



- (51) International Patent Classification:  
H01L 35/02 (2006.01) H01L 35/12 (2006.01)
- (21) International Application Number:  
PCT/US2011/065841
- (22) International Filing Date:  
19 December 2011 (19.12.2011)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
61/424,878 20 December 2010 (20.12.2010) US
- (71) Applicants (for all designated States except US): TRUSTEES OF BOSTON COLLEGE [US/US]; Waul House, 140 Commonwealth Avenue, Chestnut Hill, Massachusetts 02467 (US). GMZ ENERGY INC. [US/US]; 11 Wall Street, Waltham, Massachusetts 02453 (US).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): REN, Zhifeng [US/US]; c/o Trustees of Boston College, Waul House, 140 Commonwealth Avenue, Chestnut Hill, Massachusetts

02467 (US). YAN, Xiao [CN/US]; c/o Trustees of Boston College, Waul House, 140 Commonwealth Avenue, Chestnut Hill, Massachusetts 02467 (US). JOSHI, Giri [NP/US]; c/o Trustees of Boston College, Waul House, 140 Commonwealth Avenue, Chestnut Hill, Massachusetts 02467 (US). CHEN, Gang [US/US]; c/o GMZ Energy Inc., 11 Wall Street, Waltham, Massachusetts 02453 (US). POUDEL, Bed [NP/US]; c/o GMZ Energy Inc., 11 Wall Street, Waltham, Massachusetts 02453 (US). CAYLOR, James Christopher [US/US]; c/o GMZ Energy Inc., 11 Wall Street, Waltham, Massachusetts 02453 (US).

(74) Agents: RADOMSKY, Leon et al.; The Marbury Law Group, PLLC, 11800 Sunrise Valley Drive, 15th Floor, Reston, Virginia 20191 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,

[Continued on next page]

(54) Title: HALF-HEUSLER ALLOYS WITH ENHANCED FIGURE OF MERIT AND METHODS OF MAKING

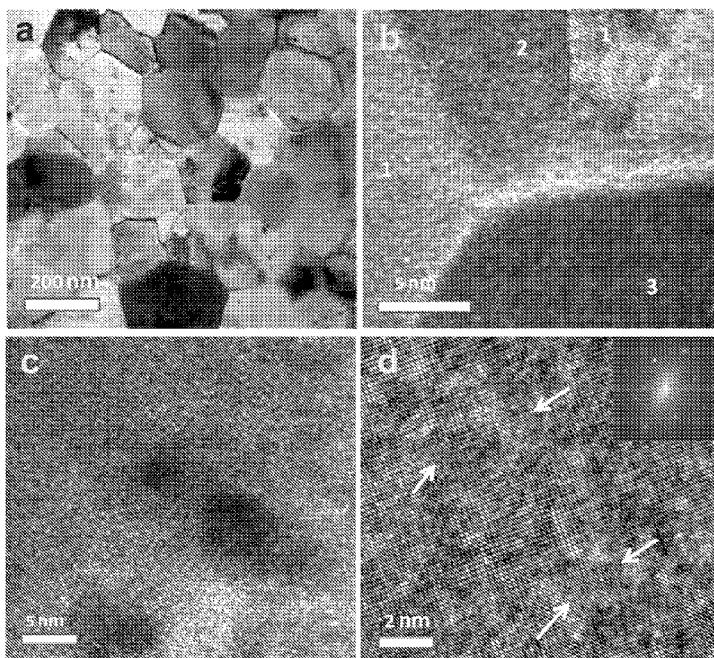


Fig. 2

(57) Abstract: Thermoelectric materials and methods of making thermoelectric materials having a nanometer mean grain size less than 1 micron. The method includes combining and arc melting constituent elements of the thermoelectric material to form a liquid alloy of the thermoelectric material and casting the liquid alloy of the thermoelectric material to form a solid casting of the thermoelectric material. The method also includes ball milling the solid casting of the thermoelectric material into nanometer mean size particles and sintering the nanometer size particles to form the thermoelectric material having nanometer scale mean grain size.





OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**(84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT,

**Published:**

— *with international search report (Art. 21(3))*

**(88) Date of publication of the international search report:**

13 December 2012

INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2011/065841**

**A. CLASSIFICATION OF SUBJECT MATTER**

*H01L 35/02(2006.01)i, H01L 35/12(2006.01)i*

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H01L 35/02; C22F 1/08; H01L 35/30; B22F 3/14; H01L 35/28; H01L 35/16; H01L 35/20

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models  
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: half, heusler, thermoelectric, grain, nano

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006-0157102 A1 (NAKAJIMA KENICHIRO et al.) 20 July 2006 See paragraphs [0016]-[0020], [0072]-[0074].	1-41
A	US 2010-0147352 A1 (MATSUBARA MASATO et al.) 17 June 2010 See paragraphs [0096]-[0115], [0128]-[0142].	1-41
A	JP 2005-019713 A (RIKOGAKU SHINKOKAI) 20 January 2005 See abstract and paragraphs [0009]-[0014].	1-41

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance  
"E" earlier application or patent but published on or after the international filing date  
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)  
"O" document referring to an oral disclosure, use, exhibition or other means  
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone  
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  
"&" document member of the same patent family

Date of the actual completion of the international search

27 SEPTEMBER 2012 (27.09.2012)

Date of mailing of the international search report

**27 SEPTEMBER 2012 (27.09.2012)**

Name and mailing address of the ISA/KR



Korean Intellectual Property Office  
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan  
City, 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

Han Jae Gyun

Telephone No. 82-42-481-5716



**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2011/065841**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006-0157102 A1	20.07.2006	JP 2009-087955 A WO 2006-075571 A1	23.04.2009 20.07.2006
US 2010-0147352 A1	17.06.2010	JP 2010-166016 A	29.07.2010
JP 2005-019713 A	20.01.2005	None	