Exhibit 4

US008524365B2

(12) **United States Patent**
O'Brien et al.

(10) **Patent No.: US 8,524,365 B2**
(45) **Date of Patent: *Sep. 3, 2013**

(54) **PREPARATION OF NANOPARTICLE MATERIALS**

(75) Inventors: **Paul O'Brien**, High Peak (GB); **Nigel Pickett**, Manchester (GB)

(73) Assignee: **Nanoco Technologies Ltd.** (GB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/267,532**

(22) Filed: **Oct. 6, 2011**

(65) **Prior Publication Data**

US 2012/0025155 A1 Feb. 2, 2012

Related U.S. Application Data

(63) Continuation of application No. 12/854,611, filed on Aug. 11, 2010, now Pat. No. 8,062,703, which is a continuation of application No. 11/579,050, filed as application No. PCT/GB2005/001611 on Apr. 27, 2005, now Pat. No. 7,803,423.

(30) **Foreign Application Priority Data**

Apr. 30, 2004 (GB) 0409877.8

(51) **Int. Cl.**
B82B 1/00 (2006.01)
B82B 3/00 (2006.01)
C30B 29/10 (2006.01)

(52) **U.S. Cl.**
USPC **428/403**; 428/402; 428/668; 428/689; 427/212; 427/214; 427/215; 977/700; 977/773; 977/813; 977/814; 977/815; 977/824; 977/827; 977/830

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,769,838	A	11/1956	Matter et al.
3,524,771	A	8/1970	Green
4,609,689	A	9/1986	Schwartz et al.
6,114,038	A	9/2000	Castro et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1394599	2/2003
EP	1176646	1/2002

(Continued)

OTHER PUBLICATIONS

Timoshkin, "Hunting for a Single-Source Precursor: Toward Stoichiometry Controlled CVD of 13-15 composites", Solid State Electronics, vol. 47, (2003), pp. 543-548.*

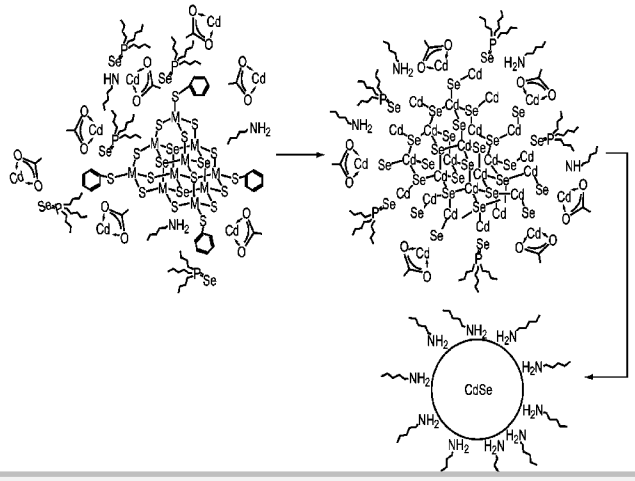
(Continued)

Primary Examiner — Nathan Empie
Assistant Examiner — Lisha Jiang
(74) *Attorney, Agent, or Firm* — Wong, Cabello, Lutsch, Rutherford & Brucculeri LLP

(57) **ABSTRACT**

A method of producing nanoparticles comprises effecting conversion of a nanoparticle precursor composition to the material of the nanoparticles. The precursor composition comprises a first precursor species containing a first ion to be incorporated into the growing nanoparticles and a separate second precursor species containing a second ion to be incorporated into the growing nanoparticles. The conversion is effected in the presence of a molecular cluster compound under conditions permitting seeding and growth of the nanoparticles.

23 Claims, 18 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,207,229	B1	3/2001	Bawendi et al.
6,221,602	B1	4/2001	Barbera-guillem et al.
6,261,779	B1	7/2001	Barbera-guillem et al.
6,322,901	B1	11/2001	Bawendi et al.
6,326,144	B1	12/2001	Bawendi et al.
6,333,110	B1	12/2001	Barbera-Guillem
6,379,635	B2	4/2002	O'Brien et al.
6,423,551	B1	7/2002	Weiss et al.
6,426,513	B1	7/2002	Bawendi et al.
6,607,829	B1	8/2003	Bawendi et al.
6,660,379	B1	12/2003	Lakowicz et al.
6,699,723	B1	3/2004	Weiss et al.
6,815,064	B2	11/2004	Treadway et al.
6,855,551	B2	2/2005	Bawendi et al.
6,914,264	B2	7/2005	Chen et al.
6,992,202	B1	1/2006	Banger et al.
7,151,047	B2	12/2006	Chan et al.
7,235,361	B2	6/2007	Bawendi et al.
7,264,527	B2	9/2007	Bawendi et al.
7,544,725	B2	6/2009	Pickett et al.
7,588,828	B2	9/2009	Mushtaq et al.
7,674,844	B2	3/2010	Pickett et al.
2003/0017264	A1	1/2003	Treadway et al.
2003/0106488	A1	6/2003	Huang et al.
2003/0148024	A1	8/2003	Kodas et al.
2004/0007169	A1	1/2004	Ohtsu et al.
2004/0036130	A1	2/2004	Lee et al.
2004/0110002	A1	6/2004	Kim et al.
2004/0110347	A1	6/2004	Yamashita
2004/0178390	A1	9/2004	Whiteford et al.
2004/0250745	A1	12/2004	Ogura et al.
2005/0098204	A1	5/2005	Roscheisen et al.
2005/0129947	A1	6/2005	Peng et al.
2005/0145853	A1	7/2005	Sato et al.
2006/0019098	A1	1/2006	Chan et al.
2006/0061017	A1	3/2006	Strouse et al.
2006/0068154	A1	3/2006	Parce et al.
2006/0118757	A1	6/2006	Klimov et al.
2006/0130741	A1	6/2006	Peng et al.
2007/0012941	A1	1/2007	Cheon
2007/0034833	A1	2/2007	Parce et al.
2007/0059705	A1	3/2007	Lu et al.
2007/0104865	A1	5/2007	Pickett
2007/0110816	A1	5/2007	Jun et al.
2007/0114520	A1	5/2007	Garditz et al.
2007/0125983	A1	6/2007	Treadway et al.
2007/0131905	A1	6/2007	Sato et al.
2007/0199109	A1	8/2007	Yi et al.
2007/0202333	A1	8/2007	O'Brien et al.
2007/0238126	A1	10/2007	Pickett et al.
2008/0107911	A1	5/2008	Liu et al.
2008/0112877	A1	5/2008	Xiao et al.
2008/0121844	A1	5/2008	Jang et al.
2008/0160306	A1	7/2008	Mushtaq et al.
2008/0190483	A1	8/2008	Carpenter et al.
2008/0220593	A1	9/2008	Pickett et al.
2008/0257201	A1	10/2008	Harris et al.
2008/0264479	A1	10/2008	Harris et al.
2009/0139574	A1	6/2009	Pickett et al.
2009/0212258	A1	8/2009	Mccairn et al.
2009/0263816	A1	10/2009	Pickett et al.
2010/0059721	A1	3/2010	Pickett et al.
2010/0068522	A1	3/2010	Pickett et al.
2010/0113813	A1	5/2010	Pickett et al.
2010/0123155	A1	5/2010	Pickett et al.
2010/0193767	A1	8/2010	Naasani et al.
2010/0212544	A1	8/2010	Harris et al.

FOREIGN PATENT DOCUMENTS

EP	1783137	5/2007
EP	1854792	11/2007
GB	1995-18910.6	9/1995
GB	2429838	3/2007
WO	WO-00/17642	3/2000
WO	WO-02/04527	1/2002
WO	WO-02/24623	3/2002
WO	WO 02/29140	4/2002
WO	WO-03/099708	12/2003
WO	WO-2004/008550	1/2004
WO	WO-2004/033366	4/2004
WO	WO-2004/065362	8/2004
WO	WO-2004/066361	8/2004
WO	WO-2005/021150	3/2005
WO	WO-2005/106082	11/2005
WO	WO-2005/123575	12/2005
WO	WO-2006/001848	1/2006
WO	WO-2006/017125	2/2006
WO	WO-2006/075974	7/2006
WO	WO-2006/116337	11/2006
WO	WO-2006/118543	11/2006
WO	WO-2006/134599	12/2006
WO	WO-2007/020416	2/2007
WO	WO-2007/049052	5/2007
WO	WO-2007/060591	5/2007
WO	WO-2007/065039	6/2007
WO	WO-2007/098378	8/2007
WO	WO-2007/102799	9/2007
WO	WO-2008/013780	1/2008
WO	WO-2008/054874	5/2008
WO	WO-2008/133660	11/2008
WO	WO-2009/016354	2/2009
WO	WO-2009/040553	4/2009
WO	WO-2009/106810	9/2009

OTHER PUBLICATIONS

Cumberland et al., "Inorganic Clusters as Single-Source Precursors for Preparation of CdSe, ZnSe, and CdSe/ZnS Nanomaterials", Chemistry of Materials, vol. 14, (2002), pp. 1576-1574.*

Agger, J.R. et al., J. Phys. Chem. B (1998) 102, p. 3345.

Aldana, J. et al. "Photochemical instability of CdSe Nanocrystals Coated by Hydrophilic Thiols", J. Am. Chem. Soc. (2001), 123: 8844-8850.

Alivisatos, A.P. "Perspectives on the Physical Chemistry of Semiconductor Nanocrystals", J. Phys. Chem., (1996), 100, pp. 13226-13239.

Arici et al., Thin Solid Films 451-452 (2004) 612-618.

Battaglia et al., "Colloidal Two-dimensional Systems: CdSe Quantum Shells and Wells," Angew Chem. (2003) 115:5189.

Bawendi, M.G. The Quantum Mechanics of Larger Semiconductor Clusters ("Quantum Dots"), Annu. Rev. Phys. Chem. (1990), 42: 477-498.

Berry, C.R. "Structure and Optical Absorption of Agl Microcrystals", Phys. Rev. (1967) 161:848-851.

Bunge, S.D. et al. "Growth and morphology of cadmium chalcogendes: the synthesis of nanorods, tetrapods, and spheres from CdO and $Cd(O_2CCH_3)_2$", J. Mater. Chem. (2003) 13:1705-1709.

Castro et al., Chem, Mater. (2003) 15:3142-3147.

Castro et al., "Synthesis and Characterization of Colloidal $CuInS_2$ Nanoparticels from a Molecular Single-Source Precursors," J. Phys. Chem. B (2004) 108:12429.

Chun et al., Thin Solid Films 480-48 (2005) 46-49.

Contreras et al., "ZnO/ZnS(O,OH)/Cu(In,Ga)Se_2/Mo Solar Cell with 18:6% Efficiency," from 3d World Conf. on Photoyol. Energy Conv., Late News Paper, (2003) pp. 570-573.

Cui et al., "Harvest of near infrared light in PbSe nanocrystal-polymer hybird photovoltaic cells," Appl. Physics Lett. 88 (2006) 18311-183111-3.

Cuberland et al., "Inorganic Clusters as Single-Source Precursors for Preparation of CdSe, ZnSe, and CdSe/ZnS Nanomaterials" Chemistry of Materials, 14, pp. 1576-1584, (2002).

Dance et al., J. Am. Chem. Soc. (1984) 106:6285.

Daniels et al., "New Zinc and Cadmium Chalcogenide Structured Nanoparticles," Mat. Res. Soc. Symp. Proc. 789 (2004).

Eychmüller, A. et al. "A quantum doi quantum well: CdS/HgS/CdS", Chem. Phys. Lett. 2008, pp. 59-62 (1993).

Gao, M. et al. "Synthesis of PbS Nanoparticles in Polymer Matrices", J. Chem. Soc. Commun. (1994) pp. 2779-2780.
Gou et al., J. Am. Chem. Soc. (2006) 128:7222-7229.
Gur et al., "Air Stable all-inorganic nanocrystal solar cells processed from solution," Lawrence Berkeley Natl. Lab., Univ. of California, paper LBNL-58424 (2005).
Gurin, Colloids Surf. A (1998) 142:35-40.
Guzelian, A. et al. "Colloidal chemical synthesis and characterization of InAs nanocrystal quantum dots", Appl. Phys. Lett. (1996) 69: 1432-1434.
Guzelian, A. et al., J. Phys. Chem. (1996) 100: 7212.
Hagfeldt, A. et al. "Light-induced Redox Reactions in Nanocrystalline Systems", Chem. Rev. (1995) :95: 49-68.
Henglein, A. "Small-Particle Research: Physicochemical Properties of Extremely Small Colloidal Metal and Semiconductor Particles", Chem Rev. (1989) 89: 1861-1873.
Hirpo et al., "Synthesis of Mixed Copper-Indium Chalcogenolates. Single-Source Precursors for the Photovoltaic Materials CuInQ2 (Q=S, Se)," J. Am. Chem. Soc. (1993) 115:1597.
Hu et al., Sol. State Comm. (2002) 121:493-496.
International Search Report for PCT/GB2005/001611 mailed Sep. 8, 2005 (5 pages).
Jegier, J.A. et al. "Poly(imidogallane): Synthesis of a Crystalline 2-D Network Solid and Its Pyrolysis To Form Nanocrystalline Gallium Nitride in Supercritical Ammonia", Chem. Mater. (1998) 10: 2041-2043.
Jiang et al., Inorg. Chem. (2000) 39:2964-2965.
Kaelin el al., "CIS and CIGS layers from selenized nanoparticle precursors," Thin Solid Films 431-432 (2003) pp. 58-62.
Kapur et al., "Non-Vacuum processing of $CuIn_{1-x}Ga_xSe_2$ solar cells on rigid and flexible substrates using nanoparticl precursor inks," Thin Solid Films 431-432 (2003) pp. 53-57.
Kher, S. et al. "A Straightforward, New Method for the Synthesis of Nanocrystalline GaAs and GaP", Chem. Mater. (1994) 6: 2056-2062.
Kim et al., "Synthesis of CulnGaSe2 Nanoparticles by Low Temperature Colloidal Route," J. Mech. Sci. Tech., Vo. 19, No. 11, pp. 2085-2090 (2005).
Law et al., "Nanowire dye-sensitized solar cells," Nature Mater. (2005) vol. 4 pp. 455-459.
Li et al., Adv. Mat. (1999) 11:1456-1459.
Lieber, C. et al. "Understanding and Manipulating Inorganic Materials with Scanning Probe Microscopes", Angew. Chem. Int. Ed. Engl. (1996) 35: 687-704.
Little et al., "Formation of Quantum-dot quanturn-well heteronanostructures with large lattice mismatch: Zn/CdS/ZnS," 114 J. Chem. Phys. 4 (2001).
Lu et al., Inorg. Chem. (2000) 39:1606-1607.
LØver, T. et al. "Preparation of a novel CdS nanocluster material from a thiophenolate-capped CdS cluster by chemical removal of SPh ligands", J. Mater. Chem. (1997) 7(4): 647-651.
Malik et al., Adv. Mat., (1999) 11:1441-1444.
Matijevic, E., "Monodispersed Colloids: Art and Science", Langmuir (1986) 2:12-20.
Matijevic, E. "Production of Mondispersed Colloidal Particles", Ann. Rev. Mater. Sci. (1985) 15: 483-518.
Mekis, I. et al., "One-Pot Synthesis of Highly Luminescent CdSe/CdS Core-Shell Nanocrystals via Organometallic and "Greener" Chemical Approaches", J. Phys. Chem. B. (2003) 107: 7454-7462.
Mews et al., J. Phys. Chem. (1994) 98:934.
Micic et al., "Synthesis and Characterization of InP, GaP, and $GainP_2$ Quantum Dots", J. Phys. Chem. (1995) pp. 7754-7759.
Milliron et al., "Electroactive Surfactant Designed to Mediate Electron Transfer between CdSe Nanocrystals and Organic Semicondictors," Adv. Materials (2003) 15, No. 1, pp. 58-61.
Murray, C.B. et al., "Synthesis and Characterization of Nearly Monodisperse CdE (E = S, Se, Te) Semiconductor Nanocrystallites", J. Am. Chem. Soc. (1993) 115 (19) pp. 8706-8715.
Nairn et al., Nano Letters (2006) 6:1218-1223.
Nazeeruddin et al., "Conversion of Light to Electricity by cis-X2Bis(2,2'bipyridyl-4,4'-dicarboxylate)ruthenium(II) Charge-Transfer Sensitizers (X=C1-, Br-, I-, CN-, and SCN-) on
Nazeeruddin et al., "Engineering of Efficient Panchromatic Sensitizers for Nanocrystalline TiO2-Based Solar Cells," J. Am. Chem. Soc. (2001) 123:1613-1624.
O'Brien et al., "The Growth of Indium Selenide Thin Films fronn a Novel Asymmetric Dialkydiselenocarbamate," 3 Chem. Vap. Depos. 4, pp. 227 (1979).
Olshavsky, M.A., et al. "Organometallic Synthesis of GaAs Crystallites Exhibiting Quantum Confinement", J. Am. Chem. Soc. (1990) 112: 9438-9439.
Olson et al., J. Phys. Chem. C., (2007) 111:16640-16645.
Patents Act 1977: Search Report under Section 17 for Application No. GB0409877.8 dated Oct. 7, 2004 (2 pages).
Patent Act 1977 Search Report under Section 17 for Application No. GB0522027.2 dated Jan. 27, 2006 (1 page).
Patent Act 1977 Search Report under Section 17 for Application No. GB0606845.6 dated Sep. 14, 2006.
Patent Act 1977 Search Report under Section 17 for Application No. GB0719073.9 dated Feb. 29, 2008.
Patent Act 1977 Search Report under Section 17 for Application No. GB0719075.4 dated Jan. 22, 2008.
Patent Act 1977 Search Report under Section 17 for Application No. GB0723539.3 dated Mar. 27, 2008 (1 page).
Peng et al., "Mechanisms of the Shape Evolution of CdSe Nanocrystals", J. AM. Chem. Soc. (2001) 123:1389.
Peng et al., "Kinetics of I-VI and III-V Colloidal Semiconductor Nanocrystal Growth: "Focusing" os Size Distributions", J. Am. Chem. Soc., (1998) 129: 5343-5344.
Peng et al., "Shape control of CdSe nanocrystals", Nature, (2000) vol. 404, No. 6773, pp. 59-61.
Pradhan, N. et al. "Single-Precursor, One-Pot Versatile Synthesis under near Ambient Conditions of Tunable, Single and Dual Band Flourescing Metal Sulfide Nanoparticles", J. Am. Chem. Soc. (2003) 125: 2050-2051.
Qi et al., "Efficient polymer-nanocrystal quantum-dot photodetectors," Appl. Physics Lett. 86 (2005) 093103-093103-3.
Qu, L. et al. "Alternative Routes toward High Quality CdSe Nanocrystals", Nano Lett. (2001) vol. 1, No. 6, pp. 333-337.
Robel et al., "Quantum Dot Sellar Cells. Harvesting Light Energy with CdSe Nanocrystals Molecularly Linked to Mesoscopic TiO2 Films," J. Am. Chem. Soc. (2006) 128; 2385-2393.
Salata, O.V. et al. "Uniform GaAs quantum dots in a polymer matrix", Appl. Phys. Letters (1994) 65(2): 189-191.
Sercel, P.C. et al. "Nanometer-scale GaAs clusters from organometallic percursors", Appl. Phys. Letters (1992)61: 696-698.
Shulz et al., J. Elect. Mat. (1998) 27:433-437.
Steigerwald, M.L. et al. "Semiconductor Crystallites: A Class of Large Molecules", Acc. Chem. Res. (1990) 23: 183-188.
Stroscio, J.A. et al. "Atomic and Molecular Manipulation with the Scanning Tunneling Microscope", Science (1991), 254: 1319-1326.
Trinidade et al., "A Single Source Spproach to the Synthesis of CdSe Nanocrystallites", Advanced Materials, (1996) vol. 8, No. 2, pp. 161-163.
Vayssieres et al., "Highly Ordered SnO_2 Nanorod Arrays from Controlled Aqueous Growth," Angew. Chem. Int. Ed. (2004)43: 3666-3670.
Wang Y. et al. "PbS in polymers, From molecules to bulk solids", J. Chem. Phys. (1987) 87: 7315-7322.
Weller, H. "Colloidal Semiconductor Q-Particles: Chemistry in the Trasition Region Between Solid State and Molecules", Angew. Chem. int. Ed. Engl. (1993) 32: 41-53.
Weller, H. "Quantized Semiconductor Particles: A Novel State of Mater for Materials Science", Adv. Mater. (1993) 5: 88-95.
Wells, R.L. et al. "Synthesis of Nanocrystalline Indium Arsenide and Indium Phosphide from Indium(III) Halides and Tris (trimethyisilyl)pnicogens. Synthesis, Characterization, and Decomposition Behavior of I_3In-$P(SiMe_3)_3$", Chem. Mater. (1995)7: 793-800.
Xiao et al., J. Mater. Chem. (2001) 11:1417-1420.
Yang et al., Crystal Growth & Design (2007) 12:2562-2567.
Yu et al., "Polymer Photovoltaic Cells: Enhanced Efficiencies via a

Zhong et al., Nanotechnology 18 (2007) 025602.
Barron, "Group III Materials: New Phases and Nono-particles with Applications in Electronics and Optoelectronics," Office of Naval Research Final Report (1999).
Dabousi et al., "(CdSe)ZnS Core—Shell Quantum Dots: Synthesis and Characterization of a Size Series of Highly Luminescent Nanocrystallites," Jrl. Phys. Chem.,(1997) 101, pp. 9463-9475.
Dehnen et al., "Chalcogen-Bridged Copper Clusters," Eur. J. Inorg. Chem., (2002) pp. 279-317.
Eisenmann et al., "New Phosphido-bridged Multinuclear Complexes of Ag and Zn," Zeitschrift fur anorganische und allgemeine Chemi (1995). (1 page—abstract).
Müller et al., "From Giant Molecular Clusters and Precursors to Solid-state Structures," Current Opinion in Solid State and Materials Science, 4 (Apr. 1999) pp. 141-153.
Timoshkin, "Group 13 imido metallanes and their heavier analogs [RMYR']n (M=Al, Ga, In; Y=N, P, As, Sb," Coordination Chemistry Reviews (2005).
Vittal, "The chemistry of inorganic and organometallic compounds with adameantane-like structures," Polyhedron, vol. 15, No. 10, pp. 1585-1642 (1996).
Zhong et al, "Composition-Tunable ZnxCu1-xSe Nanocrytals with High Luminescence and Stability", Jrl Amer. Chem. Soc. (2003).
International Search Report for PCT/GB2006/003028 mailed Jan. 22, 2007 (5 pages).
Nielsch et al., "Uniform Nickel Deposition into Ordered Alumina Pores by Pulsed Electrodeposition", Advanced Materials, 2000 vol. 12, No. 8, pp. 582-586.
Huang et al., "Bio-Inspired Fabrication of Antireflection Nanostructures by Replicating Fly Eyes", Nanotechnology (2008) vol. 19.
Materials Research Society Symposium Proceedings Quantum Dots, Nanoparticles and Nanowires, 2004, ISSN: 0272-9172.
Xie et al., "Synthesis and Characterization of Highly Luminescent CdSe-Core CdS/Zn0.5Cd0.5S/ZnS Multishell Nanocrystals," JACS Articles published on web Apr. 29, 2005.
Kim et. al., "Engineering InAsxP1-x/InP/ZnSe III-V Alloyed Core-Shell Quantum Dots for the Near-Infrared," JACS Articles published on web Jul. 8, 2005.
Rao et. al. "The Chemistry of Nanomaterials: Synthesis, Properties and Applications" (2004).
Trinidade et al., "Nanocrystalline Seminconductors: Synthesis, Properties , and Perspectives", Chemistry of Materials, (2001) vol. 13, No. 11, pp. 3843-3858.
International Search Report for PCT/GB2009/001928 mailed Dec. 8, 2009 (3 pages).
International Search Report for PCT/GB2009/002605 mailed Feb. 22, 2010 (3 pages).
Search Report for GB0813273.0 searched Dec. 8, 2008 (1 page).
Search Report for GB0814458.6 searched Dec. 5, 2008 (2 pages).
Search Report for GB0820101.4 searched Mar. 3, 2009 (1 page).
Search Report for GB0821122.9 searched Mar. 19, 2009 (2 pages).
Foneberoy et al., "Photoluminescence of tetrahedral quantum-dot quantum wells" Physica E, 26:63-66 (2005).
Cao, "Effect of Layer Thickness on the Luminescence Properties of ZnS/CdS/ZnS quantum dot quantum well", J. of Colloid and interface Science 284:516-520 (2005).
Harrison et al. "Wet Chemical Synthesis on Spectroscopic Study of CdHgTe Nanocrystals with Strong Near-infrared Luminescence" Mat. Sci and Eng.B69-70:355-360 (2000).
Sheng et al. "In-Situ Encapsulation of Quantum Dots into Polymer Microsphers", Langmuir 22(8):3782-3790 (2006).
W. Peter Wuelfing et al., "Supporting Information for Nanometer Gold Clusters Protected by Surface Bound Monolayers of Thiolated Poly (ethylene glycol) Polymer Electrolyte" Journal of the American Chemical Society (XP002529160) (1998).
International Search Report for PCT/GB2009/000510 mailed Jul. 6, 2010 (16 pages).
International Search Peport for PCT/GB2008/003958 mailed Sep. 4, 2009 (4 pages).
Banger et al., "Ternary single-source precursors for polycrystaline thin-film solar cells" Applied Organometallic Chemistry, 16:617-627, XP002525473 Scheme 1 Chemical Synthesis (2002).
D Qi, M Fischbein, M Drndic, S. Selmic, "Efficient polymer-nanocrystal quantum-dot photodetectors", Appl. Phys. Lett., 2004, 84, 4295.
Shen et al., "Photoacoustic and photoelectrochemical characterization of CdSe-sensitized Ti02 electrodes composed of nanotubes and nanowires" Thin Solid Films, Elsevier-Sequoia S.A. Lausanne, CH vol. 499, No. 1-2, Mar. 21, 2006, pp. 299-305, XP005272241 ISSN: 0040-6090.
Smestad GP, et al., "A technique to compare polythiophene solid-state dye sensitized Ti02 solar cells to liquid junction devices" Solar Energy Materials and Solar Cells, Elsevier Science Publishers, Amsterdam, NL, vol. 76, No. 1, Feb. 15, 2003, pp. 85-105, XP004400821 ISSN: 0927-0248.
Chen et al., "Electrochemically synthesized CdS nanoparticle-modified Ti02 nanotube-array photoelectrodes: Preparation, characterization, and application to photoelectrochemical cells" Journal of Photochemistry and Photobiology, a: Chemistry, Elsevier Sequoia Lausanne, CH, vol. 177, No. 2-3, Jan. 25, 2006, pp. 177-184, XP005239590 ISSN: 1010-6030.
Wang, et al., "In situ polymerization of amphiphilic diacetylene for hole transport in solid state dye-sensitized solar cells" Organic Electronics, El Sevier, Amsterdam NL, vol. 7, No. 6, Nov. 18, 2006, pp. 546-550, XP005773063 ISSN: 1566-1199.
International Search Report and Written Opinion for PCT/GB2008/001457 mailed Aug. 21, 2008 (14 pages).
Richardson et al., "Chemical Engineering: Chemical and Biochemical Reactors and Process Control," vol. 3, Third Edition pp. 3-5 (1994).
Hu et al., Solar Cells: From basics to advanced systems. McGraw-Hill Book Co. pp. 73-74 (1983).
Talapin et al. "Synthesis of Surface-Modified Colloidal Serniconductor Nanocrystals and Study of Photoinduced Charge Separation and Transport in Nanocrystal-Polymer Composites," Physica E, vol. 14, pp. 237-241 (2002).

* cited by examiner

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS
Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS
Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS
Sync your system to PACER to automate legal marketing.