Thermoelectric properties of $Mg_{2.2}Si_{x-0.03}Sn_{1-x}Bi_{0.03}$ (x = 0.4, 0.6, 0.8) compounds based on Si-kerf from PV manufacturing

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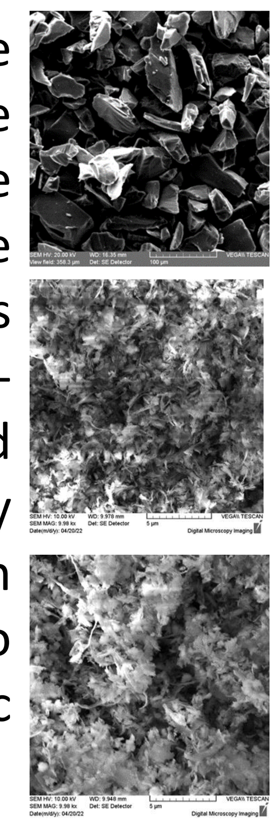
Abstract: It is of high importance to find ways of retrieving electricity from waste heat in several industries and automobiles, providing solutions to environmental and energy challenges. Towards the pathway of environmentally friendly and low-cost thermoelectric (TE) silicide-based compounds are highly promising candidates. In this work, we report on the structural and thermoelectric properties of Mg_2Si-based materials, using two kinds of Si-kerf from PV manufacturing. The properties of the produced TE materials are very promising for commercial scopes.

Experimental processes

SEM and ICP-MS results for Si-5N and Si-kerfs: Silicon kerf from the diamond wire sawing process for the production of monocrystalline silicon wafers for the PV industry has been processed by Resitec. The silicon kerf particles have a characteristic flake-like morphology, the bulk is highly pure, while the surface is oxidized. The main impurities present in the material are particles from the beam-and-wire-materials employed in the sawing process. Resitec has developed different processes for the recovery of the kerf, bringing it from a slurry to a finished dry, highly pure, and deagglomerated powder material. In these experiments different process routes were used, yielding two kerf products, where kerf 2 exhibits lower contents of metallic impurities than kerf 1, as can be seen in the ICP-MS analyses below.

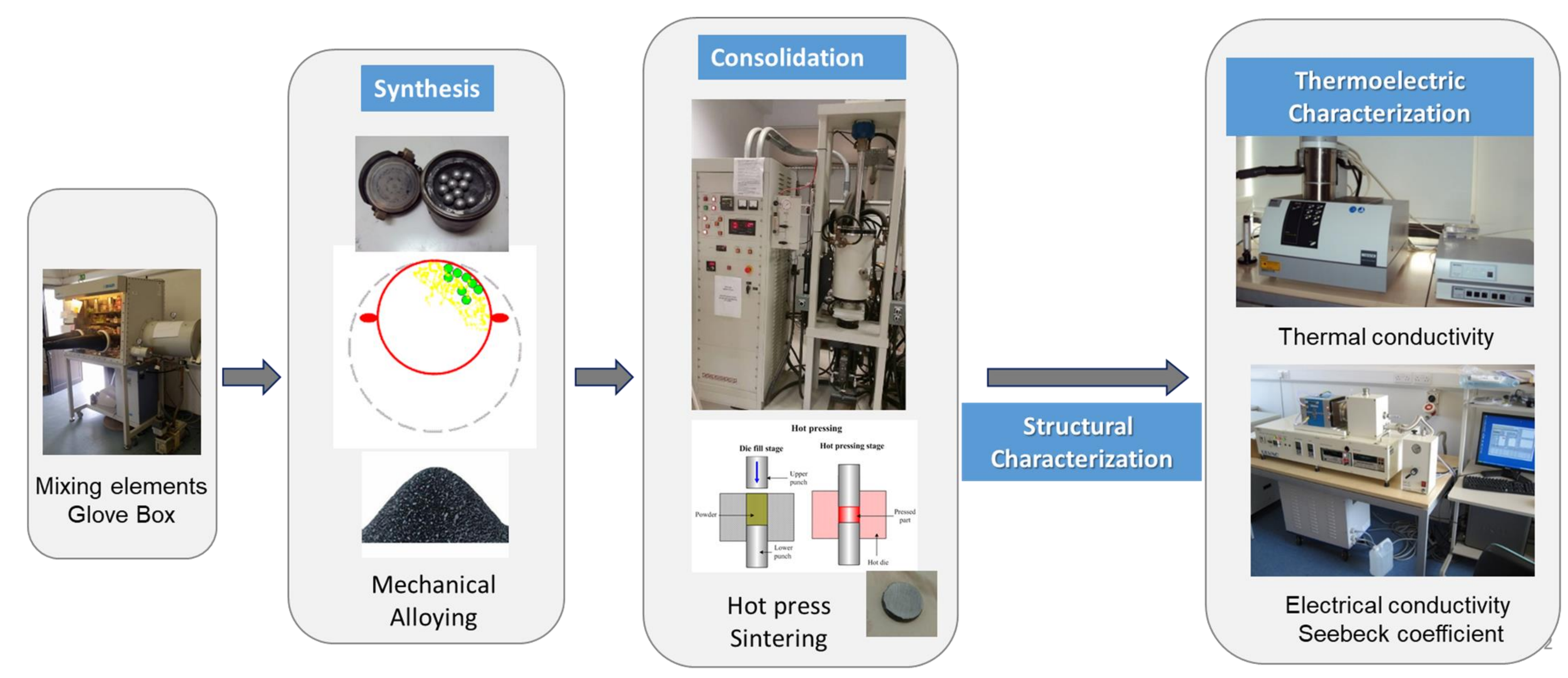


Si-5N
Alfa Aesar
Silicon powder crystalline
100+325 mesh
99.999%

Kerf-1
Al: 7000 ppmw
Ca: 460 ppmw
Fe: ~5 ppmw
Ni: ~135 ppmw
B: 0.37 ppmw
Ga: 68 ppmw
P: 4.1 ppmw

Kerf-2
Al: 30 ppmw
Ca: 560 ppmw
Fe: ~5 ppmw
Ni: ~25 ppmw
B: 0.42 ppmw
Ga: ~5 ppmw
P: 4.1 ppmw

Synthesis and characterization of TE materials



Experimental results

Structural fingerprint

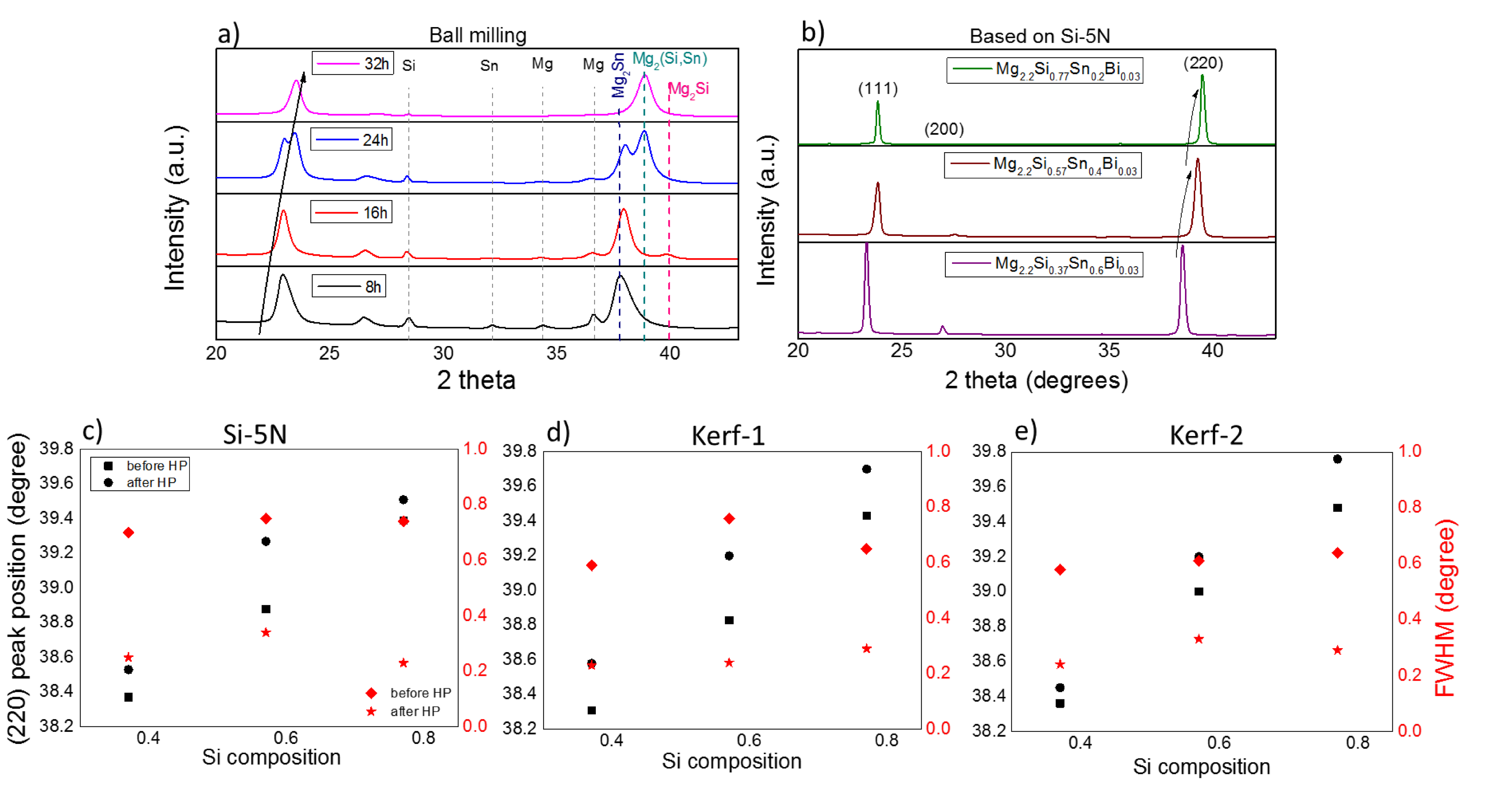


Figure 1. a) Representative XRD patterns demonstrating the phase formation in the case of $Mg_{2.2}Si_{0.37}Sn_{0.6}Bi_{0.03}$-based on pure Si-5N. b) XRD patterns for all three compositions, based on S-5N. c) (220) peak position (in degrees; in black) shift and FWHM (in degrees; in red), as a function of Si concentration. d) Same as in c), for Mg2.2Si0.37Sn0.6Bi0.03-based on kerf-1. e) Same as in c), for $Mg_{2.2}Si_{0.37}Sn_{0.6}Bi_{0.03}$-based on kerf-2.

Morphology

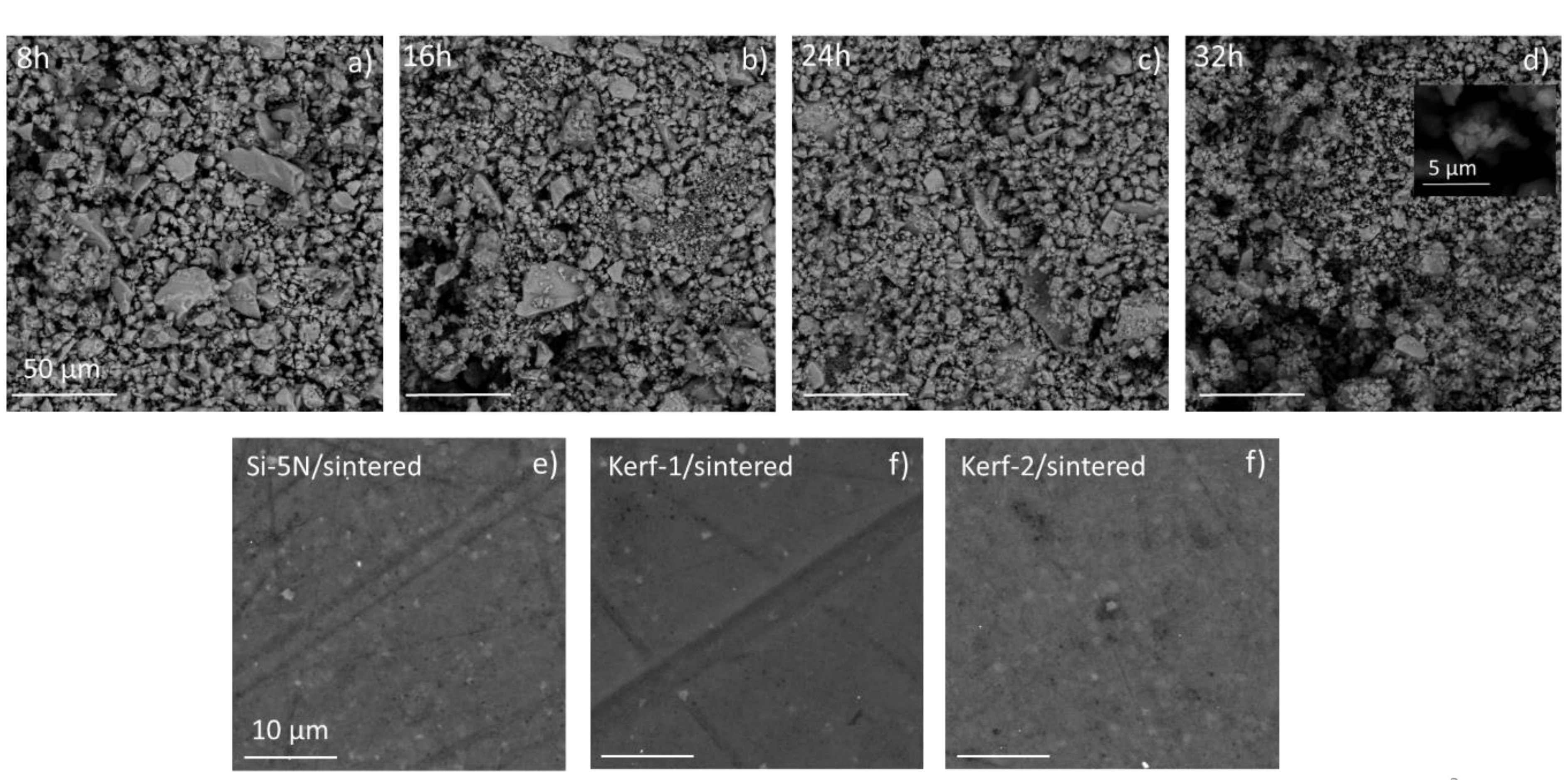


Figure 2. a)-d) Top-view morphology images of the ball-milled powder of $Mg_{2.2}Si_{0.57}Sn_{0.4}Bi_{0.03}$ based on Si kerf-1, for 8h, 16h, 24h, and 32h, respectively. The scale bar is 50 µm for these images, except for the inset in figure d) which is 5 µm. E)-f) Top-view SEM images for the sintered $Mg_{2.2}Si_{0.57}Sn_{0.4}Bi_{0.03}$ –based on Si-5N, kerf-1, and kerf-2, respectively. The scale bar in these images is 10 µm. The occurrence of second phases is very limited.

Thermoelectric properties

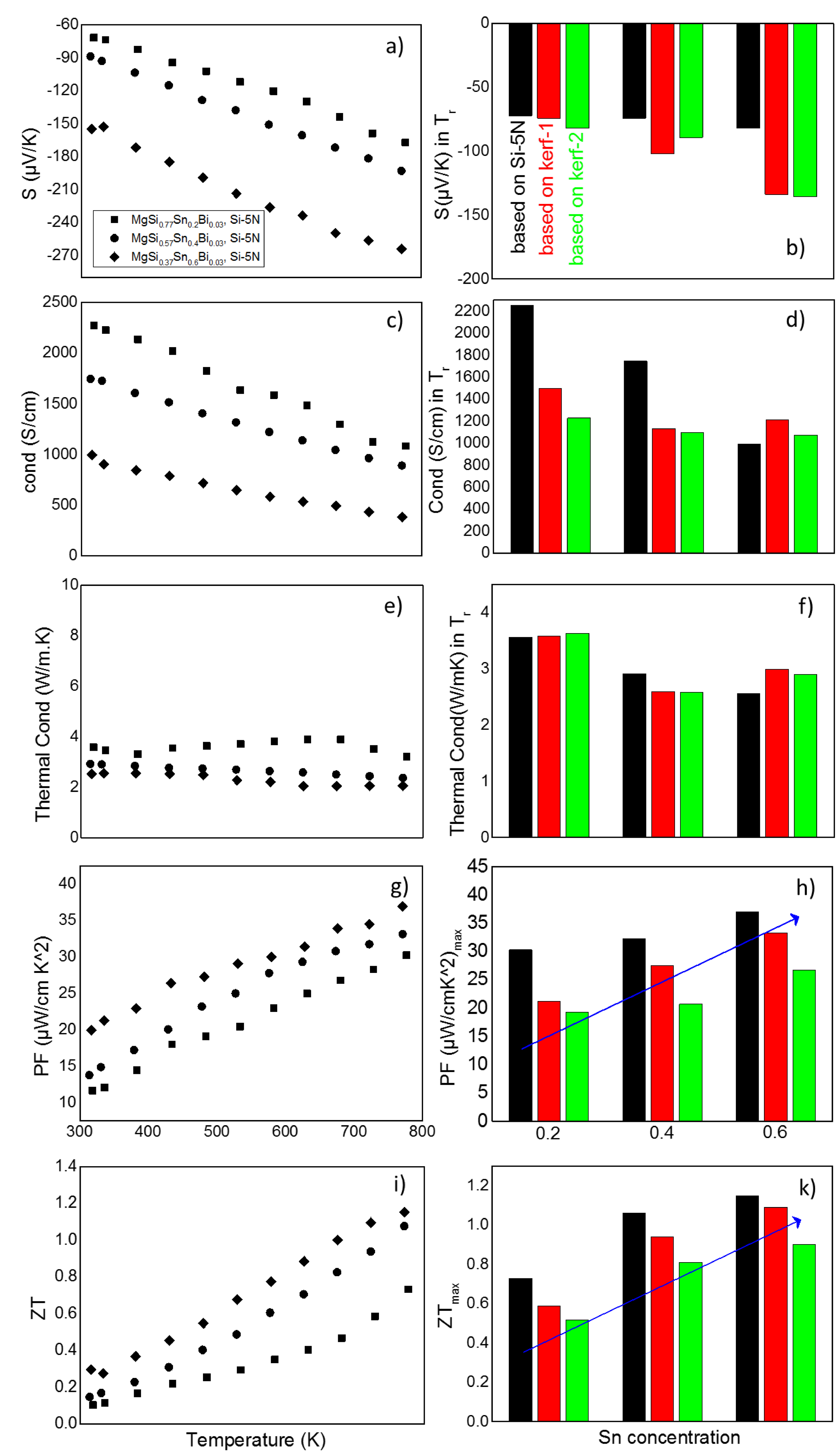


Figure 3. a), c), e), g) and i) Seebeck coefficient, electrical conductivity, thermal conductivity, PF and ZT for the $Mg_{2.2}Si_{x-0.03}Sn_{1-x}Bi_{0.03}$, (x = 0.4, 0.6, 0.8) sintered TE materials based on Si-5N. b), d), f), h) and k) A comparison of the Seebeck coefficient in Tr, electrical conductivity in Tr, thermal conductivity in Tr, PF_{max}, and ZT_{max} between Si-5N compositions, and kerf-1 and kerf-2 compositions, respectively.

Conclusions

- A comparative investigation between $Mg_{2.2}Si_{x-0.03}Sn_{1-x}Bi_{0.03}$, (x = 0.4, 0.6, 0.8), based on pure Si-5N, and namely kerf-1 and kerf-2 took place.
- Similar structural properties, in all cases of the produced TE compounds.
- Promising thermoelectric properties, with ZT_{max} values varying from 0.6 to 1.2, depending on the Si case and composition.
- This work proves that pure and expensive Si-5N can be replaced by Si-kerf for producing high-quality TE compounds.

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