Development of High-image quality and High-durability Direct Conversion Digital Radiography System “FDR AcSelerate”

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Abstract

FUJIFILM’s newly-developed “AcSelerate”, a digital radiography system, simultaneously realizes high-image quality, low-dose image acquisition and highly improvement on durability. “AcSelerate” contains a new direct conversion detector using a fullerene (C60)-doped polymer layer added on a thick amorphous selenium (a-Se) layer coupled to an amorphous silicon thin film transistor (a-Si TFT) array. The C60-doped polymer layer changes the electronic junction between a-Se and the electron-transporting layer smoothly, leading to the improved lag reduction characteristics. This polymer layer also improves the durability of the detector. The crystallization of a-Se which causes the pixel defects is drastically prevented by the polymer layer. With respect to low dose examination, the preview image is available on the Console Advance screen in only 2 seconds, allowing quick review of the image. Additionally, cycle time between exposures is approximately 4 seconds, allowing the technologist to work efficiently and make the process smoother for the patient. Moreover, “AcSelerate” can relieve the technologist of calibration work.

1. Introduction

We have succeeded in developing a new X-ray image detector. The detector “directly converts” the X-ray signals that have passed through a patient to electric signals using amorphous selenium (a-Se). The detector reads the electric signals using a-Si TFT to produce a digital image while keeping the high image quality which is characteristic of a direct-conversion a-Se detector. In addition, we have reduced the image lag and enhanced durability of a-Se semiconductor layer. The FDR AcSelerate (Fig. 1) equipped with this detector is a digital radiography system which realizes high image quality and low radiation dose, as well as high throughput. The background of development, the configuration, features of the system and the capabilities will be outlined in this report.

1.1 Background of Development

In recent years, more and more digital radiography (DR) systems are being used in the diagnostic radiography as a medical field is going digital. FUJIFILM pioneered digitalization of diagnostic X-ray imaging using computed radiography (CR). Since then, we have been providing digital diagnostic X-ray imaging systems. These systems are well received; existing X-ray systems can be easily digitized by combining with our digital products.
Compared with the conventional screen/film (S/F) system or CR system, digital radiography has a higher efficiency in X-ray use and that leads to high image quality and radiation dose reduction. Especially, the “direct-conversion” flat panel detector (FPD) using a-Se is high in both image sharpness and sensitivity. On the other hand, in connection with FPDs using a-Se, the improvement of the throughput by reducing lag and the reduction of pixel defects resulting from a-Se crystallization have been required.

Solving these problems, we have developed the AcSelerate (Model: FDR200). The diagnostic capabilities are improved with high sensitivity and high sharpness. Good workflow, such as comfortable throughput, and high reliability are also achieved.

1.2 AcSelerate System Configuration

As shown in Fig. 1, the AcSelerate consists of the imaging unit (X-ray source unit and image detector unit) and the console. The imaging unit comes in one-tube two-panel (upright and supine positions) system or one-tube one-panel (upright or supine position) system. The images captured by the imaging unit are processed and displayed on the console. The images then can be sent to an external server, stored on a PC or edited on an application program. The imaging unit consists of the X-ray source unit that emits X-rays and the newly developed image detector that detects an image of X-rays passing through a patient’s body. The following sections describe the image detector that features in the AcSelerate and provide the capabilities of the system equipped with the detector.

2. Image Detector

The AcSelerate is equipped with a high image quality X-ray detector characterized by the amorphous selenium and the polymer protective layer used for image lag reduction and high reliability. Fig. 2 shows the overview of the image detector. The detector has layers, which are formed with hole-transporting layer, X-ray photoconductive layer (PCL), protective layer, electron-transporting layer and top electrode, on the TFT for reading out signals. The following sections will explain each function of the individual layers and the principle of imaging.

2.1 Principle of Imaging

When X-rays enter the energized semiconductor layer, the X-ray quantum is absorbed in the layer, and the electrons and holes which are finally produced are transported along the electric field. The “direct conversion” system uses this photoconductive effect to convert X-ray signals to electric signals. As shown by the cross section of the detector in Fig. 2, if X-rays enter when a positive voltage is applied to the top electrode, the produced holes are carried to the pixel electrodes. Then by controlling the TFT device, the detector reads out the charge of each pixel, and converts them to digital signals via the amplifier circuit and the ADC circuit, thereby acquiring image data.

2.2 Enhancing Reliability

As a-Se is a semiconductor, the glass transition point is as low as 40 °C, and for this reason, it crystallizes at room temperature gradually into crystalline selenium which is a conductor. An FPD using a-Se requires a cooling mechanism, such as water-cooling. The operating ambient temperature range is also limited.

The AcSelerate employs the protective layer containing polymer to improve the temperature resistance of a-Se. That provides air cooling and expands the operating ambient temperature range. The polymer protective layer bonded to the a-Se surface prevent from the crystallization of a-Se1).

2.3 Reducing Image Lag

A direct-conversion FPD is liable to image lag resulting from a delay in transportation of free charges produced in the X-ray PCL. An energy barrier in the interface between the layers is pointed out as one of the causes of the delay.

To improve the transportation of free electrons, the AcSelerate uses a fullerene (C60)-doped layer as the protective layer. Fig. 3 shows the energy level diagram of the device.

![Fig. 2 Schematic view of the image sensor.](image)

![Fig. 3 Proposed energy level diagram of the detector stack.](image)
The Co-doped polymer protective layer improves connection between the X-ray PCL and the electron-transporting layer to enhance the transportation of free electrons produced in the X-ray PCL. The hole flow by the bias applied to the top electrode is also minimized and that helps to reduce dark current. With these electric characteristics, the AcSelerate achieves stable image lag reduction.

### 3. System Capabilities

#### 3.1 Image Quality

DQE and MTF are widely used as comprehensive indices for image quality evaluation. DQE and MTF of the AcSelerate and our conventional model “FCR VELOCITY” are shown in Fig. 4. We used RQA5 as a beam quality in accordance with the IEC standard. As shown in Fig. 4, the AcSelerate has a high MTF compared with the VELOCITY. It demonstrates the effect of the direct conversion using amorphous selenium. About DQE, the AcSelerate is higher than VELOCITY with 1 mR, which is a standard dose for general radiography (2.5 times higher at 1 ccm/mm and 5 times at 2 ccm/mm). Additionally, the DQE of the AcSelerate is also high with 0.3 mR which is in a low dose range, and these indicate the potential of the AcSelerate for radiation dose reduction.

#### 3.2 Workflow

The AcSelerate has the following functions and provide comfortable workflow which enhances the efficiency of examinations.

1. **Comfortable throughput**
   We have optimized time to accumulate charges and time to read out the accumulated charges for low-dose radiography that requires short radiation time. As a result, the preview will appear in two seconds and the processed image will appear in four seconds. That allows quick review of images and reduces the examination time.

2. **No calibration by user is needed**

3. **CR/DR common console**
   For the console to operate the DR and do image processing, we have employed the favorably received CR console for FCR, “Console Advance”, with some improvements. If an operator is using an FCR, he or she can still operate the examination with DR in the same way. The console is also intuitive and it is easy to operate for an unfamiliar user. In addition, the AcSelerate and a digital FCR reader (models specified by us) can be operated on one “Console Advance” and the image processing work will be integrated. When several imaging machines are working in one room, the Console Advance will simplify the workflow without redundancy in distribution from the RIS (Radiography Information System) or transmission of images to the PACS (Picture Archiving and Communication Systems) (Fig. 5).

4. **Auto positioning functions**
   The ceiling suspension system with a 5-axis motor works in conjunction with the radiography menu and automatically moves the X-ray tube to the predetermined position.

5. **Tilting functions**
   The flat panel for upright position can be tilted from minus 20 to plus 90 degrees.

6. **Dose-Area-Product (DAP) meter**
   The DAP meter keeps a record of the area dose of every image. It is used for patient dose management.

7. **Grid replacement direction is selectable (both right and left)**
   The installation location in the room is not restricted.
4. Conclusion

The digital radiography system “AcSelerate” is high in both image sensitivity and sharpness, thanks to its image detector, which is characterized by direct conversion with amorphous selenium. The conventional problems of image lag and pixel defects due to crystallization have been resolved. The MTF remains high at high frequencies and the system is expected to have higher visibility of very fine bone trabeculae. The DQE remains high in a low dose range and the system is expected to reduce the radiation dose. At the moment, no other radiography systems provide both high image quality and throughput as this system. We expect AcSelerate will help improve the precision and efficiency of examinations and diagnoses and reduce patients’ exposure to radiation.

References


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