R&D AND ENERGY BENEFITS OF HIGH TEMPERATURE TOLERANT CERAMIC OXIDE THERMOELECTRIC MATERIALS

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Goals behind Research

- Thermoelectric requirements in global thermoelectric markets such as vehicles
  - Low system cost per watt
  - Lightweight designs
  - High temperature tolerant materials and modules in order to harvest waste energy near heat source
  - Large scale production of materials and devices

Initial High Temperature Test Results

Nb Doped TiO2	Seebeck Coefficient (micro-v/K)			Resistivity (Ohm-cm)			Power Factor (micro-watt/cm.K^2)		
Temperature (.C)	A-1	A-2	A-3	A-1	A-2	A-3	A-1	A-2	A-3
700	515	410	385	0.185	0.105	0.350	1.4	1.6	0.4
800	470	420	380	1.185	0.105	0.250	0.2	1.7	0.6
900	400	430	380	0.160	0.105	0.220	1.0	1.8	0.7
1000	430	430	390	0.160	0.105	0.200	1.2	1.8	0.8
1100	470	480	400	0.190	0.105	0.180	1.2	2.2	0.9
1200	480	510	420	0.200	0.105	0.170	1.2	2.5	1.0

Research Pathway

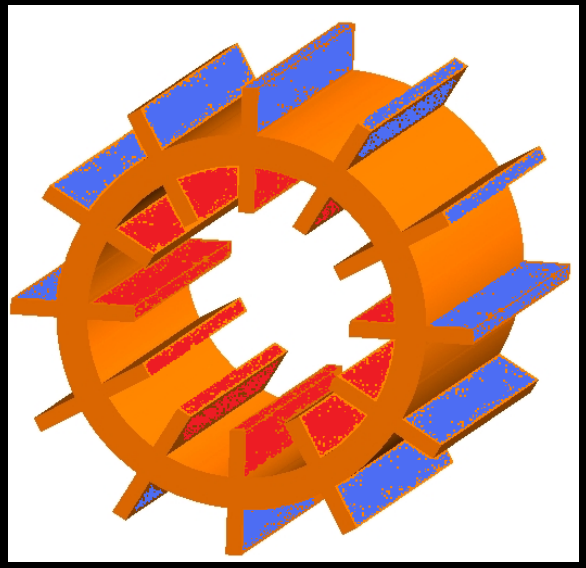
- Titanate based Perovskite Compounds
  - Currently sold to customers in the welding rod industry as fluxes and into the friction industry as materials in brake pads.
  - By doping with Sr, Nb, Ta, rare earth materials, and/or nanoparticles we have been able to vary electrical and thermal conductivity.
  - We have also conducted processing in different atmospheric conditions in order to increase electrical conductivity without the Seebeck coefficient suffering.
  - Nanopores created through proprietary processing along with size reduction to nanoparticles, resulting in increased thermal resistance by scattering the phonons.

Device Designs

- By making the modules out of proprietary ceramics we can lower the cost and weight of the TEG module.
- Ceramics can be developed to replace exhaust pipes in vehicles and in industrial plants, by casting into required shapes and dimensions.
- An insulating ceramic can be utilized to reduce thermal energy loses to the air in order to maintain a large temperature difference.
- Heat exchangers thus have less demands and can be less complex.

Efficiency through Design

- The key to power output of a thermoelectric device is high temperature difference.
- By placing the hot side thermoelectric material in the exhaust gases we can take advantage of temperatures of up to 800 Celsius peak load. (ceramic catalytic converters)
- Different coolant designs will result in different ΔTs.



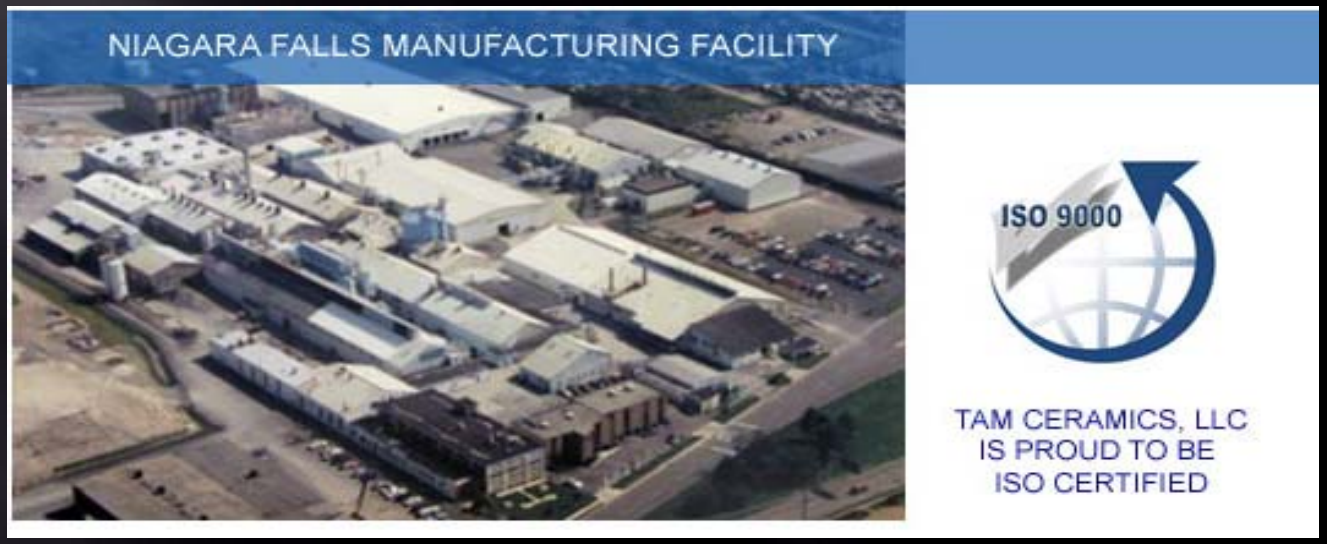
Air cooled designed through collaboration with Dr. Helenbrook.

ZT Improvements vs. Temperature Differences

$$\eta_{max} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1 + Z\bar{T}} - 1}{\sqrt{1 + Z\bar{T}} + \frac{T_C}{T_H}}$$

- Efficiency and device power output both depend on the ZT and the temperature difference.
- The increase in temperature difference utilizing novel ceramic designs can have a larger effect on theoretical device efficiency than increasing the ZT over three fold.

Resources



- Facility was started in 1908.
- In 2008, TAM employed approximately 50 personnel, 10 of which are salaried employees and 40 hourly in production and maintenance. Just 10 years ago, 250 employees worked at TAM manufacturing high purity advanced materials for the electronics industry, in addition to the existing product lines at TAM.
- The facility is currently at 50% capacity, thus immediate potential for large scale up.
- Currently we have 11 MWs of hydro allotment to achieve low carbon emissions in material and module production.

Scale up Pathway

- Industrial and vehicle uses will demand large scale production, similar to TAM's current ceramic production for brakes, refractory, and investment casting markets.
- TAM has developed methods to control the density and weight of materials made.
- Material costs can be reduced by leveraging over 50 years of experience and trade secrets in ceramic materials processing.

Conclusion

- By collaborating on ceramic oxide thermoelectric material development and device design, successful operation in higher temperatures can occur in many industries and vehicle applications.
- Novel design concepts will eliminate the need for additional heat exchangers, which add cost, weight, and additional power.
- Collaboration can lead to improvements that will result in global market acceptance and adoption by consumers that will result in lower carbon emissions and increased energy efficiency.