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The Imagine about Thermoelectric Power Generation Glass

Hongrui Peng, Heping Liu

***Abstract*—Thermoelectric power generation is an environment-friendly power source which can rationally use the low-grade heat energy such as solar heat, geothermal energy, industrial waste heat and so on, to generate electricity. In order to take better advantage of the solar heat, an idea to create a kind of thermoelectric power generation glass was introduced. Referring to solar glass, the thermoelectric materials are inserted into two layers of the glass. The feasibility of the thermoelectric power generation glass was analyzed, and the cost analysis was mentioned. With the performance improvement of the thermoelectric materials and modules, thermoelectric power generation glass will have a broad prospect.**

***Index Terms*—Thermoelectric materials, Thermoelectric power generation, innovation glass, Glass curtain wall.**

I. The Principle of Thermoelectric Power Generation

Thermoelectric effect is the general term of the thermal effects from electric effect and the current-caused temperature difference, including seebeck effect, peltier effect and thomson effect[1-3]. These three effect can be connected by kelvin relationship.

A. *Seebeck Effect*

Seebeck effect was first discovered by the German physicist Thomas Seebeck in 1823. It is the ability to transfer heat into electricity. When there is temperature difference at the junction of a closed loop, which is formed by two different conductors, the loop will generate a current. Shown in Fig 1.1, when connectors 1 and 2 maintain at different temperatures, denoted as T1 and T2(T1 > T2), it will produce electrical potential difference between the two ends of the conductor(y and z). The electrical potential difference is named as Vs, which is the thermal electromotive force. Value Vs can be expressed as:

$$V_s = \alpha_{ab}(T_1 - T_2)$$

When the temperature difference at the junction is small, the ralationship between the force and the temperature difference ΔT can be seen as linear. The scaling factor at this time can be regarded as a constant, which is defined as the relative Seebeck coefficient of conductor a and b:

$$\alpha_{ab} = lim_{\Delta T \to 0} \frac{V_{yz}}{\Delta T} = \frac{dyz}{dT}$$

The unit of Seebeck coefficient is μV/K, may be positive or negative, depengding on the conduction characteristics of the two conductors. Generally, Seebeck coefficient of P-type semiconductor thermoelectric material is positive, while the coefficient of N-type semiconductor thermoelectric material is negative.

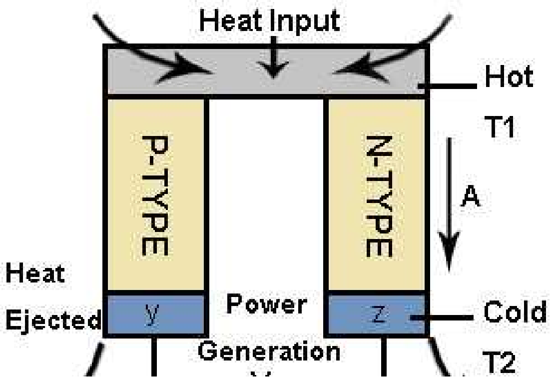

Fig. 1.1 Schematic diagram of Seebeck Effect

B. *Peltier Effect*

Peltier effect has opposite phenomenon compared with Seebeck effect. When there is a current flows through a closed loop, formed by two different conductors, a temperature difference will be produced near the junction of two conductors. The effect was first discovered by the French J.C.A.Peltier in 1834. Shown in Fig 1.2, applying a force, whose value is V, between the two ends(y and z) of the conductor, a current will occur in the closed loop consisting with two materials(a and b). At this point, absorbing heat will happen in the junction of the two materials. The speed of absorbing heat is proportional to the current

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I, generated in the loop. Heat dQ is the energy generated in a very short period of time dt, the relationship of the speed of heat absorbing and current can be expressed as:

$$\frac{dQ}{dt} = \pi_{ab} I_{ab}$$

The scale factor π_{ab} is called Peltier coefficient, whose unit is V. When π_{ab} is positive, it indicates endothermic reaction. When π_{ab} is nagetive, it indicates heat reaction. Peltier effect id reversible, while the current direction is changed, the same energy release or absorb will happen at the joints.

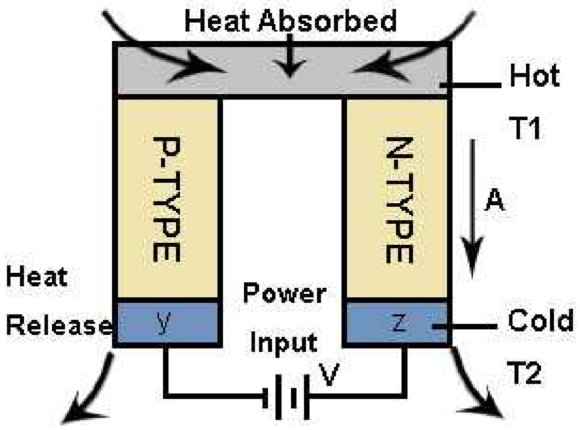


Fig. 1.2 Schematic diagram of Peltier Effect

C. *Thomson Effect*

We found out that the two effects are related to two different conductors of the loop. And in 1851 a British physicist Thomson found that this thermoelectric conversion phenonmenon also occurs in the single homogeneous conductor. Thomson analyzed Seebeck effect and Peltier effect using thermodynamic methods, and found a third temperature-related phenomenon. When a current goes in a uniform conductor which has temperature difference, the conductor will absorb or release the heat addition to the resistance-related Joule heat. The part of the heat is called Thomson heat, the phonemnon of heat exchanging is called Thomson effect. The heat absorption or release speed of Thomson effect is proportional to the current and temperature difference, which can be expressed as:

$$\frac{dQ}{dt} = \tau l(\frac{dT}{dx})$$

τ is Thonsom coefficient whose unit is V/K. At the position when directions of current and temperature difference are the same, τ is positive if the conductor absrobs heat; τ is negative if the conductor releases heat.

The Seebeck coefficient, Peltier coefficient and Thomson coefficient introduced above is important to characterize the performance of the thermoelectric material parameters. Their correlations can be expressed by Kelvin relationship:

$$\pi_{ab} = \alpha_{ab} T$$

$$\tau_a - \tau_b = T \frac{d\alpha_{ab}}{dT}$$

We can see above, once α_{ab} is known, Peltier coefficient and Thomson coefficient can be determined. If Thomson coefficient is known, Seebeck coefficient can be obtained by intergration of a single material at any temperature.
Seen from the above, Seebeck effect, Peltier effect and Thomson effect is reversible effect to thermal conduction and electrical conduction. Application in area of thermoelectric conversion is thermoelectric power generation using Seebeck effect and thermoelectric cooling using Peltier effect. It should be noted that although the performance of thermoelectric effect in the joint is at the inerface, but the process is throughout the conductor. Therefore thermoelectric effect is not screen effect but the body effect.

II. Imagine of Thermoelectric Power Generation Glass

A. *Solar Glass[4]*

Solar glass is a new product, which emerges and is burgeoning mainly with the development of the photovoltaic industry. Global total demand fo solar glass in 2006 is about 28 million to 35 million square meters. In China, only in the field of photovoltaic the demand of solar glass will reach 25 million square meters in 2020. The solar glass market prospects are very bright. The solar glass sold by East Haihua Science Ltd in Beijing is a combination of solar and energy-saving vacuum glass box. a 1.5 square-meter solar glass can produce 120W of power per hour. Between two pieces fo glass there is a layer of black film, a very thin file solar cell. The idea is to sandwich some generation materials in a vacuum glass while not affect the light transmission properties of the glass but can generate electricity itself.

B. *The presence of a temperature difference(Application)*

According to nowadays the people's living situation and habbits, people who live in area of high outdoor climatic temperatures in summer will turn on the air conditioning for cooling indoors; Meanwhile people live in area of low outdoor climatic temperatures in winter usually turn on the air conditioning for warming. In these situations the indoor and outdoor temperature difference will be at about 10-30℃. The temperature difference periodically exists, and whether we take advantages of it or not it exists. Also thermoelectric power generation unit itself needs to cool down at the low temperature side in order to raise the efficiency of thermal power generation. If there is air conditioning indoors, the flow of the cooler air can help cool down the interior side of the glass, ensuring the temperature difference between the indoor side and the outdoor side of the glass. Conversely, if the outdoor temperature is lower, heater would be used indoor to keep warm so the cool air outdoor can cool down the outdoor side of the glass to keep high temperature difference.

The figure below shows the monthly average temperature throughout the year 2014 in Harbin.

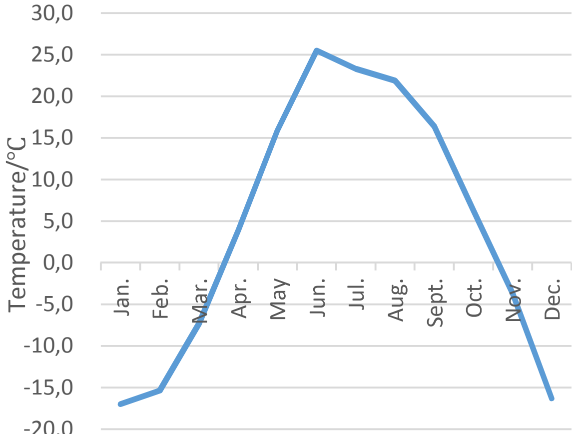


Fig. 2.1 Monthly Average Temperature throughout the Year 2014 in Harbin

The figure below shows the monthly averge temperature throughout the year 2014 in Chongqing.

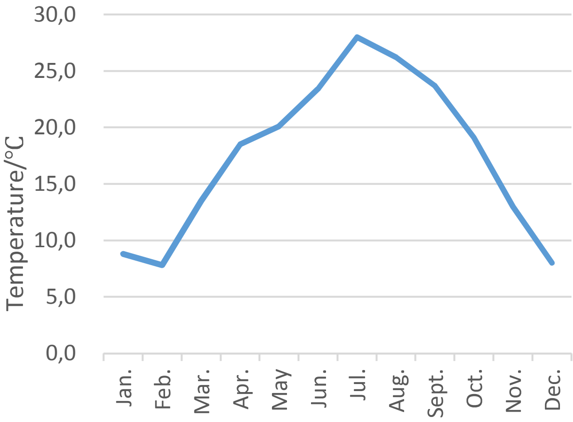


Fig. 2.2 Monthly Averge Temperature throughout the Year 2014 in Chongqing

C. *Imagine of Thermoelectric Power Generation Glass Physical Structure*

Refering to the design of solar glass[4], add thermoelectric power generation element, namely PN junction, between two glass layers, in an vacuum area. In between two layers which has temperature difference place a layer of insulation material (The red line shown in Fig. 2.3-2.4) to ensure the presence of a temperature difference. Place the insulation layer B at high-temperature side, while A side at low-temperature side, in this situation CD side will have electromotive force. After each such unit put in series as shown in Figure 2.4, the output voltage can be

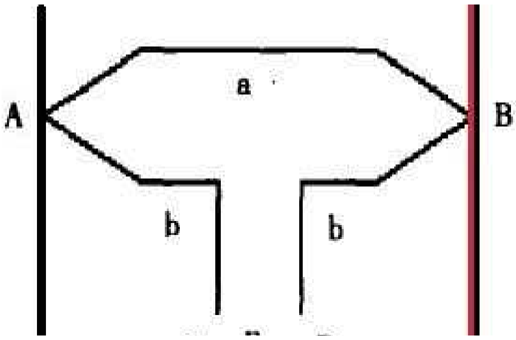


Fig. 2.3 Sectional View of a Thermoelectric Power Generation Glass

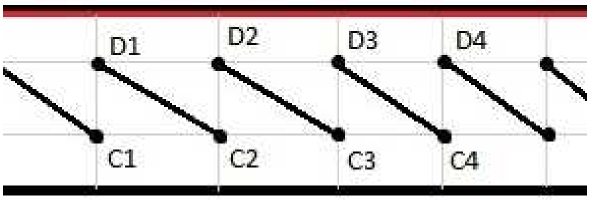


Fig. 2.4 Bottom View of a Thermoelectric Power Generation Glass

improved.

III. The Transparency Properties of the Insulation Material

In order to ensure the transparency of the glass, thermal insulation material must be chosen with transparence. Transparent thermal insulation material must have the optical properties of visible light with high transparent and near-infrared absorption/reflection shielding. At present, the core of developing transparent insulation material is design, optimize and achieve the subband regulation of spectrum. Solar radiation energy mainly distribute between 0.25-3μm wavelength, and the energy of the UV-light, visible light and near-infrared light is 5%、45% and 50% respectively. Visible can guarantee the indoor lighting and reduce lighting energy consumption. Thus, we should ensure that visible light has proper transmittance. The energy of near-infrared light need be shielded outside to get temperance difference. According to the energy distribution characteristics of different wavelength of light, we can make sure the high transmittance of visible light and shield infrared-light and UV-light as far as possible.

The ideal solar control map is shown in figure 3.

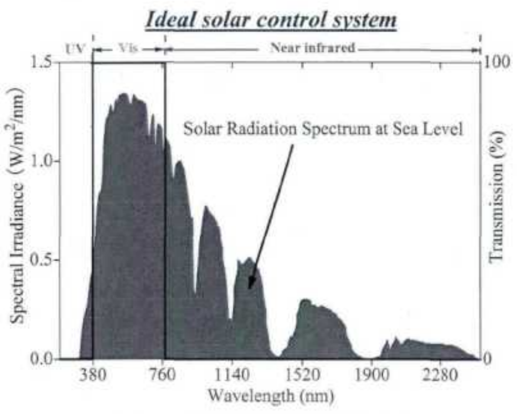


Fig. 3 Map of Ideal Solar Control System

A. *YB6 and LaB6 are suitable for high transparency thermal insulation material. For 50nm LaB6 coating layer, the transmittance of 559nm visible light is 60.0% and the transmittance of 1125nm near-infrared light is 4% which is 56% lower than the former. The reason that LaB6 has high transmittance in visible region is body plasmon and the reason that near-infrared absorption is dipole style of plasma oscillation*

B. *The value band and conduction band of TiN are mainly composed by N-2p state and Ti-3d state electrons. The thin film of TiN has the optical properties of visible light with high transparent and near-infrared absorption/reflection shielding.*

C. *Rutile VO2 has the optical properties of high absorption/reflection for visible region.*

The table 2 in appendix shows the optical properties of transparent thermal insulation material.

IV. INVESTIGATION OF GLASS CURTAIN WALL

A. *Thu using status of glass curtain wall [6-8]*

China began to import glass curtain wall from the 1980s of the last century. After 20 years of development, glass curtain wall has been used in lots of buildings in all parts of China, especially some sign public building in some regions. Taking the Central Plaza in Hong Kong, the Jin Mao Tower and Jin Jiang Tower in Shang Hai, Xidan international building in Beijing as example, they all adopted the large area glass curtain wall. According to incomplete statistics, Shanghai presently has about more than 1300 glass curtain wall buildings which have 8 floors over and the total area of curtain wall is more than 10,000,000 m^2. 6,000,000 m^2 curtain wall is putted into use annually in China and continue to grow at a rate of 10%.

According to statistics of glass and industrial glass association, in China, the proportion that the glass curtain wall of new urban public buildings use double silver glass is 30% to 40% until 2011 which is double increasing from 20% in 2010. The number of annual production of glass curtain wall in China is 70,000,000 m^2 which accounts for 3/4 of global output. So, China has become the biggest producing country and using country of glass curtain wall in the world.

List of Wolrd Wide and China's glass production/× $10^4 m^2$

Year			2003	2004	2005	2006	2007
World	Then	Total Production	3500	5200	7300	8100	9000
		Glass Curtain Wall	1400	1700	1950	2320	2550
	Grand total	Total Use	23000	27000	32500	40000	47500
		Glass Curtain Wall	11000	12500	14000	16000	18000
China	Then	Total Production	3040	4660	5550	6800	7000
		Glass Curtain Wall	950	1150	1700	1900	2200
	Grand total	Total Use	15500	16000	20000	26000	31500
		Glass Curtain Wall	6000	7500	8000	9500	11000

Table 1 List of Wolrd Wide and China's glass production

At present, public buildings in China, especially some big buildings such as large shopping malls, high-end hotel and high-grade office building, its air conditioning and refrigeration and heating system consumption occupy about 50%~60% in annual energy consumption. In heating system consumption, the energy consumption of heat transfer of external envelope structure is about 20%~50%. Glass curtain wall is one of the most using external envelope structure in modern building, and is the most active and sensitive part of heat change and heat conduction in buildings. Its heat loss is 5-6 times of traditional wall and its energy consumption occupies 40% of entire building consumption. Thus, it is an important part for building energy efficiency that research on energy conservation design of glass curtain wall of big public buildings.

B. *Development trend of glass curtain wall [6]*

1) *Adopt new energy conservation and environmental protection structure*

The development of glass curtain wall is that changing the original fashionable function which just make for decoration and beautiful. That is to say, glass curtain wall should break limit that they are just the adjunct of main structure of building and become a part of main structure of building which make them truly become the significant part of energy conservation and environmental protection.

2) *Using energy conservation and environmental protection glass*

Glass is the main material of glass curtain wall the performance of which depend on the performance of glass. So it is necessary to use energy conservation and environmental protection glass to make sure that glass curtain wall have needed function. Medium and long-term specific plan of energy conservation of China is proposed: “By 2010, 1/3 of new building achieve the goal of 50% energy conservation. By 2020, the nationwide new building all reach the target of 65% energy conservation.” At present, about 50% of the loss energy of the whole building is lost in windows and doors. Thus, it is the most important for the modern building energy conservation is that scientific and reasonable application of energy conservation glass.

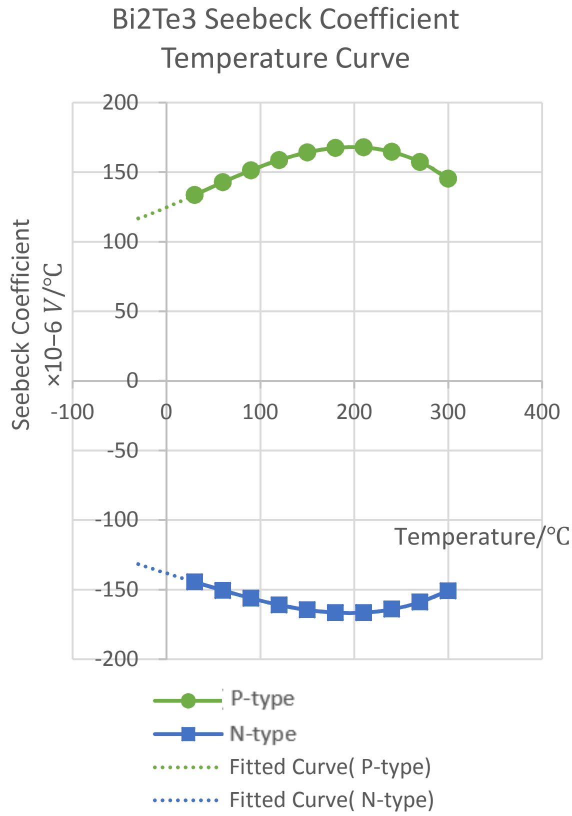
3) *New function of glass curtain wall*

In addition to the above trend of security, energy conservation, environmental protection and fashion, the most significant development trend is to give glass curtain wall new functions, such as photovoltaic function and ecological function and so on. Thermoelectric power generation glass is totally a new concept which abandon the characteristic of photovoltaic glass that just generating electricity under light and broaden the usage range.

V. THE FORECASTING CALCULATE OF POWER

A. *The forecasting calculate of single PN junction*

Neglecting the conductivity and thermal conductivity of material, at 30℃, the P Seebeck coefficient of Bi2Te3 is $133 \times 10^{-6} V/℃$ and the N Seebeck coefficient is $-144 \times 10^{-6} V/℃$.



According to the fitted curve , we can approximately think that the Seebeck coefficient is linear in the -20~30℃. At 0℃, the P Seebeck coefficient of Bi2Te3 is $125 \times 10^{-6} V/℃$ and the N Seebeck coefficient is $-138 \times 10^{-6} V/℃$.

After fitting, the P Seebeck coefficient of Bi2Te3 is:

$$S_P(T) = (0.2667 \times \mathrm{T} + 125) \times 10^{-6} V/℃$$

After fitting, the N Seebeck coefficient of Bi2Te3 is:

$$S_N(T) = (-0.2000 \times T - 138) \times 10^{-6} V/℃$$

According to calculation formula:

$$V_{SS} = \int_{T1}^{T2} (S_P(T) - S_N(T))dT$$

The result is:

$$V_{SS}(\Delta T) = 0.2334(\Delta T)^2 + 263\Delta T$$

Neglecte the conductivity and thermal conductivity of material and suppose that temperature constant and non-existing heat exchange between two sides of the glass.

When the temperature difference of thermoelectric power generation glass is 10℃,

$$V_{ss}(10) = 2.65334 \times 10^{-3}\ V$$

When the temperature difference of thermoelectric power generation glass is 30℃,

$$V_{ss}(30) = 8.10006 \times 10^{-3}\ V$$

The voltage that a PN junction unit generate is mV level. Thus the output of 1000 PN junction units cascaded can meet the power supply of most sensor.

B. *Optimization of PN junction connection in one glass*

In the use process, PN junction will be wear even damaged. If all PN junction unit in one glass in series, the whole thermoelectric power generation glass will lead to invalid when one PN junction disconnect. Thus it is necessary to consider to optimize the connection of PN junction. By using series-parallel connection can not only improve the reliability, but also improve the load capacity of thermoelectric power generation glass. Figure 5 shows the optimization connection

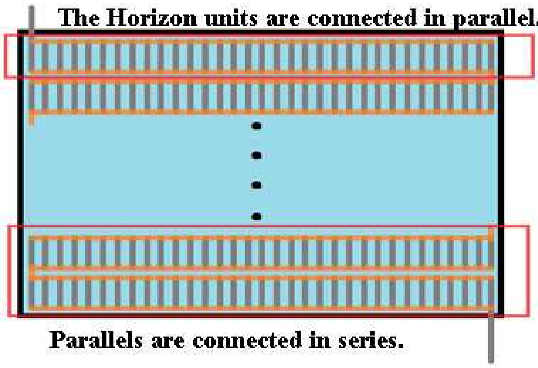


Fig. 5 The front view of intern connection in one glass

style:

Grey short-term in figure 5 represent one PN junction unit. All horizontal PN junction unit connected in parallel which will not affect the horizontal output of voltage and current even some PN junction disconnected and improve output current and strength load capacity. And horizontal rows are connected in series to enhance the whole output voltage of one glass. A pieces of glass is left two output joints to be convenient to connect and fix glass.

The connection mode of single glass can redesign the number of parallel and series groups according to the specific usage. But the connection mode of multi parallel and multi series is inevitable.

VI. Economic Benefits of Thermoelectric Power Generation Glass Curtain Wall

Take the unit type curtain wall engineering of South China International Financial Centre of Shenzhen Eyuan construction co., LTD as example, the curtain wall area is 156,300 m^2. In 2011, Shock and other people of JPL manufactured the thermoelectric elements with gradient structure which is composed by CoFe4Sb3/Bi2Te3. After element structure optimization, the output power of a PN junction reached 1.5W and the power area radio is1.36W•cm^{-2}. There are thermoelectric generation module. Actually, the coefficient of multi parallel and multi series PN junction unit is 0.01 and conductance loss is 5%. And the final output voltage regulation efficiency is 0.85 assuming the effective time of thermoelectric generation is 6 hours, 10:00-16:00.

Annual power generation of per square meter thermoelectric generation glass:

$$1.36 \times 100^2 \times 0.01 \times (1 - 5\%) \times 0.85 \times 6 \times 280 = 184.49\ kw \cdot h$$

According to the general office electricity consumption, annual electricity consumption per square meter is:

$$\frac{25\text{W}}{m^2} \times 280 \times 4 = 28\ kw \cdot h$$

Power generation per square meter can meet 5.3 m^2 electricity consumption of general office. But the curtain wall area of South China International Financial Centre can satisfy about 828,400 m^2 electricity consumption. Thus the economic benefits of thermoelectric power generation glass curtain wall is considerable.

VII. Conclusion

With the development of the construction industry, more and more people focus on energy conservation building. And the use rate of glass curtain wall in modern building increases gradually. They are not only beautiful but also has the huge conservation development function. Based on the prototype of solar glass, this paper proposed thermoelectric power generation glass and introduce its principle. This paper also analyzed the feasibility of transparent thermal insulation material, the usage, application prospect and the existence of usable temperature difference between indoor and outdoor sides. By ideal simulation calculation, this paper get output voltage of thermoelectric generation unit of one PN junction and discuss to adopt multi parallel and multi series connection style to promise the reliability and improve load capacity of power output of one glass. And we also briefly discuss the economic benefits of thermoelectric generation glass curtain wall. We can get conclusion that thermoelectric generation glass has high feasibility and development prospect. With the development of thermoelectric materials and material science, we can get better effect thermoelectric material and improve the function of thermoelectric generation glass.

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Appendix

Optical Properties of Transparent Thermal Insulation Material

Compounds	The plasma frequency Cal.Exp.	The reflectivity minimum	The minimum absorption coefficient of visible light	The maximum abosorption of coefficient of near infrared	The maximum transmittance of 50 nm thick sputtering film	The minimum transmittance of 50 nm thick sputtering film	Difference between maximum and minimum of 50 nm thick sputtering film	The maximum transmittance of 50 nm thick coating film	The minimum transmittance of 50 nm thick coating film	Difference between maximum and minimum of 50 nm thick coating film
YB_6	1.71eV /~1.8eV	7.5% (691nm)	77192cm^{-1} (639nm)	474449cm^{-1} (1199nm)	55.0% (669nm)	7.6% (1199nm)	47.4%	68.0% (639nm)	9.3% (1199nm)	58.7%
LaB_6	2.0eV /2.0eV	6.8% (591nm)	102043cm^{-1} (559nm)	643718cm^{-1} (1125nm)	50.5% (578nm)	14.1% (975nm)	36.4%	60.0% (559nm)	4.0% (1125nm)	56.0%
TiN	1.86eV /—	10.3% (593nm)	110324cm^{-1} (527nm)	381755cm^{-1} (1021nm)	44.8% (550nm)	2.7% (1110nm)	42.1%	57.6% (527nm)	14.8% (1021nm)	42.8%
VO_2(R)	1.52eV /—	17.5% (718nm)	122130cm^{-1} (656nm)	290818cm^{-1} (1156nm)	36.2% (670nm)	5.6% (1364nm)	30.6%	54.3% (656nm)	23.4% (1156nm)	30.9%

Table 2 Optical Properties of Transparent Thermal Insulation Material

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