# Advanced Materials in the field of Energy and Environmental Science

1. Rechargeable battery, secondary battery, rechargeable aluminium air battery, lithium ion battery for next generation
2. Fuel Cell (Solid Oxide Fuel Cell: SOFC, Polymer Electrolyte Fuel Cell : PEFC), Electrode, Solid Electrolyte, Electrolyte, carbon alloy catalyst as non-platinum catalyst etc…
3. Materials for solar cell (dye sensitized solar cell, perovskite solar cell, quantum dots solar cell)
4. Thermoelectric materials
5. Inorganic infrared light shielding (Absorbing) material (ATO, ITO, Tungsten based complex oxide)
6. Oxide Nanocolloids
7. Metal Nanocolloids, conductive silver ink, conductive carbon ink
8. Silver nanowire
9. Cellulose nanofiber
10. Carbon nanotube dispersion
11. Ionic liquid
12. Solid acid catalyst
13. Quantum Dots
14. Metal organic framework (MOF)
15. Visible light response photocatalytic material, materials for artificial photosynthesis
16. hydroxyapatite

## Rechargeable Aluminium Air Battery

Aluminium air battery has theoretical cell capacity of 30 - 40 times of that of lithium ion battery. So that if current EV can drive 400 Km with one time recharge, EV equipped with aluminium air battery should be able to drive 8000 – 12000 Km theoretically. Especially recently, I created rechargeable aluminium air battery with ionic liquid based electrolyte, and carbide, or nitride ceramic being used as air cathode, it was able to create rechargeable aluminium air battery with suppressed byproducts formation. Since byproducts such as $Al_2O_3$, $Al(OH)_3$ are the major electrochemical inhibitor for aluminum air battery, suppressing their formation during battery operation, by applying new

Coin cell type of aluminium air battery

materials, was a great achievement. Because of this discovery, rechargeable aluminium air battery can be practical sooner. This is the first time discovery in the world and this achievement was published in RSC journal, Sustainable Energy Fuels in 2017. Nowadays, we started to collaborate with other companies or research institute to make actual battery and test them since these research was performed with only handy made battery level so far. And we need to make actual battery in order to create our rechargeable aluminium air battery for industrial practical use. Company or research institute who can collaborate with us, are very welcomed.

Scientific published paper regarding aluminium air battery from our company.


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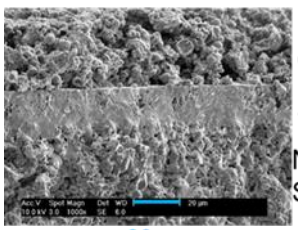
And presented at many other international conferences

## Electrode, solid electrolyte for lithium ion battery

General cathode and anode such as $LiCoO_2$, $LiMn_2O_4$, $LiFePO_4$, $Li_4Ti_5O_{12}$ etc… on top of those, we research on cathode with higher capacity, voltage such as $LiNi_{0.5}Mn_{1.5}O_4$、NMC(523, 622, 822), Li rich cathode, silicon based anode etc… also, we supply research on solid electrolyte such as LLTO, LLZO etc…

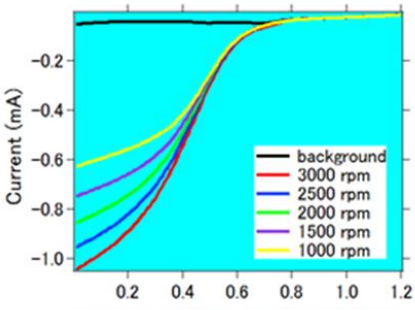
## Electrode, solid electrolyte for solid oxide fuel cell (SOFC)

We synthesize and supply electrode, solid electrolyte for solid oxide fuel cell (SOFC). We also synthesize these materials as customer desired chemical composition. We can make both powder and printing ink.



## Catalyst, electrode material for polymer electrolyte fuel cell (PEFC) non platinum catalyst material Carbon Alloy Catalyst

We research on and sell non-platinum catalyst such as carbon alloy catalyst for polymer electrolyte fuel cell (PEFC). This type of catalyst can be applied to metal air battery as well since the cathode reaction of metal air battery is also oxygen reduction reaction as PEFC. We are also planning to develop separator, electrolyte materials for PEFC.




Catalytic measurement of carbon alloy, Current against voltage (rotation speed dependent)

## Materials for dye sensitized solar cell, perovskite solar cell, quantum dots solar cell

$TiO_2$ ink, oxide ink for anode, carbon material based ink for counter electrode, precursor materials for perovskite layer, various types of quantum dots materials for perovskite, quantum dots solar cell.

## Thermoelectric materials

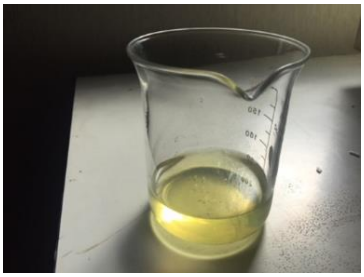
We research and supply thermoelectric materials. Especially we focus on oxide based materials for thermoelectric technologies.

## Inorganic infrared light (heat) shielding material (ATO, ITO, Tungsten based complex oxide)

Organic materials are weak to sunlight so that we focus on making inorganic infrared light shielding material. We synthesize Antimony Tin Oxide (ATO), Indium Tin Oxide (ITO) and tungsten based oxide complex materials as infrared light shielding materials. We also disperse our synthesized powder materials into nano size dispersion in water. Also, in various types of organic solvent such as alcohol, ketone, toluene, glycol ether, acetate etc… as customer requests. We also started to mix our infrared shielding materials into resin to make masterbatch. Tungsten based complex materials absorb more near infrared light region compared to ATO and ITO, and also potentially can be cheaper. Nano size dispersed infrared light shielding material can let visible light go through whereas absorb only infrared light. Therefore, this is very environmentally friendly products by lowering the temperature of room inside of the building especially in the summer, by coating or mixed into the window, for example.

## Oxide nanocollids

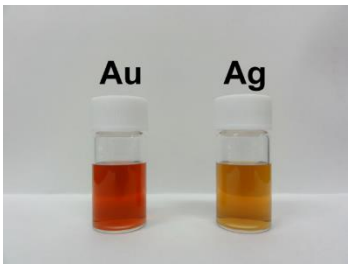
When the size of metal, semiconductor or oxide materials becomes in nanometer range, they start to show interesting unique physical and chemical behavior based on their quantum size effect. For example, nanometer sized materials have higher catalytic effect or optical properties etc… By utilizing this unique quantum



$CeO_2$ Nanocolloids (particle size: 1 - 2 nm)

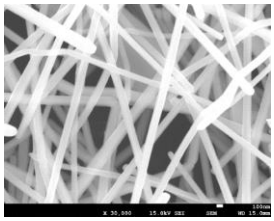
size effect on materials, nanometer sized oxide materials can be applied to UV absorption, infrared light absorption, electro luminescent, various types of functional coating, solar cell, rechargeable battery, fuel cell, fluorescent materials, catalysis, gas absorption, magnetism, sensor, cosmetic and for bio medical use and so on. Our company prepare nanometer sized $TiO_2$, $Al_2O_3$, $ZrO_2$, $CeO_2$, $WO_3$, $Nb_2O_5$ and ZnO etc…and other requested materials by customer. We make these oxide nano collioids by dispersing or synthesizing.

## Metal nanocolloids (Ag, Au, Pt other metal), Ag nanoink, Ag Nanowire



Metal Nanocolloids (particle size 1-2 nm)

Metal nanocolloids (less than 10 nm) have different unique optical, electronical, magnetic and catalytic behavior compared to its bulk sized metal materials based on their physical property called surface plasmon effect. Ag nanocolloids have anti-bacterial effect, Au nanocolloids have can be catalytic and bioimaging materials. Pt nanocolloids have anti-bacterial effect and also can be applied as cosmetic materials. Ag nanocolloids can be conductive ink when size is modified in the appropriate larger size. We have made Ag nanocolloids ink for pen. We can write on paper, plastic, ceramic, glass and make them conductive when those written parts were heated over 80 C°. In addition, we have also succeeded in making Ag nanowire based on our metal synthesis technology.


Silver Nanowire

## Cellulose Nanofiber : CNF (Nano Cellulose)

Cellulose nanofiber (nano cellulose) is the nanometer sized highly advanced materials made from cellulose which is the main component of plants and woods. Raw material of cellulose nanofiber is tremendous because they can be obtained from all woods and plants on this planet. Also they are very environmental friendly due to recyclability and they can be cheap. Cellulose nanofiber has also biodegradability to some extent. The major application is the plastic mixed masterbatch with expected mechanical strength improvement and weight saving. PE, PP, PLA, PVC, acrylate, PET, PBT and other plastics can be cellulose nanofiber mixed masterbatch. We in fact made PE, PP, PLA nd acrylate masterbatch with higher mechanical strength when mixed with our CNF. We also supply cellulose nanofiber (CNF) in water dispersion, also, in various types of organic solvent such as alcohol, glycol ether base, ketone, acetate, toluene, NMP and many other


Test pieces of CNF mixed PE, PP

organic solvent as customer request etc… In addition, we also manufacture CNF with hydrophobic chemical group on surface. This CNF should have good compatibility with hydrophobic resin and organic solvent when mixed, because normally CNF have high hydrophilic nature due to their essential existence of -OH group. Due to large surface area and absorbing ability of CNF, their application also expands to cosmetic, bio medical use, paint, ink, battery separator, anti friction, viscosity increaser, catalytic support etc…

## Carbon nanotube dispersion

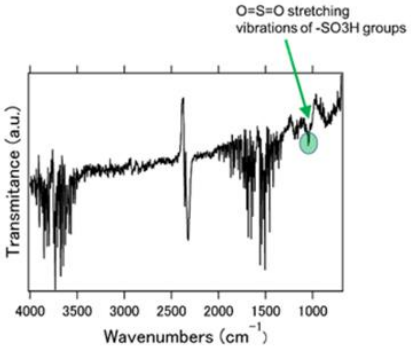
We prepare carbon nanotube dispersion ink (single wall, multiwall) in water, and various type of organic solvent including alcohol, ketone, NMP, glycol ether, toluene, acetate and many other organic solvent as customer requests. Carbon nanotube conductive ink can be advantageous compared to general conductive carbon one when printed area stretches, due to their elongated shape which would hold conductivity when stretched. They have been also researched in terms of strong black color hue and mechanical strength etc…

## Ionic Liquid

Ionic liquid is the new materials and defined to be the 100 % liquid salt under 100℃. They referred as designer solvent or third liquid on earth next to water and organic solvent since the variation of ionic liquid can be tremendous because they can be synthesized by numbers of combination of numerous numbers of cation and anion species. Ionic liquid exists as liquid and can be used at wide range of temperature range from low temperature to high temperature. They are thermally, chemically, electrochemically stable, not flammable and vapor pressure is very low. In addition, they can dissolve which normal solvent can not dissolve such as cellulose. Therefore, their application can be anti-statics, electrolyte, wetting chemical under high temperature or vacuum condition. Also ionic liquid could be reactant solvent for organic synthesis, and $CO_2$ absorber etc…

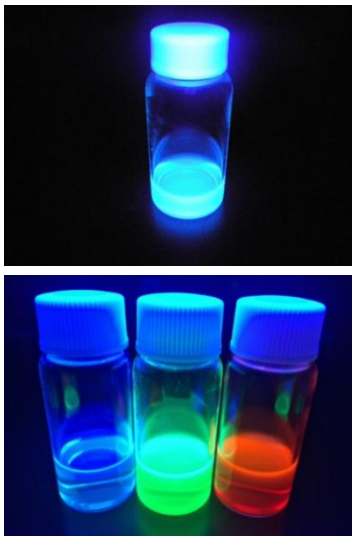
## Solid Acid Catalyst

Acid catalyst such as sulfonated acid, is the indispensable catalyst for oil refinery, raw materials for various types of chemical, pharmaceutical products, and catalyst for bio fuel such as bio ethanol, bio diesel. However, sulfonated acid can not be recycled and needs to be separated from products by any means such as neutralization. Hence, over 15 million tons of sulfonated acid is consumed per year as non recyclable catalyst which burdens the environment because of huge quantity of energy usage and waste. In this regard, solid acid can be collected by such a process as filtration and can be reused again. Already existed solid acid




Sulfon group can be confirmed by IR spectra of carbon based solid acid catalyst

catalyst are zeolite, meso porous materials, hetero poly acid and sulfonated zirconia etc… Among them, mostly known solid acid catalyst is the amberlyst although they are very expensive and have difficulty as becoming large quantity catalyst for industrial use. Therefore, we especially focus on new types of solid acid catalyst as carbon based solid acid catalyst as they can be cheap in the end since raw material is abundant and also have high catalytic activity.



Graphene quantum dots (upper)
Perovskite quantum dots(lower)

## Quantum Dots

Quantum Dot is the nanometer sized crystal with specific optical properties originates from the phenomenon which can be explained by the quantum chemistry and quantum mechanics. They are extremely small with general size range of 1 - 9 nm and possess 10-10000 atoms or molecules in each particle. Band gap can be modified by controlling the size of colloidal nano crystal. The concept of energy level, band gap, conduction band, valence band can be applied to normal bulk sized semiconductor except one clear difference. When the particle size of semiconductor becomes closed the size of Excition Bohr Radius, electron energy level losses its continuity and becomes separate, namely small separation can be observed among energy level. This separated energy status is called quantum confinement and semiconductor materials becomes no longer bulk status but “quantum dot” status. Therefore, they exhibit specific luminescence emission light properties depending on the particle size. We have semiconductor based quantum dots (InP/ZnS, PbS, CIS, CIS/ZnS etc…), graphene quantum dots, carbon quantum dots, silicon quantum dots, perovskite qua ntum dots etc… Quantum dots can be applied to quantum dots sola cell, bio medical imaging, displays, laser, thermoelectric devices, artificial photosynthesis, various type of electronics devices, quantum dots computer etc…

$$E\psi(x) = -h^2/2m\, d^2\psi(x)/dx^2 + U(x)\,\psi(x)$$

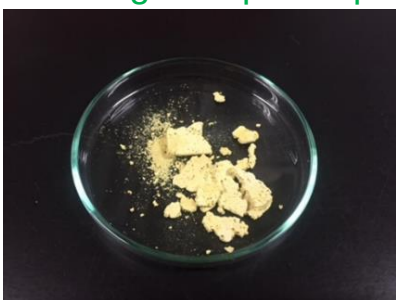
Schrödinger equation

## Metal Organic Framework : MOF

Metal Organic Framework (Porous Coordination Polymer : PCP) is the porous materials obtained by self-assembling metal ion and organic ligands. The cavity which is built in this framework can act as the space for molecule uptake parts. Therefore, MOF (PCP) is the porous material with very large surface area (1000 – 10000 $m^2/g$). The already existing porous materials such as zeolites and activated carbon are used as the catalyst, separation materials, purifying and deodorant of water. These porous materials are important and they

are indispensable to our lives. However, it is not possible to precisely finely modify the structure and size of these porous parts in nanometer size level. This fact impedes the possibility of porous materials to further develop to possess high and multi functions as the future materials. In this regard, metal organic framework can exhibits the very complex structure and high dimension function by incorporating the rigid concept of coordination bonding in their molecular structure. Especially by utilizing the metal complex, materials with new concepts such as porous materials and nanometer sized capsules can be created which can break through the boundaries between organic and inorganic materials. Therefore, it is even possible to modify and control the porous structure in nanometer scale level (2 - 50 nm in range) which was never possible in the materials existed so far. Metal organic framework can be applied to gas absorption ($H_2$, methane, $CO_2$ etc…), selection and storage of molecules, ion, separation (isomer, p-xylene, m-xylene, ethyl benzene etc…). In addition, solid catalyst, drug release, transport, electrode, electrolyte, sensor can be made from metal organic framework.

## Visible light response photocatalytic material, artificial photosynthesis material



Visible light response photocatalytic material ($g\text{-}C_3N_4$)

Photocatalytic materials can be used for catalysis, antifouling etc… Especially visible light response type photocatalytic materials could be applied to artificial photosynthesis. We have metal doped $TiO_2$ and$WO_3$ as visible response type. Recently, we developed g-carbon nitride ($C_3N_4$). We have both synthesized powder and also, ink for photocatalytic coating.

## Hydoroxyapatite

Hydoroxyapatite is basic calcium phosphate with chemical composition of $Ca_{10}(Po_4)_6(OH)_2$. They are the main component of bone, tooth with high bio-compatibility inside human body. They also exist in natural ore. Hydoroxyapatite can be supporting body of chromatography for protein purification, bio material etc… Its high bio compatibility to the tissue such as bone, also, high affinity and ion exchange capability to amino acid, protein, lipids, sugar is well known chemical property. We synthesize this hydoroxyapatite.