

Technical comparison between SED and FED

**Presenting Author: R. L. Fink,
Applied Nanotech, Inc.
3006 Longhorn Blvd., Suite 107
Austin, TX 78758
Phone 512-339-5020
Fax 512-339-5021
dfink@appliednanotech.net**

**Additional Authors: Zvi Yaniv, L. H. Thuesen, Igor Pavlovsky
Applied Nanotech, Inc.
3006 Longhorn Blvd., Suite 107
Austin, TX 78758
Phone 512-339-5020
Fax 512-339-5021**

Paper Number: 30010 Session CRT/FED

Technical comparison between SED and FED

R. L. Fink, Zvi Yaniv, L. H. Thuesen, Igor Pavlovsky
Applied Nanotech, Inc. 3006 Longhorn Blvd., Suite 107, Austin, TX 78758, USA
Phone: 512-339-5020; FAX: 512-339-5021; email: dfink@appliednanotech.net

Abstract: The surface-conduction electron-emitter display (SED) and the field emission display (FED) have many things in common, mainly they are both technologies that realize a thin, flat display with CRT-like qualities of fast response time and high efficiency, brightness and contrast ratio. The market direction for both technologies is the large-screen, HDTV. Both technologies rely on controlling an array of electron beams to write an image on a phosphor-coated anode. Both technologies require an evacuated glass envelope supported by multiple spacers distributed throughout the display. Both are ultimately based on field emission concepts, but major differences in the emitter structure lead to significant differences in electronic drivers and display operation. This presentation will focus on the similarities and differences between the two technologies and their effect on performance.

Key words: Field Emission Display, FED, Surface-conduction Electron-emitter Display, SED, Surface Conduction Emitter, SCE

1. Introduction

The information display is a critical human interface to electronic systems. Industry experts have been working for decades to manufacture them larger, lighter, brighter, and thinner— particularly for television use. Furthering the quest for the exemplary display television is the introduction of High Definition Television (HDTV). HDTV provides means for transforming the entertainment experience. By delivering crystal clear video in high resolution, high-fidelity surround sound, full screen graphics and the ability to drive interactive applications, HDTV delivers an immersive user experience that is attracting consumers all over the world.

Because of the inherent flaws in current display technology for HDTV, many researchers have turned to the field emission display (FED) utilizing carbon nanotubes (CNTs) as an electron emitter [1] as the technology of choice for HDTV [2]. It is this technology that will be able to support the HDTV revolution at an acceptable cost. On the other hand, Canon and Toshiba have developed another class of FED that is based on a lateral field emitter and called the Surface-conduction Electron-emitter Display (SED). We have classified the SED in the FED family for two reasons. First, the Society for Information Display (SID) and other display conference organizers generally place SED presentations and posters together with FED talks; we will be consistent with this convention. Second, there are many things that the FED and SED have in common. Before we begin with what makes the SED unique, let us first begin with how they are similar.

2. Similarities of FED and SED

SED and FED technologies have many things in common, as follows:

2.1 Form Factor

First, they are both flat- and thin-screen technologies that, depending on the approach, can achieve HDTV specifications for large-screen displays. Ishizuka [3] describes a 36-inch diagonal SED panel having (H)1280 X 3 X (V)768 pixels

corresponding to a pixel size of 205 μm X 3 X 615 μm . This display is only 7.3 mm thick [4], which is the sum of 2.8 mm (cathode plate), 2.8 mm (anode plate) and 1.7 mm (vacuum spacing). The panel weight is 7.8 kg. The weight and thickness of an FED of comparable size is expected to be about the same. The target market for both FED and SED is large area HDTV [5].

2.2 View Technology

Second, they are both direct view, or emissive display technologies. Each pixel or sub-pixel generates its own light energy that is seen directly by the viewer, allowing high contrast and efficiency and other performance improvements. For SED and other FED technologies, the light that forms the image is created by energetic electrons striking a phosphor screen anode, very similar to the anode screen of a cathode ray tube (CRT). The phosphors used are also the same or very similar to those used in CRTs [6,7, 8].

2.3 Structure

Third, because electron acceleration requires a vacuum to avoid corona or plasma discharge, the mechanical structure of the SED and other FEDs consists of a hermetically sealed glass envelope that is evacuated to form the vacuum space required to accelerate the electron beams. Depending on the size of the display and thickness of the glass walls, spacers are generally required in order to support the glass walls against the atmospheric pressure. The spacers must also be capable of standing off high voltage gradients and be optically invisible to viewers under normal operating conditions. The 36-inch SED required 20 rib-type spacers to maintain the 1.7 mm vacuum gap. A schematic of the SED display is shown in Figure 1. FED displays have been demonstrated with both rib-type and post-type spacers [9]. Furthermore, all FED technologies, including SED, require a form of getter technology [10] to maintain the required vacuum inside the glass envelope after the display is evacuated and sealed.

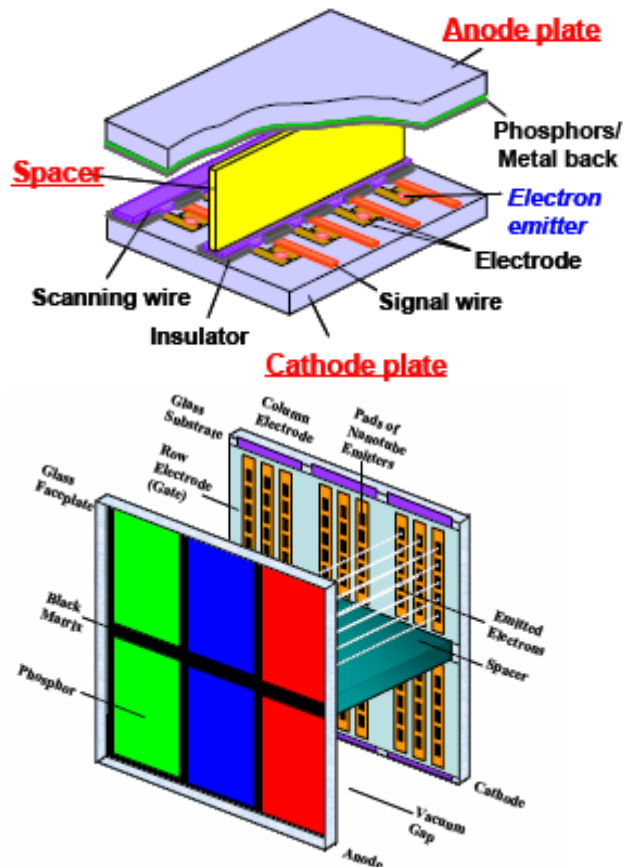


Figure 1: Structure of SED (top) showing Cathode plate, rib-type spacer and Anode plate [3]. The structure for FED (bottom) [11] is similar except for details of the Cathode plate.

2.4 Manufacturing

Finally, the fabrication and assembly approaches are also very similar, with the major exception being the cathode plate, as will be described later. All FED approaches being developed today require assembling a face-plate (anode) with a back-plate (cathode or electron source), together with sidewalls, spacers and getters. First the anode and cathode plates are fabricated separately, assembled with the other components, sealed using glass frit or other novel materials and then evacuated. Figure 2 diagrams the assembly process for a CNT-based FED [12], but can be applied to other FED technologies, including SED. In some approaches, the sealing and evacuation steps are combined and still other approaches hope to eliminate or reduce the number of spacers [13]. New materials are under development to replace frit-glass seals in order to lower the sealing temperature and to avoid materials with high lead content [14].

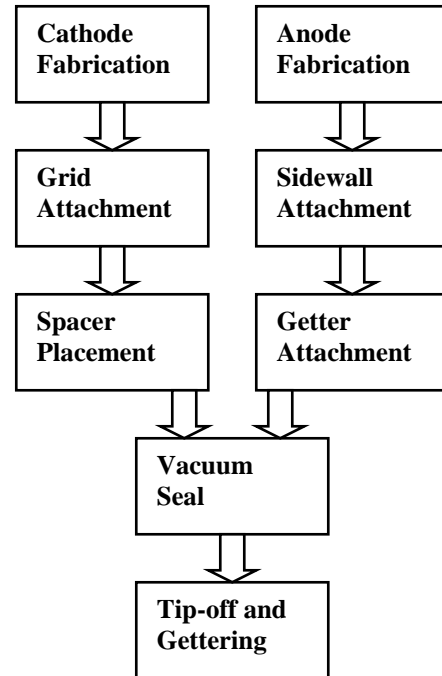


Figure 2: Diagram showing the basic flow of display fabrication.

The anode fabrication process is very similar for both SED and FED. Figure 3 shows the details of the anode configuration for an SED panel [3]. The black matrix and color filters are used to improve contrast and the metal back film is used to improve brightness and efficiency and also acts as an electrode for the high voltage potential and bleeds charge away from the phosphor during e-beam illumination. These are standard technical modifications used in CRT, FED and high-voltage VFD to improve the performance of the phosphor.

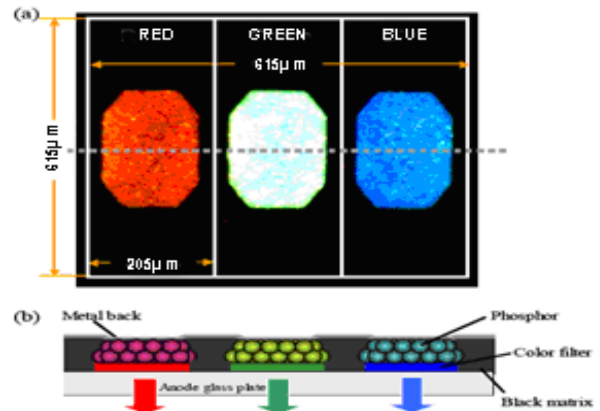


Figure 3: Enlarged photo of anode plate for an SED panel [4]. Although the dimensions may vary, the structure is very similar for other FED displays.

Finally, both SED and CNT-based FED displays have used printing to fabricate the anode and cathode plate, as will be detailed in the following section. Thus depending on your point of view, the SED and other FED technologies have many components in common, such as the anode and phosphors used on the anode, spacer technology, getters and much of the assembly process. Now let's look at what is unique to SED and other FED technologies.

3. Differences between SED and FED

The significant differences between SED and FED are clearly seen in the electron source plate and the drive electronics. Before we discuss the significance of the differences, we must first understand how each is structured and operated.

3.1 Standard FED emitter configurations

Some typical configurations using carbon nanotube emitters are shown in Figure 4. Microtip emitters have similar configurations. In either case, electron beams are created by extracting electrons from the emitter structure (CNT or microtip) as a result of the high electric fields applied to the emitter from voltage differences between the anode, gate and cathode electrodes. In some cases, the anode field contributes to the electron emission, but the cathode-gate voltage difference controls the emission current intensity.

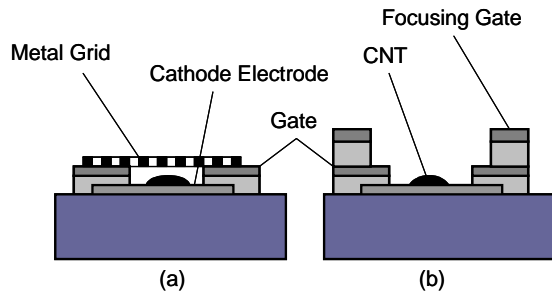


Figure 4: Configurations used for CNT emitters. (a) A metal grid is suspended over the CNT electron-emitter patch that sits on top of a cathode line. This is a configuration used by ANI. (b) The gate structure is fully integrated and photolithographically formed on the cathode plate. This design also exhibits additional focusing electrodes to help control the electron beam width.

Electron current from the FED emitters is controlled by the field applied to the emitter as a result of the cathode to gate bias and is governed by the Fowler-Nordheim equation [15]. The current from the emitter as a function of the applied voltage is highly non-linear. An example of the I-V characteristics for a CNT emitter is shown in Figure 5. In addition to the applied field, the emission current is also dependent on the workfunction (ϕ) of the emitter and the shape of the emitter. As the workfunction is decreased, such as with a coating of alkali metal, it is easier to extract electrons at lower fields. As the shape of the emitter becomes sharper, it is also easier to extract electrons since the local electric field is higher at the point of the emitter.

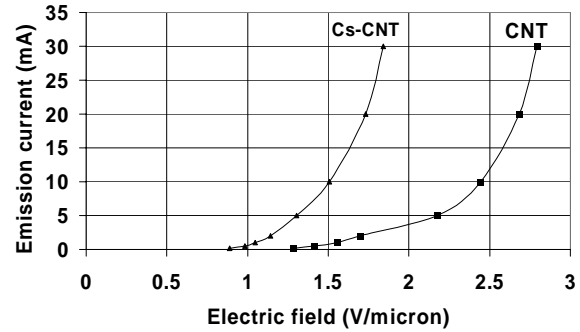


Figure 5: Emission current as a function of electric field applied to a CNT emitter and a CNT emitter coated with cesium. Cesium lowers the workfunction and allows emission at lower extraction fields [16].

There are two important points to make concerning the standard FED approaches. First, the configuration is largely vertical. Typically, the gate is placed near the cathode electrode such that the applied electric field is mostly vertical at the cathode electrode where the CNT emitter is deposited. The electrons that are emitted from the cathode travel directly to the anode. Some broadening of the beam does take place as a result of the lateral components of the applied field, but these are limited as much as possible by the design or are corrected with additional focus electrodes placed in the path as needed. Typically, the goal of the FED designer is to prohibit the electrons from striking any other surface other than the anode after the electrons leave the emitters. As you will see later, the SED emitter includes a multiple-scattering process.

Secondly, typical FEDs are voltage-drive devices. In a passive matrix FED display, it is difficult to apply more than two or three voltage levels between the cathode and the gate (ON and OFF voltages), so gray scale in the image is achieved by pulse width modulation. As for all passive matrix flat panel displays, the image is created line-by-line. As one line is activated, the pixels in that line are switched ON by the column drivers; the period that each pixel in the line is left ON is determined by the luminous intensity required from that pixel for that image frame. Since the emission current from the emitters is highly non-linear and the fabrication of the emitters is difficult to control, emission uniformity and thus image uniformity is the major problem to overcome for microtip and CNT displays. Fabrication techniques have improved the uniformity of CNT-based FEDs. Often emission uniformity across the cathode is controlled by a current feed-back resistor placed in line with the cathode electrode.

Fabrication of FED emitter is dependant of the approach taken by the FED development team. Motorola and LETI have developed processes that require CNT growth directly on the cathode substrate while groups like ANI and Samsung have developed processes that allow printing of the CNT. Printing approaches are more favorable for fabricating large area cathodes with uniform emission in high volume as opposed to high-temperature CVD approaches required for direct CNT growth. The printing approaches require an

activation step, but even this has been optimized for large-area fabrication using a bead-blasting technique [17].

3.2 Structure of SED

The SED structure is unique to other FED approaches in that the electron beam current supplied to the anode for each pixel is generated in a 2-step process. Step 1) The electron source operates by first emitting electrons laterally (parallel to the cathode substrate) across a very narrow gap formed between two electrodes. The gap between the electrodes, although small, on the order of a few nanometers, is still a vacuum gap that requires application of an electric potential to extract electrons from one electrode through the vacuum tunneling barrier to the other electrode. The current across electrode gap follows the Fowler-Nordheim law and is thus highly non-linear, allowing for matrix addressability as will be discussed later. This lateral emitter structure is where the term Surface Conduction Emitter (SCE) comes from. Figure 6 is a diagram of the SED emitter structure [4].

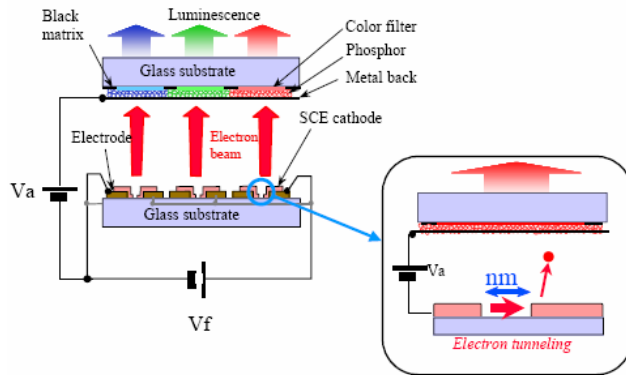


Figure 6: Structure of SED [4]. Each sub-pixel has a unique pair of electrodes that supplies an electron current.

Step 2) The electrons that tunnel across the gap and strike the counter-electrode are either absorbed into the counter-electrode (thereby creating only heat and no light) or they are scattered, captured by the electric field created by the anode potential and accelerated to a particular phosphor dot, thus creating a spot of red, green or blue light. This combined electron emission plus electron beam scattering process is illustrated in Figure 7 where V_a is the anode potential and V_f is the driving potential across the gap. Multiple scattering events may take place before the electron is captured by the anode field. The efficiency of the number of electrons captured by the anode field (I_e/I_f , Figure 7) is quite low, on the order of 3%, but the power efficiency is reasonable since V_f is low, on order of 20 V [7]. Note also that the uniformity of electron current reaching that anode is dependant on field emission current at the gap convoluted with the efficiency of scattering events from pixel-to-pixel.

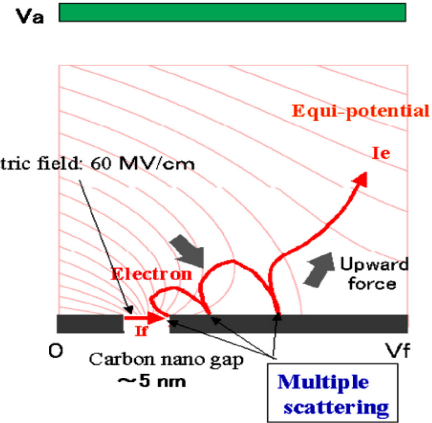


Figure 7: Surface Conduction Emitter emission mechanism [7].

The emitter that is described above is fabricated using a combination of technologies [7]. The simple matrix wires are deposited by a printing method using silver wires and insulating films at the crossovers. Platinum electrodes are formed using thin-film lithography, the gap between these electrodes is 60 μm . The carbon nano gap is created in a two step process, beginning by depositing a PdO film (10 nm thick) by ink-jet printing over and between the Pt electrodes. This film is composed of ultrafine particles of PdO of diameter about 10 nm. First, a gap is “formed” in this film by reducing the oxide by passing a series of voltage pulses across this PdO film between the two Pt electrodes. The PdO is reduced by the heat of the pulses as the substrate is in a vacuum environment. As the PdO is reduced, the film is stressed and eventually a sub-micron gap is formed across the diameter of the PdO dot. Second, the gap is “activated” by exposing the cathode to an organic gas and more pulse voltages are applied across the gap. These pulse voltages create a local discharge that leads to CVD-like deposition of a carbon film in the gap, such that the gap narrows to a self-limiting distance of order 5 nm. When the gap is large, carbon material is deposited as a result of the disassociation of the hydrocarbon molecules in the plasma resulting from the discharge. As the gap becomes smaller, the local discharge current created by the pulse becomes large and material is evaporated. At a gap of about 5 nm, deposition and evaporation of carbon material reaches equilibrium. The width of this gap is controlled by the pressure of the organic gas and the pulse voltage. A cross section image of this gap is shown in Figure 8.

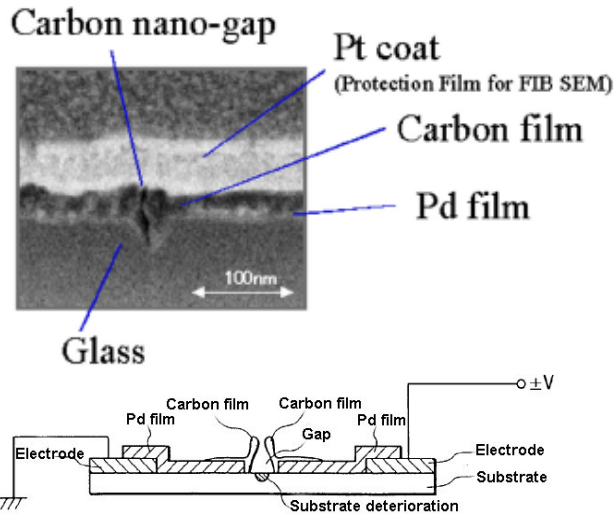


Figure 8: (Top) SEM cross section image of the carbon nano gap fabricated by the forming and activation processes [7]. (Bottom) Diagram of the carbon nano gap structure. The substrate deterioration is a result of the high temperature created locally by the activation process. [18].

Similar to the FED, the SED is driven line-by-line as shown in Figure 9. The scanning circuit generates the scan signal (V_{scan}) and the signal modulation circuit generates a pulse width modulation signal (V_{sig}) that is synchronized with the scan signal. Because of the highly non-linear I_c - I_f characteristics of the surface conduction emitter, it is possible to drive each pixel selectively using a simple matrix x-y configuration without active elements and still achieve a luminance contrast ratio of 100,000:1 with a signal voltage of 18.9 V and a scanning voltage of 9.5 V [7]. Contrast these values with typical signal voltage of 35 – 50 V and scanning voltage of 50 – 100 V for CNT-based FED structures. The SED switching devices are much lower voltage but they must be designed for much higher steady-state current loads, as much as a factor of 30 higher as a result of the inefficiency of the SCE electron scattering mechanism. The larger currents of the SED also forces the interconnect lines to have lower resistances compared to FED as even a small voltage drop along the line can result in edge-to-edge non-uniformity.

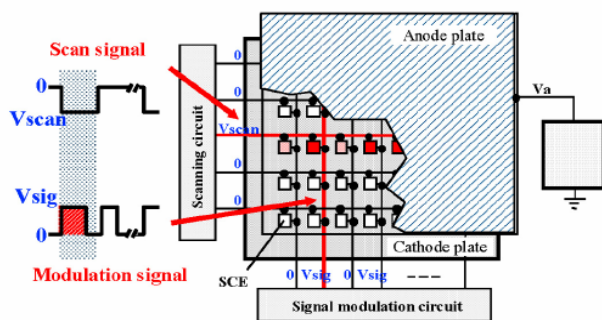


Figure 9: Diagram of SED matrix-addressed driving method [7].

4. Conclusions

The SED and other FED technologies have many components in common, such as the anode configuration and phosphors used on the anode, spacer technology, getters and much of the assembly process. Significant differences exist in the emitter structure although both SED and other CNT-based FED structures can be fabricated using printing technology to help lower manufacturing cost for large area displays. Both emitter structures obey the Fowler-Nordheim characteristic allowing high contrast ratio using simple x-y matrix addressing. SED has already demonstrated 100,000:1 contrast ratio; FED could also demonstrate similar values if the same anode structure is used. Both SED and CNT-based FEDs (for printed CNT layers) require an activation step, although the nature of the activation process is much different. The SED is driven at voltages about 20 V or lower, but require much higher current capability. Demonstrated CNT-based FEDs typical operate in the range of 50 – 100 V but the drive current is much lower. Because of the high drive currents and low drive voltages required, the interconnect lines for SED need to be much more robust. Thus both SED and CNT-based FED have demonstrated or have the potential to demonstrate low-cost approaches for making high-quality, large area HDTV displays. The fact that SED is closer to market reflects the fact that this technology has been in development longer.

5. References

- [1] U.S. Patent 5,773,921 and RE38,223E; and RE38,561E.
- [2] J. Dijon, *et al.*, Proceedings IDW 2005.
- [3] Y. Ishizuka, *et al.*, p. 1655, Proceedings IDW 2005.
- [4] T. Oguchi, *et al.*, p. 1929, SID 2005 Digest.
- [5] J. M. Kim, 2nd International Symposium on Nanomanufacturing (ISNM 2004), p. 47.
- [6] E. J. Chi, *et al.*, SID 2006 Digest, p. 1841.
- [7] K. Yamamoto, *et al.*, J. of the SID, Vol. 14, p. 73 (2006).
- [8] B. Cummings, *et al.*, p. 422, SID 2001 Digest.
- [9] K. A. Dean, *et al.*, p. 1847, SID 2006 Digest; and Z. Yaniv, *et al.*, "Nanoelectronics as Applied to Field Emission Displays Using Carbon Nanotubes", elsewhere in these proceedings.
- [10] Marco Amiotti and Stefano Tominetti, p. 25, Vacuum Solutions, July/August 1988.
- [11] K. A. Dean, *et al.*, p. 1936, SID 2005 Digest.
- [12] R. L. Fink, *et al.*, p. 1748, SID 2006 Digest.
- [13] T. Sugawara, *et al.*, p. 1752, SID 2006 Digest.
- [14] K. Ishizeki, *et al.*, p. 1756, SID 2006 Digest.
- [15] Robert Gomer, *Field Emission and Field Ionization*, pub. American Institute of Physics, 1993.
- [16] US Patent 6,885,022 and Z. Yaniv, 2nd International Symposium on Nanomanufacturing (ISNM 2004), p. 705.
- [17] R. L. Fink, *et al.*, p. 1251, Proceedings IDW 2004.
- [18] Taiko Motoi, *et al.*, US Patent Publication 20020096986.