Improvement of Thermoelectric Performance of Mg_2Si Compound by Removing Ag impurities in Si Extracted from Photovoltaic Waste

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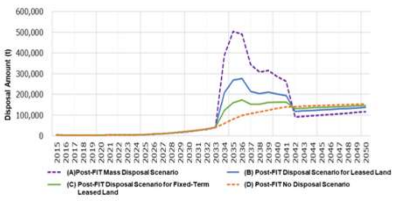
INTRODUCTION

Futural outlook for discarded PV modules in Japan

◆Following the 2012 FIT scheme, solar panels rapidly spread in Japan. With a lifespan of 20-30 years, a large number are expected to be discarded after 2030.



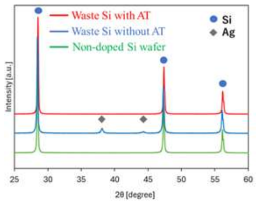
Estimated amount of solar module disposal.[1]

Si extracted from discarded PV modules

◆Waste Si cells from discarded solar panels contain many impurities, and their reuse is a highly sought-after solution. Our research aims to repurpose the Si powder extracted from these cells as a thermoelectric material.

Ag Impurity in Si cells

◆Ag is contained as the main impurity in Si cells of discarded solar panels. The discarded Si used in this experiment contained 2.8 wt% Ag.



XRD comparison of Si powders.

Thermoelectric power generation

◆ Power generation method utilizing the Seebeck effect.

◆ This method converts a temperature difference into electrical energy.

$$ZT = \frac{S^2\sigma}{\kappa}T \qquad \kappa = \alpha\, C_p\, \rho$$

ZT: Index of thermoelectric performance
S : Seebeck coefficient (V/K)
σ : Electrical conductivity (S/m)
κ : Thermal conductivity (W/m·K)
α : Thermal diffusivity (m^2/s)
C_p: Specific heat capacity (J/kg·K)
ρ : Density(kg/m^3)

EXPERIMENTAL DETAILS

STEP 1: Separation of SI cell sheets

Si cell sheets were separated from solar panels using the Hot Knife method®.

STEP 2: Combustion

EVA resin in the cell sheet was combusted in the cell sheets at 900℃ for 1h.

STEP 3: Removal of impurities

Impurities were removed using HNO_3 and HF solutions.

STEP 4: Pulverization

Si fragments were milled and the powders were sieved to less than 45 μm.

Four types of Si powders, the discarded Si powders with and without acid treatment (AT), and the non-doped Si wafer powders with and without the same amount of Ag as the discarded Si powder, were prepared. The following process was simillarly carried out on these powders.

STEP 5: Weighing and mixing

Powders of Si, Mg, and AZ61 (Magnesium alloy) were weighed and mixed. The powders were mixed at a molar ratio of Si : Mg = 1 : 2.

Chemical composition of AZ61.

	Al	Zn	Mn	Fe	Si	Cu	Ni	Mg
content [wt%]	5.5-7.2	0.50-1.5	0.15-0.40	≦0.010	≦0.10	≦0.10	≦0.005	Bal.

Al doping enhances the thermoelectric performance of Mg_2Si. [2]

As an additional experiment, a sample with added Al, considering the Ag-Al alloy component, was also prepared.

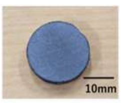
STEP 6: Synthesis of Mg_2Si

Mg_2Si compounds were synthesized using Liquid-solid phase reaction (LSPR) method at 680℃ for 1h.

Synthesized Mg_2Si powder.

STEP 7: Sintering

Samples were sintered using the spark plasma sintering (SPS) method at 800℃ for 5min under 35MPa in vacuum.



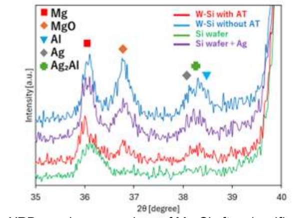
Mg_2Si after sintering

STEP 8: Characterizations

Thermoelectric properties, SEM-EDS, XRD, and Hall effect of the sintered samples were measured.

RESULTS and DISCUSSION

XRD

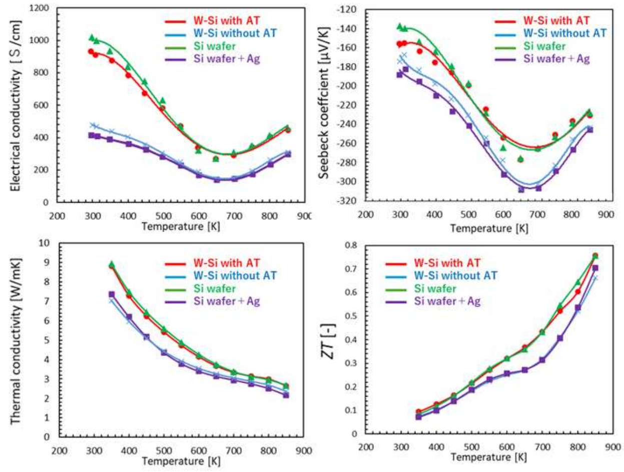


XRD powder comparison of Mg_2Si after classification.

◆In the Ag-containing samples (W-Si without AT and Si wafer+Ag), Ag, Al, and Ag_2Al phases were identified.

▶Ag may have inhibited the lattice substitution of Al at the Mg sites of Mg_2Si, leaving Ag and Al as residual impurities.

Thermoelectric properties

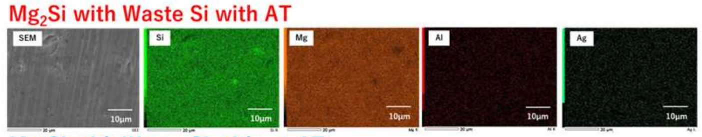


◆The performance showed significant differences with and without Ag.

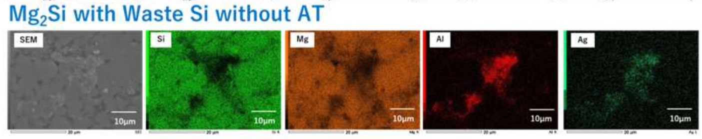
◆ The removal of Ag led to an increase in thermal conductivity and a significant improvement in electrical conductivity, consequently improving the *ZT* value across all temperatures.

SEM-EDS

Mg_2Si with Waste Si with AT



Mg_2Si with Waste Si without AT



◆Ag and Al were confirmed to be concentrated at Mg_2Si grain boundaries.

Hall measurement by Van der Pauw method

	W-Si with AT	W-Si without AT	W-Si without AT +Al
Carrier Concentration [cm^{-3}]	-2.48×10^{19}	-1.54×10^{19}	-2.24×10^{19}
Carrier Mobility [$cm^2 \cdot V^{-1} \cdot s^{-1}$]	300	154	174
Conductivity [S/cm]	998	333	544

◆In an additional experiment, carrier concentration was increased when excess Al was added, anticipating the formation of Ag_2Al compound.

▶Ag_2Al compound formation during synthesis likely reduces the Al doping amount in Mg_2Si, leading to decreased performance.

CONCLUSION

◆Successfully fabricated a Mg_2Si sintered body from discarded Si (ZT = 0.76 at 850 K).

◆Ag impurity removal significantly improved performance.

◆The formation of an Ag_2Al compound during synthesis likely led to reduced Al doping and subsequent performance degradation.

REFERENCES

[1] New Energy and Industrial Technology Development Organization (NEDO). (2019). *Solar Photovoltaic Power Generation Recycling Technology Development Project Register (Public Version)*.

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