Digital X-ray inspection: from alpha to gamma

Hello, Habr!

I have been engaged in digital X-ray inspection for 5 years already so I have been itching to write something good, eternal about it for quite some time. A little bit about myself – I've devoted 12 years of my life to hardware development. I started working as a mechanical design engineer, then I dealt with circuit engineering, development of printed circuit boards (PCB), documentation development, work with CNC, HW/SW integration, project management, marketing. Basically, a little bit of everything.

We develop and manufacture digital flat panel X-ray detectors (FPD) for industry and medicine in Russia. In case you forgot what X-ray is, see «Home-based experience with X-raying», «Home-made CT scanner» - and don't forget about harm of ionizing radiation during home experiments.

What fields need this?

Firstly, medicine, it's the largest market. X-ray on film becomes outdated, major cities apply the digital one.

Secondly, military and security services. Body scanners use a detector looking like a narrow ruler but when it's necessary to get a high quality image, for example while detecting prohibited products smuggled in some weird places of human body or searching for stashes of drugs/bugs, a flat panel detector is used.

Thirdly, production. It's about control of quality of welding, castings, soldering and assembly of electronic components. While analog X-ray method(film) has still been being actively used for non-destructive testing of welding and castings as the standard on the use of digital X-ray was adopted in Russia only in 2017, major operators of PCB assembly line have X-ray inspection of BGA chips at least.

A little bit of history

The first X-ray imager was the film, it's produced in cassettes of different sizes and sensitivity, it's working principle is the reaction of light-sensitizing agent to X-ray with further developing/amplification. It's difficult, it's long, in case you've made a mistake during the process of exposition you won't be able to know about that before the developing.

Of course natural laziness instigated to look for a more convenient solution, and computed radiography (CR) played this part. There is a phosphoric storage plate at the entrance, it saves the latent X-ray image. To see the result place the plate into a digitizer where the IR laser scans the entire surface and the photosensor detects luminescence. So you get a digital image, then you erase the previous image by means of light-striking. Diameter of the laser beam (25-100 µm) defines resolution of the system. It's an easier way than in case of analog X-ray but it's not in the blink of an eye. One plate suffices for a few thousands of expositions.

Since then progress have created different systems of instantaneous conversion, for example, X-ray image intensifier(XRII). XRII allowed working in real time though with distortions. The working principle is the following. There is a luminophor (scintillator) at the entrance that generates visible light, the light generates electrons on a photocathode, the electrons are accelerated and detected by the luminophor again; there's also a lense and a CCD-sensor. Not that easy, is it? Ability of focusing electron beams and image scaling were an advantage of such a system but it also had some drawbacks - geometric distortions of X-ray image converter and its size. It could weigh up to 50 kg. XRII looks something like this (you can see the CCD camera and huge X-ray image converter):

The next stage – detectors based on CCD matrices. Scintillator, optics and the sensor itself – they are already state-of-the-art. Advantage – high resolution, up to 2kx2k. Disadvantage – size of the CCD sensor is about 2x2 cm, let's remember photo cameras. They are used in microtomography as a low cost equivalent of flat panel detectors.

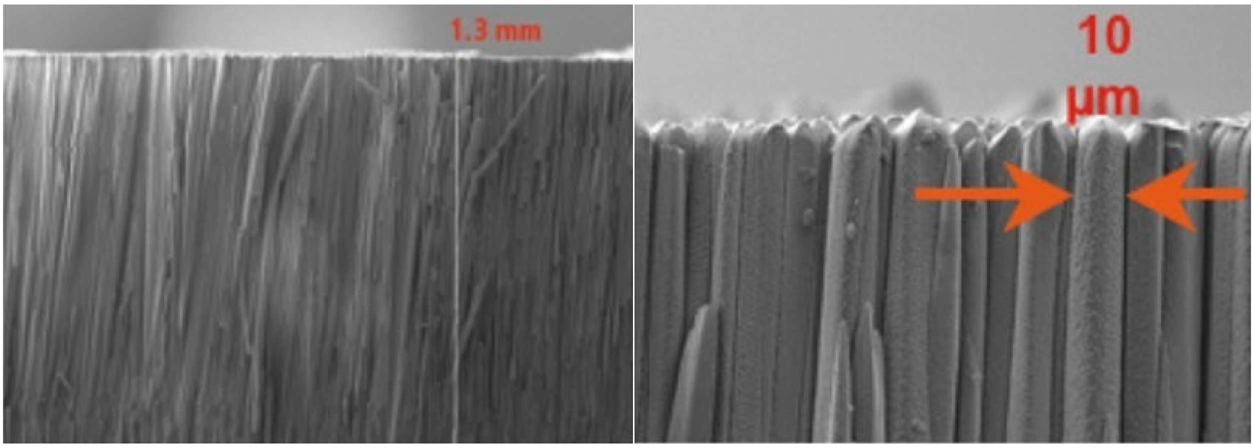
Present day

Almost all modern detectors are based on CMOS sensors or TFT photo sensors, in our production we use CMOS sensors. Size of the matrix is from 10x10 cm to 40x40 cm, well enough. CMOS sensors have smaller size than TFT but with pixel 25-70 µm. TFT with size

40x40 cm have pixel 130-200 µm. CMOS are usually used when high sensitivity is required (mammography, microtomography), in any other case TFT should be applied. All the sensors are manufactured in Asia.

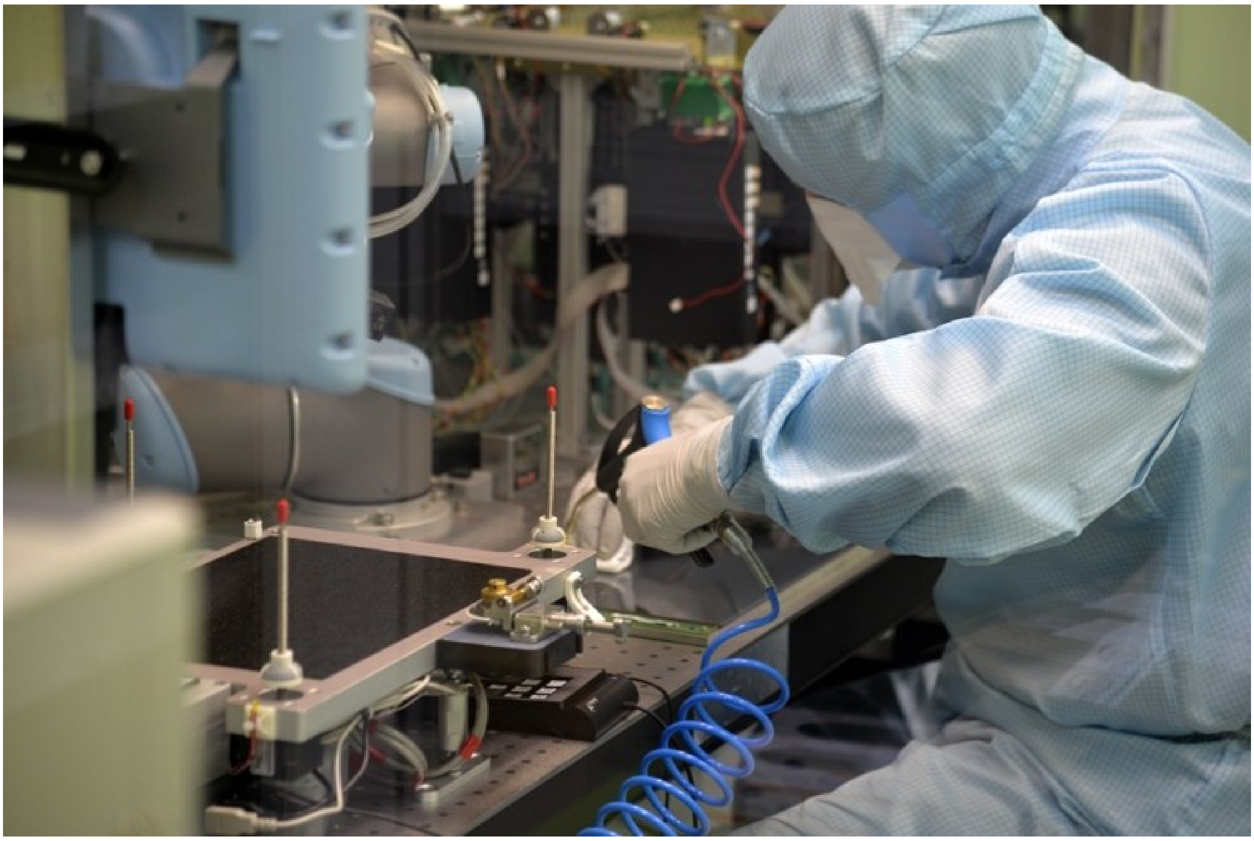
You can see the detector scheme in the figure. X-radiation is converted into optical radiation by means of a scintillator layer. As CMOS sensor doesn't work well with ionizing radiation, we separate it from the luminophor by means of a fiber optic plate (FOP). FOP is not just a glass, it has cerium additives to prevent darkening under X-ray over time.

The scintillator material is usually caesium iodide (CsI) or gadolinium oxysulphide (GadOx). They differ in structure. CsI is needle-like crystals through which light passes as through fiber, GadOx is a continuous layer with strong scattering effects. This is what a caesium iodide crystal looks like:



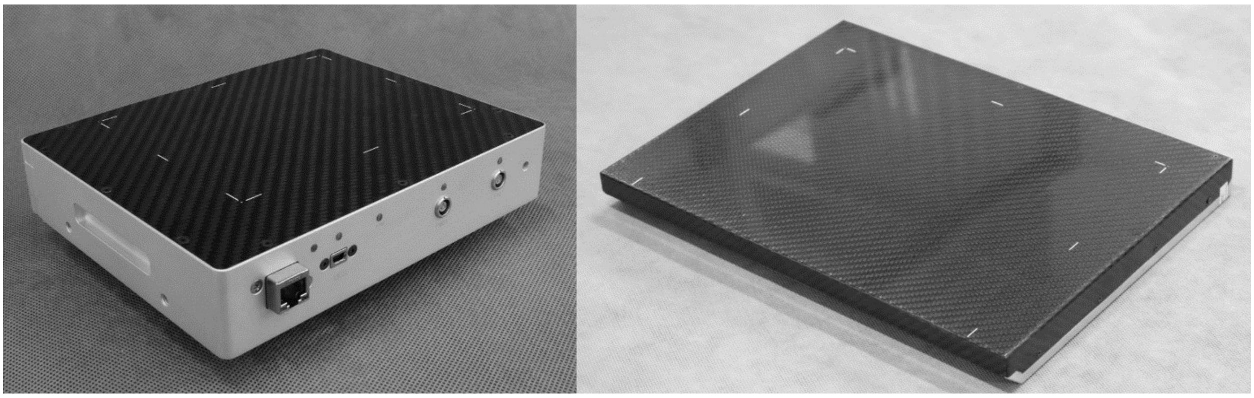
X-ray conversion to light and passing through luminophor is rather a complicated process, everything matters: thickness, type of coating (it's better to grow crystals on FOP), radiation energy. I won't go into details, if you want to learn more about sensitivity – read «X-Ray Detector Characterization — a comparison of scintillators». Loosely speaking, GadOx is used for energy up to 60 kv, Csl for energy over 100 kv, for midpoint both variants are possible. For your information: the range for mammography is 20-40 kv, for other medical fields is 50-150 kv, for industry – 150-450 kv.

I almost forgot, you can't just assemble this all into one block, you need a dust-free room and equipment for aligning sensors as accurately as possible, we stay within 1 pixel.



GigE Vision/Genicam Is often used as a data transfer protocol as 1Gb/s Ethernet is a physical layer of data transfer. It's insufficient for a matrix of large size and dynamic operation mode, you have to use Full CameraLink or optical fiber.

As a result the detectors look like this:



It's possible to take images of welding, ceramics, metal powder printing, boards with BGA chips, laboratory animals and do tomography of small objects. In case you are interested or have original ideas on application – don't hesitate to write to us, your feedback will be appreciated.