉄道車両、標識板、信号などの着雪があり、それぞれ対策が考えられています。着雪は、湿型着雪、乾型着雪に分類されます。

Snow accretion refers the phenomenon of snow accumulating on structures, or to the snow blocks that are attached to objects. Snow accretion occurs on various structures, including transmission lines, antennas, aircrafts, railway cars, sign boards, and signal lights. Measures for preventing or removing snow accretion are used by the administrators of such facilities. Snow accretion is classified into wet snow accretion and dry snow accretion:

湿型着雪 含水量の大きな雪片が物体に付着して発生する着雪で、気温0℃付近で発生して風速が大きいほど着雪の密度が大きくなる

乾型着雪 含水量の小さな雪片が物体に付着して発生する着雪で、気温-2℃以下で弱風でも発生し、着雪の密度は小さく付着力も小さい

Wet snow accretion Wet snow accretion occurs when a block of snow with high moisture content attaches to an object. Wet snow accretion starts to occur when the air temperature is around 0°C, the density of accretion becoming higher with an increase in the wind speed.

Dry snow accretion Dry snow accretion occurs when snow with a low moisture content attaches to an object. Dry snow accretion occurs when the air temperature is -2°C or lower and the wind speed is low. The density and adhesion of accreted dry snow is small.

着雪・落雪対策の分類
Classification of measures against snow accretion and the prevention of falling snow blocks

着雪・落雪対策

- ○難着雪法・・・雪を付着させない
  - 形状変更・・・雪が付着しにくい構造
  - 性状変更・・・雪が付着しにくい性質
- ○付着した雪を取り除く・・・着雪除去法
  - 機械的除去・・・強制的に着雪を取り除く
  - 融解除去・・・着雪を融かす
- ○落雪防止法・・・付着した雪を落下させない

Classification of measures against snow accretion and the prevention of falling snow blocks

- Accretion retardation methods: methods to prevent snow from attaching to structures
  - Changing the shape: Utilizing structures on which snow accretion do not easily occur
  - Changing the properties: Utilizing materials on which snow accretion does not easily occur
- Snow removal methods: methods to remove snow accretion from structures
  - Mechanical removal: Removal of snow accretion by force
  - Melting removal: Removal of snow accretion by melting with heat
- Fall-prevention methods: Preventing accreted snow from falling off structures

レーザー撥水表面付与技術による着雪防止
Prevention of snow accretion by using laser technology that creates a water repellent surface

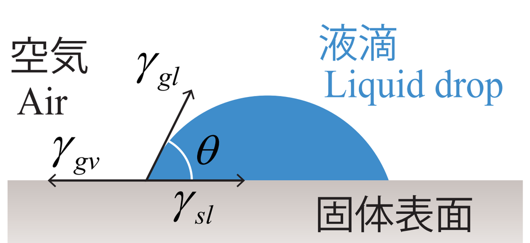
撥水表面加工で雪が着きにくい、または着雪が成長しにくい表面を人工的に超短パルスレーザーで作製する方法に挑戦しています。

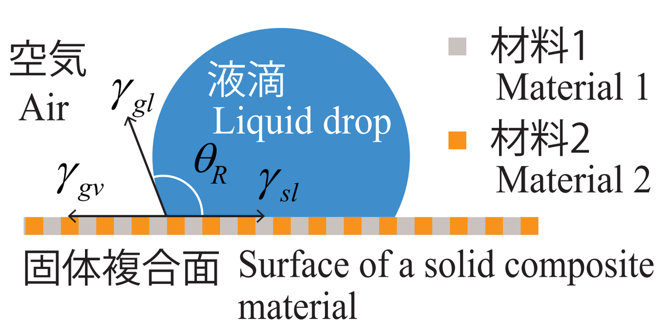
We have been developing a surface processing technology that uses ultrashort laser pulses. By using this technique, water repellent (superhydrophobic) properties are produced on the surface of structures. Therefore we expect that snow will not easily attach to the surface, or that snow accretion will not easily grow on the surface.

蓮の葉の表面には数ミクロンの多重凹凸構造があります。このような凹凸構造を人工的に作製することにより撥水性が付与されることが解っており、世界中で研究開発が進められています。

In nature, the surface of a lotus leaf has micro or even nano-ripples, several microns in scale. Using this “lotus structure” model, it is possible to create artificial superhydrophobic properties on the surface of structures. R&D for creating such structures has been promoted worldwide.

撥水特性が付与されるメカニズム
Mechanism behind the creation of water repellance





表面張力の釣り合いから、以下の式が表現されます。

The following equation expresses this condition based on the balance in the surface tension.

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \cos\theta$$

- γ_{sv} 固気界面張力 Solid-gas interfacial tension
- γ_{sl} 固液界面張力 Solid-liquid interfacial tension
- γ_{lv} 気液界面張力 Gas-liquid interfacial tension
- θ 接触角 Contact angle

複合面（材料１、材料２）で構成される表面の場合は、以下の式で表現されます。

The following equation expresses this condition for a surface of composite materials (Material 1 and Material 2).

$$\cos\theta_R = f_1 \cos\theta_1 + f_2 \cos\theta_2$$

$$f_1 + f_2 = 1$$

- f_1: 材料１の面積比 Area ratio of Material 1
- f_2: 材料２の面積比 Area ratio of Material 2
- θ_1: 材料１の接触角 Contact angle of Material 1
- θ_2: 材料２の接触角 Contact angle of Material 2
- θ_R: 見かけの接触角 Apparent contact angle

f_2を空気とすれば以下の式になります。

When f_2 is assumed as air, the following equation is results.

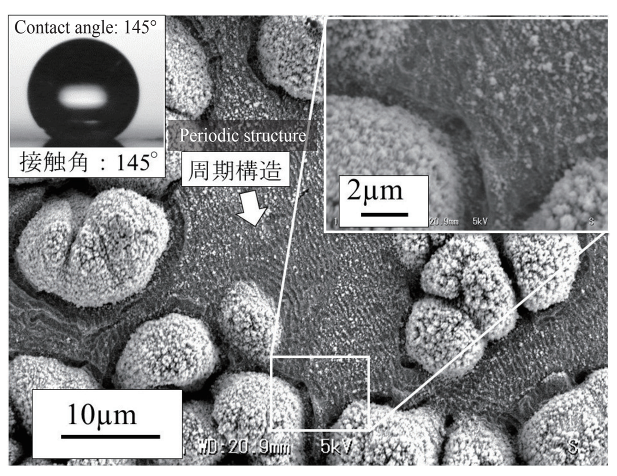
$$\cos\theta_R = f_1(\cos\theta_1) - 1$$

表面積 f_1を限りなく小さくすることで見かけの接触角θ_Rが変化し、場合によって撥水特性が発揮される（θ_Rが180°に近づく）ことが知られています。

It is known that, by making the surface area f_1 as small as possible, the apparent contact angle θ_R changes, and superhydrophobicity appears (θ_R approaches 180°) in some cases.

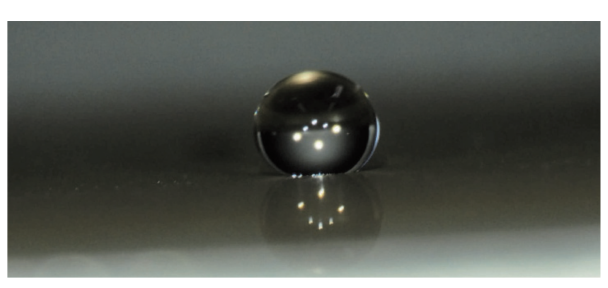
撥水特性が付与される理由は、凹凸の微細構造の凹面に空気の層があるためです。

A layer of air on the surface of the indentation of the minute uneven surface provides the superhydrophobic surface.



▲超短パルスレーザーを亜鉛めっき鋼板に照射すると、蓮の葉の表面に良く似た大小の多重凹凸構造が生成され、撥水性が付与されます。

When ultrashort laser pulses are emitted to a galvanized sheet, it creates micro or even nano-ripples, resembling the structures on the surface of a lotus leaf, and give the metal surface superhydrophobicity.



▲レーザー照射後の金属に載せた水滴がコロコロと転がります。

A water drop placed on the metal surface after laser irradiation rolls on the surface.

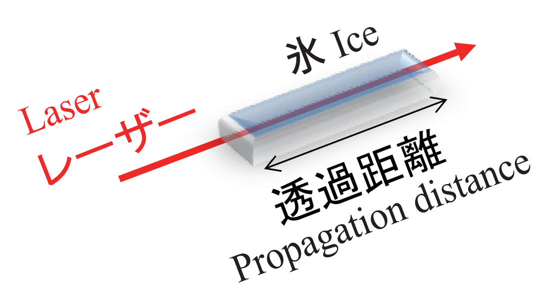
遠隔レーザーによる着雪処理
Treating accreted snow by using laser irradiation from a distance

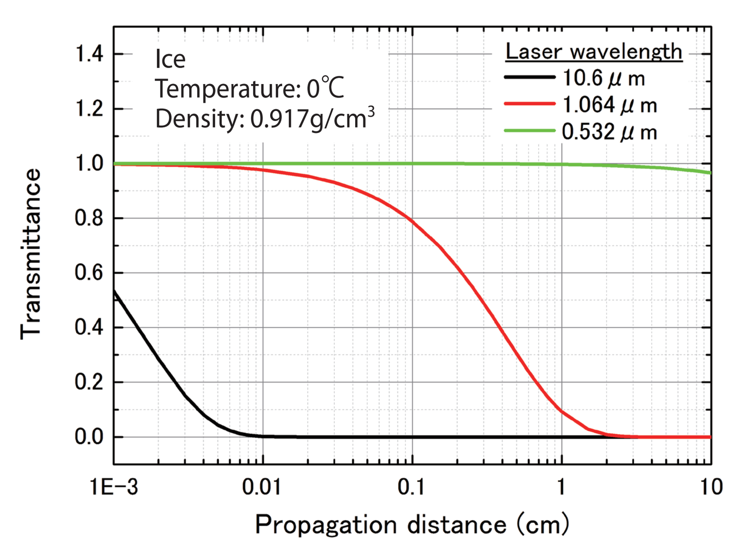
遠隔レーザーを道路付属施設等に照射することで、雪を効率的に融かす方法を検討しています。

We have been examining a method for effectively melting snow and ice on road structures by irradiating them with a laser beam from a distance.

氷は、光の波長によって透過する光の量が異なり、波長10.6μmの光を良く吸収します。

The amount of light passing through ice differs by the light wavelength. Ice readily absorbs light with a wavelength of 10.6μm.



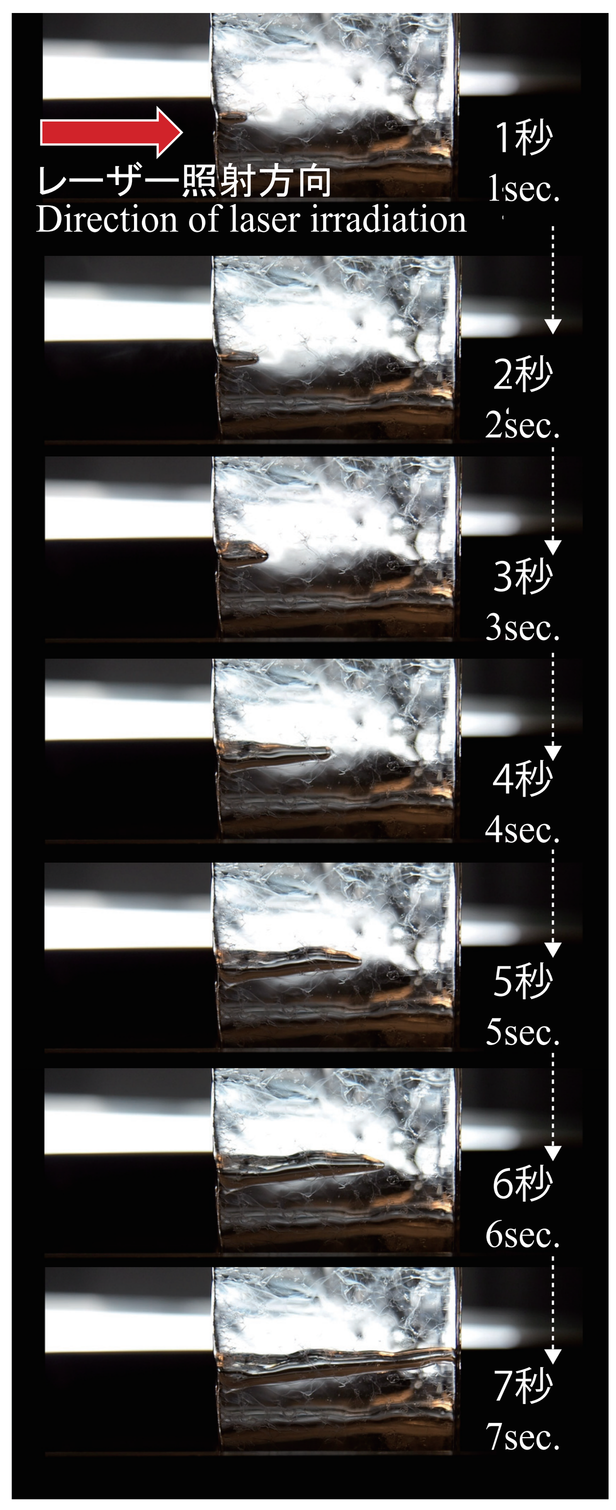


▲氷における光の透過距離（計算）

Light propagation distance in ice (calculated)

レーザーを氷に照射すると、波長によって氷内部を透過する距離が異なります。透過しない光はほぼ吸収されて熱にかわり、氷が融解します。

When a laser beam is used to irradiate ice, the propagation distance of the light in the ice differs by wavelength. The light that does not pass through the ice is absorbed by the ice, changing into heat and melting the ice.



▲波長10.6μmのレーザー（43W）を氷に照射したときの様子。

These photos show ice being irradiated by laser light with a wavelength of 10.6μm (43W).