Nanoscience and Nanotechnology: Two New Exciting Fields for Future Display Applications

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Abstract

Though just two years ago nanoparticles and nanotechnology were little more than a blip on the industrial applications radar, over $1 billion in annual venture capital is expected to be invested in the field over the next two years. The National Science Foundation predicts that the market for nanotechnology products and services in the US alone will conservatively reach $1 trillion by 2015. Next year, the US Government's National Nanotechnology Initiative has proposed to spend over $500 million on nanoparticles and nanotechnology research and development.

Recently, highly luminescent silicon nanocrystals with discrete optical transitions were produced utilizing a very simple synthetic method. Stable silicon nanocrystals were manufactured that show blue, green and red luminescence at room temperature.

This paper presents the optical properties of these silicon nanocrystals as an exciting potential material for display and other optoelectronic applications. A number of nanotechnologies applied in the display field such as guest host LCDs, PDLCs and stabilized cholesteric materials, electrophoretic inks, the new Optiva polarizers and carbon nanotube field emission displays will be discussed.

Keywords: nanotechnology, silicon nanocrystals, carbon nanotubes, display, quantum dots.

Introduction

Display scientists and engineers are continuously searching for new materials that exhibit optical properties compatible with display applications. Recently, organic light emitting diode materials (OLEDs) are the darling of the display technologists. Other materials such as carbon nanotubes[1] and memory-stable liquid crystals [2] are of high interest. We are all witnessing a very strong growth of nanotechnology. New nanoparticles and nanocrystals are announced almost daily. It is safe to assume that these new nanotechnologies and new nanomaterials are already penetrating and will strongly influence in the future the display industry[3]. Silicon nanocrystals have a special interest for electronic and display specialists because they are based on classical silicon. This is the first time that one can contemplate optoelectronic devices made from silicon such as nanodiodes and nanolasers with proven stability and high efficiency. This "miracle" is achieved by quantum confinement. In bulk silicon light emission requires phonon assistance resulting in very low emission capability.[4] As a result, bulk silicon photoluminescence is very weak or non-existent. Quantum confinement effects in silicon nanocrystals and porous silicon were shown to enhance the luminescence efficiencies and quantum yield. This behavior is a result of the confinement of electron and hole wave functions and their behavior as "a particle in a box." The result is quantized energy levels that depend on the size of the "box," that can be correlated to the size of the nanocrystallites. As the crystals become smaller and smaller, we have a transition from the bulk band structure to the quantized atomic energy structure whereby the gap is increased by decreasing the size of the crystal. This is how one can obtain tunable absorption spectra with discrete "atomic like" peaks.

Luminescence from silicon nanocrystals

In the past some aerosol and chemical methods [5] were used for producing silicon nanocrystals with very little progress. These methods produced silicon nanocrystals in low quantity with extremely broad size distributions that could not be utilized for display applications. The method presented below[6] is using a supercritical solvent reaction whereby the silicon nanocrystal steric stabilization is done by a coating of flexible organic molecules. These molecules inhibit the continuing interaction between the nanocrystals in such a way to prevent uncontrolled particle growth. The process takes place at 500°C in a high pressure cell, promoting the silicon crystallization from diphenylsilane in a solution of octanol or hexane. The resulting silicon nanocrystals consist of a crystalline core that is coated by hydrocarbon ligands. Highly stable silicon nanocrystals ranging from approximately 1 nanometer to 40 nanometers in diameter are produced. Figure 1 presents the luminescence of the silicon nanocrystals obtained for different sizes. Spectra from violet to blue and from green to yellow are shown.

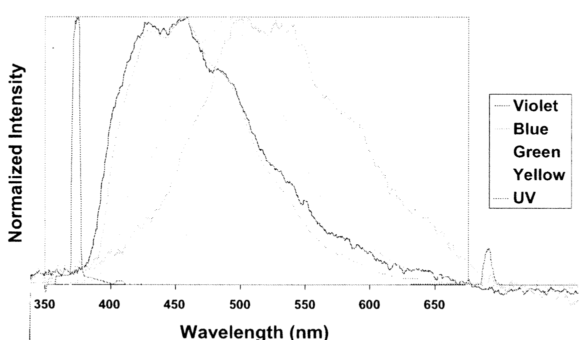

Figure 1. Photoluminescence spectra obtained from silicon nanocrystals suspended in solution with size distribution between 1 and 30 nanometers. A UV excitation source was used.

Silicon nanocrystals as potential cathodoluminescent material

Cathodoluminescence (CL) of the Si nanocrystals was studied using a thermionic electron gun and carbon nanotube cold cathode as an electron source. To make a nano-Si CL sample, Si nanocrystals were diluted in hexane, and dispersed over an ITO-coated glass. After drying in air, the sample brightness and luminescence spectra were studied using a Minolta CS-100 Chroma Meter and an Ocean Optics PC2000 spectrometer. [7]

The CL measurements were performed in vacuum of $1.2 \cdot 10^{-7}$ Torr. The CL brightness from a 5-mm diam. spot was 0.05±0.01 cd/m^2 when the nanocrystals were irradiated by an electron beam with a DC current of 0.20 mA and electron energy of 4.5 keV. For comparison, under the same conditions, the brightness of a standard green CRT phosphor was about 10 cd/m^2. Keeping in mind that the nanoparticle solution was very dilute, this value for the brightness seems reasonable and indicates a sufficient CL efficiency.

CL spectra for samples of blue and green photoluminescent nanocrystals are shown in Figure 2.

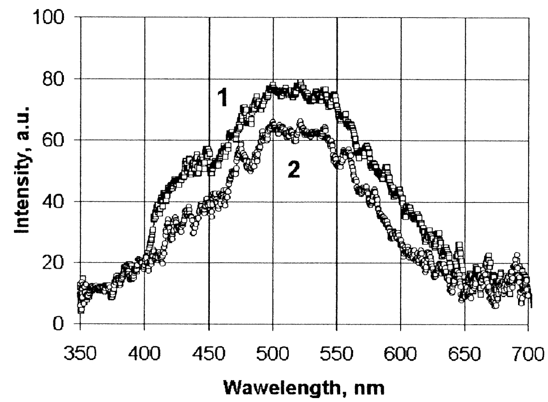

Figure 2. CL spectra for blue (1) and green (2) photoluminescent silicon nanoparticle samples.

Carbon nanotubes for display applications

Display devices based on carbon materials are considered the best candidate for affordable field emission large area displays (40" diagonal or larger).[8] For this size display, the only existing thin, flat panel technology on the market is plasma (PDP), which is expensive. CRT and projection technologies are either too bulky or not suitable for the application. Carbon cathode materials have an advantage for a number of reasons: [9]

- They have low threshold electric fields.
- They can emit high electron current densities, much higher than required for most display applications.
- They exhibit high emission site densities.
- Deposition over large areas is easily achievable.
- Low deposition temperatures now allow fabricating these materials on glass.
- Their manufacturability is very competitive (low cost, known processes).
- Researchers have demonstrated long lifetimes and good stability.

The table below shows the required current density for a variety of FED applications.[10] A material capable of supplying 40 mA/cm^2 will satisfy most display applications. Requirements for some non-display applications can be much more demanding, but these applications do not have the display market potential.

Table 1: Performance parameters and cathode requirements for some flat-panel field emission display applications.

Application	Peak cathode current density (mA/cm^2)
Picture element tube (PET) for low resolution, large area display	0.4 – 2.0
VGA FED passive color triode, 10" diag. 5kV anode.	5-10
VGA HyFED[8], 14.2" diag., 10kV anode	15 – 30

Using glass substrates for carbon film deposition is very advantageous with respect to other materials since it simplifies the assembly of the cathode back plate with the glass screen face plate. Also, glass is an inexpensive material and is easily available in large area plates (Figure 3).

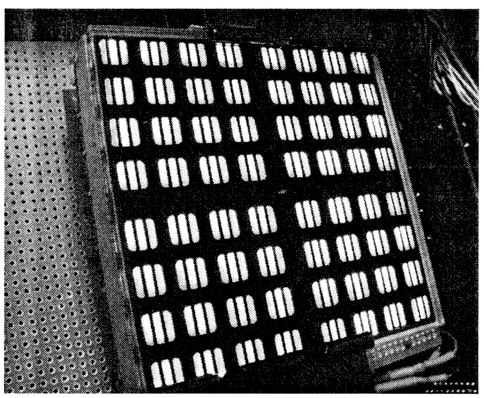

Figure 3. A 10 mm pitch picture element tube (PET) utilizing only glass substrates and printing manufacturing technologies prototyped by Applied Nanotech, Inc.

Nothing new under the sun!

Although nanotechnology recently receives a lot of hype, in the display industry nanotechnology and nanomaterials have been applied for a long time. To mention a few:

- liquid crystal surface alignment on treated and untreated polymer surfaces for LCD applications [11]
- e-type polarizers utilizing discotic liquid crystal phases[12] using supramolecular lyotropic liquid crystals
- the structure of PDLCs (polymer dispersed liquid crystals) [13]
- a polymer network of PSCTs (polymer stabilized cholesteric textures) [13]
- photo enforced stratification liquid crystals (PES) [14]
- electronic ink displays utilizing encapsulated electrophoretic materials [15]
- nanochromic^{TM} paper quality display technology [16]

These are a few examples of past and current applications of nanotechnology in the display industry. As nanotechnology becomes more pro-eminent and understood, new materials, new effects at nanometric ranges will create vast opportunities for the display technologists.

Biodisplay?

It is expected that in the next ten years nanotechnology and biotechnology will converge. Ordering of nanocrystals (quantum dots) using genetically engineered viruses was shown by Angela M. Belcher and her associates.[17] A liquid crystal system of genetically engineered viruses was used for fabrication of highly ordered composite materials containing ZnS nanocrystals. The viruses that formed the base of the self-ordering system were selected to have a specific recognition moiety for ZnS crystal surfaces. In this way a new hybrid film spontaneously evolved that was ordered in the micro- and nanoscale. Ordered domains as large as one centimeter long were obtained. In addition, the hybrid material showed lyotropic liquid crystalline behavior by controlling the solvent concentration or by the use of a magnetic field. In the same work Prof. Belcher showed smectic and cholesteric type genetically engineered viruses structures with optical and magnetic properties very similar to the smectic and cholesteric phases known to us from the thermotropic liquid crystal materials.

Conclusion

Nanotechnology and nanoscience appear to become new exciting field for future display applications. Display scientists and technologists have been using nanotechnology and nanomaterials for a long time in developing and manufacturing electronic displays. The new quantum dots (nanocrystals), carbon nanotubes and even ordered structures of genetically engineered viruses will create a vast opening for further breakthroughs in the display industry.

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