ADVANCED MATERIALS

Supporting Information

for *Adv. Mater.,* DOI: 10.1002/adma.202008539

Multimodal Digital X-ray Scanners with Synchronous Mapping of Tactile Pressure Distributions using Perovskites

Jiuk Jang, Sangyoon Ji, G. Krishnamurthy Grandhi, Han Bin Cho, Won Bin Im, and Jang-Ung Park**

Supporting Information

Multimodal Digital X-ray Scanners with Synchronous Mapping of Tactile Pressure Distributions using Perovskites

Jiuk Jang, Sangyoon Ji, G. Krishnamurthy Grandhi, Han Bin Cho, Won Bin Im, Jang-Ung Park**

Dr. J. Jang, Dr. S. Ji, Prof. J.-U. Park
Nano Science Technology Institute, Department of Materials Science and Engineering, Yonsei University, Seoul 03722, Republic of Korea
E-mail: jang-ung@yonsei.ac.kr
Dr. G. K. Grandhi, H. B. Cho, Prof. W. B. Im
Division of Materials Science and Engineering, Hanyang University, Seoul 04763, Republic of Korea
E-mail: imwonbin@hanyang.ac.kr

This supporting information includes:

Supporting Methods

Supporting Figure S1–S14

Supporting Table S1

Caption of Supporting Movie S1

Supporting Methods

Fabrication of the single pixel diode device

For bottom and top electrode, the indium tin oxide (ITO) films were deposited onto two different polyimide (PI) films using the RF magnetron sputtering with an ITO (In_2O_3:SnO_2 = 90:10 wt%) target. The sputtering conditions were RF power of 150 W, working pressure of 1 mTorr, a gas flow rate ratio of Ar/O_2 = 10/1 in standard cubic centimeter per minute (sccm), and deposited at room temperature. The HTL was fabricated onto ITO coated PI film by spin-coating the poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS, AI 4083, Clevios) solution and annealed at 115 °C for 10 min. The HBL was fabricated by spin-coating the titanium dioxide nanopowder (TiO_2, particle size: 21 nm, Sigma Aldrich) dispersed in 2-propanol (2 wt%) onto ITO coated PI film. An Al protection layer with a thickness of 100 nm was thermally deposited on the opposite side of HBL/ITO/PI film to protect the perovskite layer from moisture as well as to prevent noise caused by the absorption of visible light. The perovskite layer was formed onto the bottom panel using doctor blades with a thickness of 300 μm. The thickness of the coated MPC films was controlled by the guide frames. Finally, the diode device was completed by covering the top panel and annealing (at 100 °C for 3 h) together before the perovskite solution was solidified.

Fabrication of the pressure-sensitive IGZO TFT backplane

The 20 nm-thick n-type IGZO (In_2O_3 : Ga_2O_3 : ZnO = 1:1:1 atomic ratio) channel was deposited onto a PI substrate with the radio frequency (RF) magnetron sputtering at the sputtering condition of RF power of 200 W, working pressure of 3 mTorr, a gas flow rate ratio of Ar/O_2 = 12/8 sccm, and the substrate was annealed at 200 °C during the deposition process. And IGZO film was patterned photolithographically with a channel width (W) and length (L) with the 16 μm and 6 μm, respectively. As a source (S) and drain (D) electrode, Al/Au (20 nm/60 nm) were formed by thermal evaporation and photolithography. Here, Al and

Au were used to prevent ohmic contact with IGZO and oxidation of Al, respectively. For elastomeric partition spacer, the 20 μm-thick polydimethylsiloxane (PDMS) film was cut by laser ablation system (CO_2 laser, Epilog Mini 18, Cutting Edge Systems, Inc.) to make via holes for connecting between perovskite and drain electrodes as well as for defining the local air gap as the air dielectrics. Then, the PDMS layer was laminated with the as-prepared bottom panel. The electrode of gate (G) with Cr/Au (5 nm/60 nm) was form by thermal evaporation and photolithography on the other panel of a PI (thickness of 25 μm) film, and via holes were then formed by CO_2 laser at the same position with those of PDMS layer. And, this panel was laminated onto bottom panel. Before the lamination process, the surface of PDMS was exposed using ultraviolet/ozone (UVO) for 10 minutes to enhance the adhesion between the gate electrode layer and a bottom panel. For precise alignment of each layer, a stage that can be moved in the x-y-z axis and an optical microscope were used.

Measurement of the basic spatial resolution

The basic spatial resolution of the multiplexed detector was determined with a double wire image quality indicator (IQI, duplex, EN 462-5). The X-ray image of the duplex IQI sample was obtained at X-ray tube voltage of 50 kV with dose rate of 1.6 mGy_{air} s^{-1} for 500 ms. And the image was evaluated mathematically using a line profile tool. By pulling the line profile over the X-ray image, the average of the peaks corresponding to two lines of a wire pair is determined.

Supporting Figures

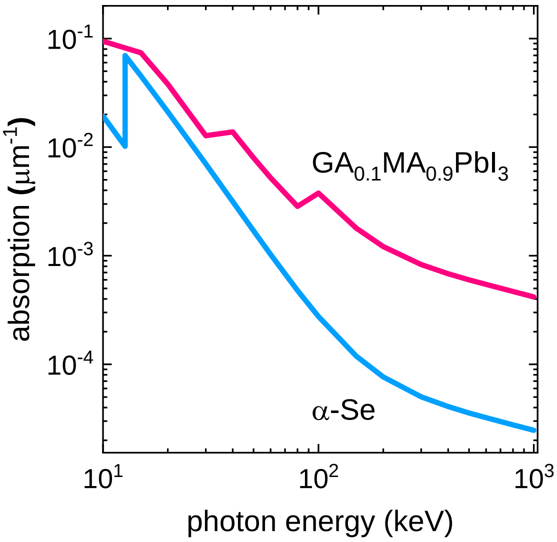

Figure S1. Comparison of absorption of $GA_{0.1}MA_{0.9}PbI_3$ and α-Se as a function of photon energy. The data was plotted based on the atomic absorption coefficients of the individual constituents of materials.[1]

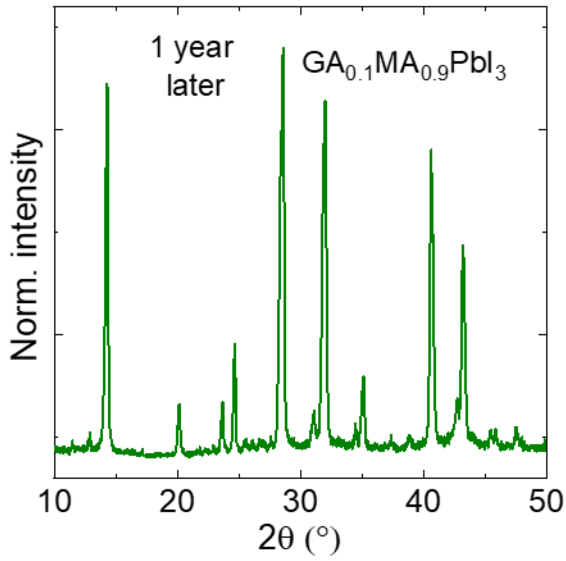

Figure S2. XRD pattern of $GA_{0.1}MA_{0.9}PbI_3$ thick film which was stored in the ambient condition for a year.

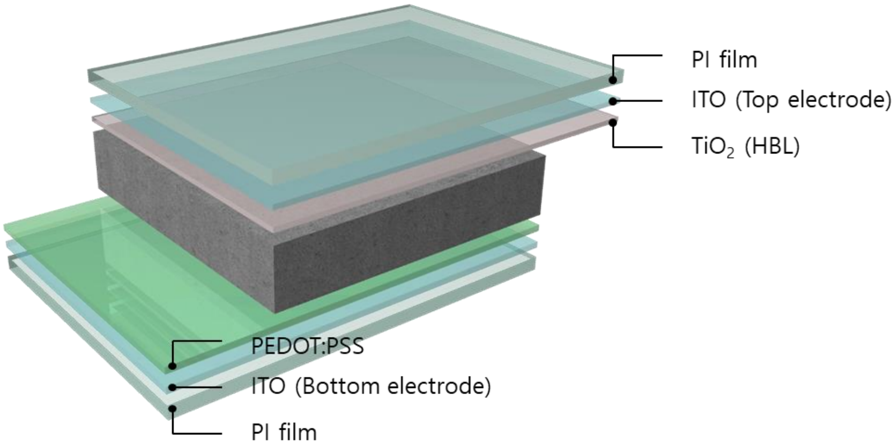

Figure S3. Schematic illustration of the diode-configured X-ray detector.

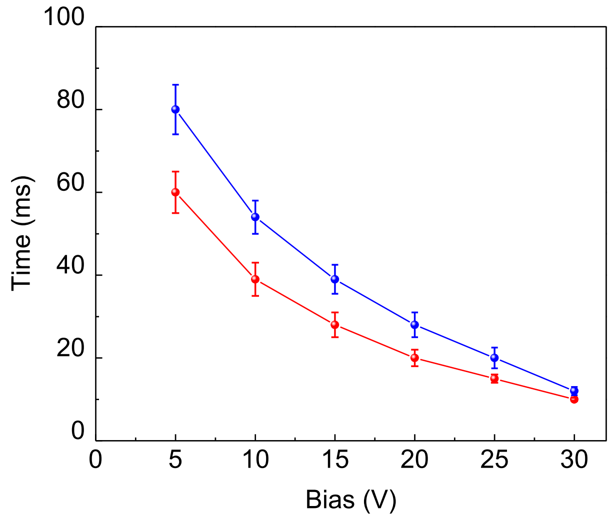

Figure S4. The response (red) and recovery times (blue) as a function of applied bias voltages.

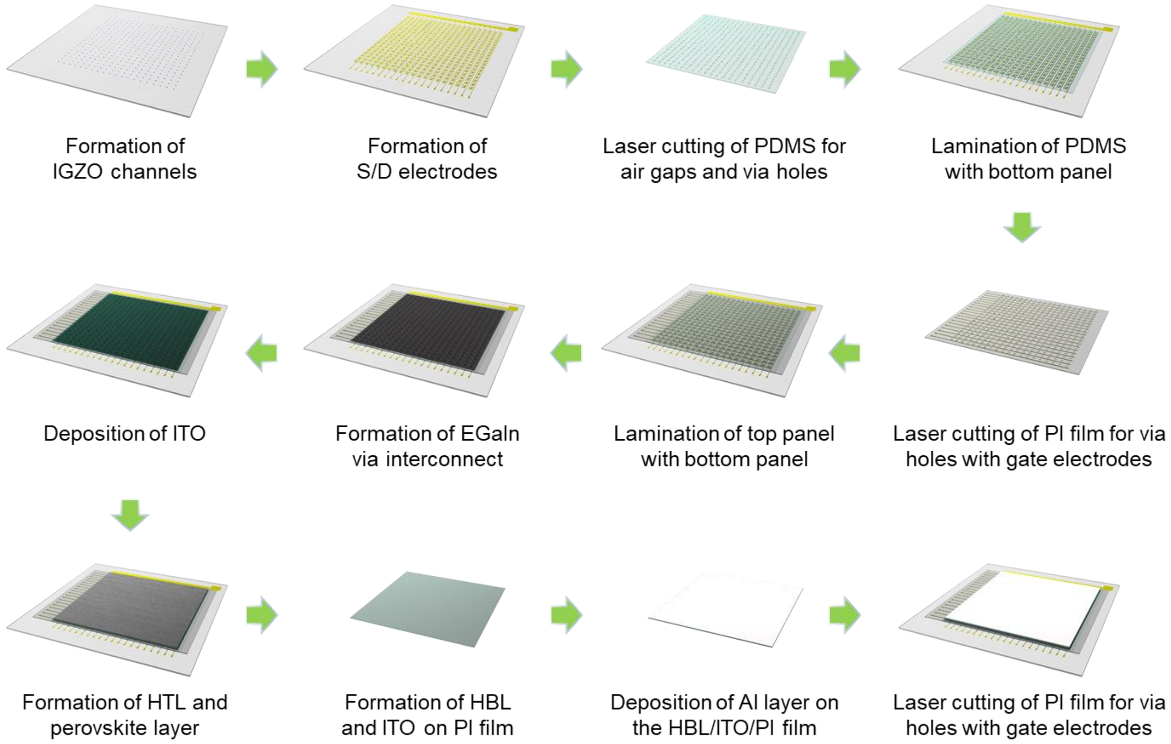

Figure S5. Schematic illustration on the fabrication process of the multiplexed detector.

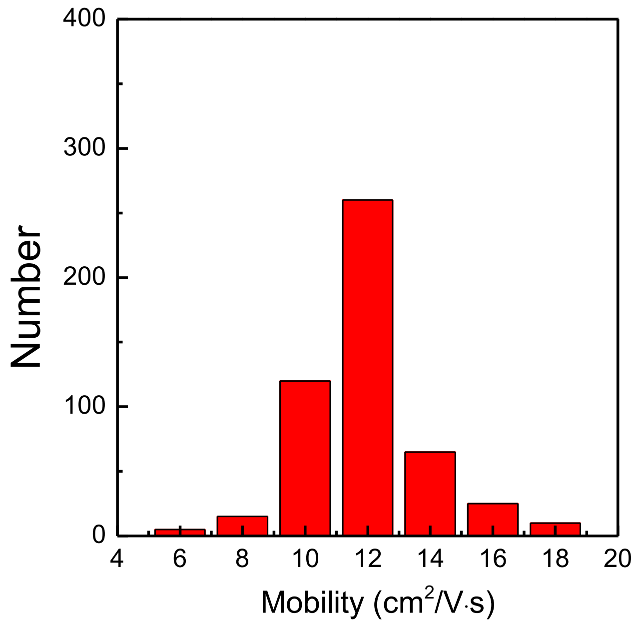

Figure S6. Statistical distribution of the n-channel mobility of the 500 pressure-sensitive IGZO TFTs.

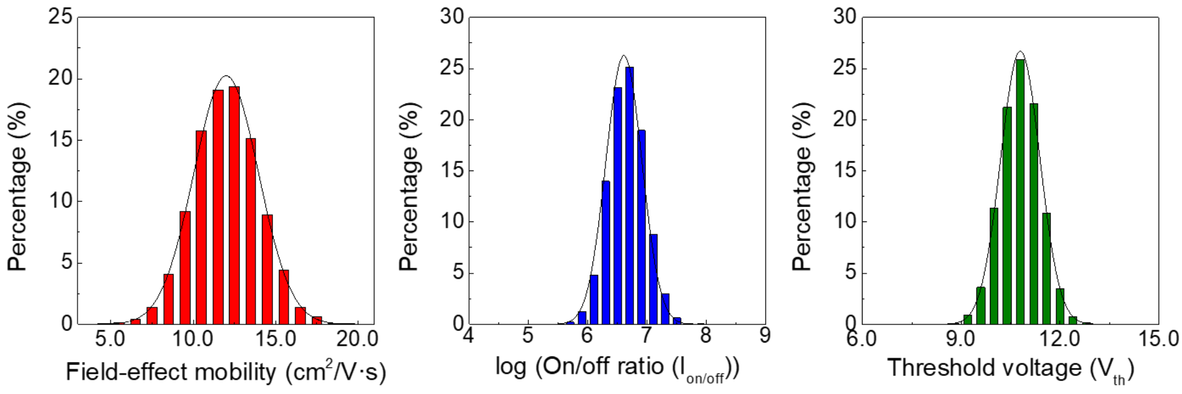

Figure S7. The statistical distributions of the averaged field-effect mobility, on/off ratio of I_D ($I_{on/off}$), and threshold voltage (V_{th}) of 16,000 TFTs.

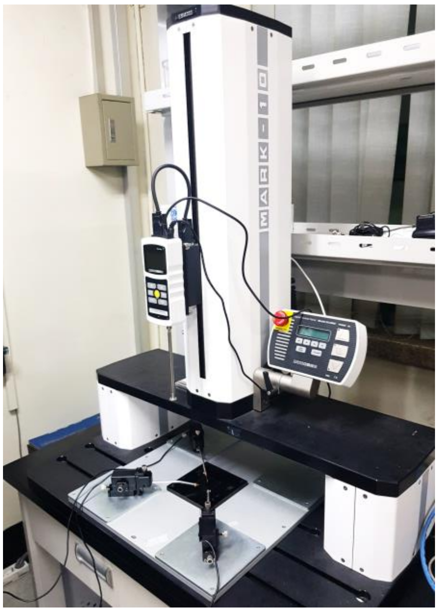

Figure S8. The experimental setup that consisted of a motorized z-axis stage (Mark-10 ESM303) and a force gauge (Mark-10 M7-20).

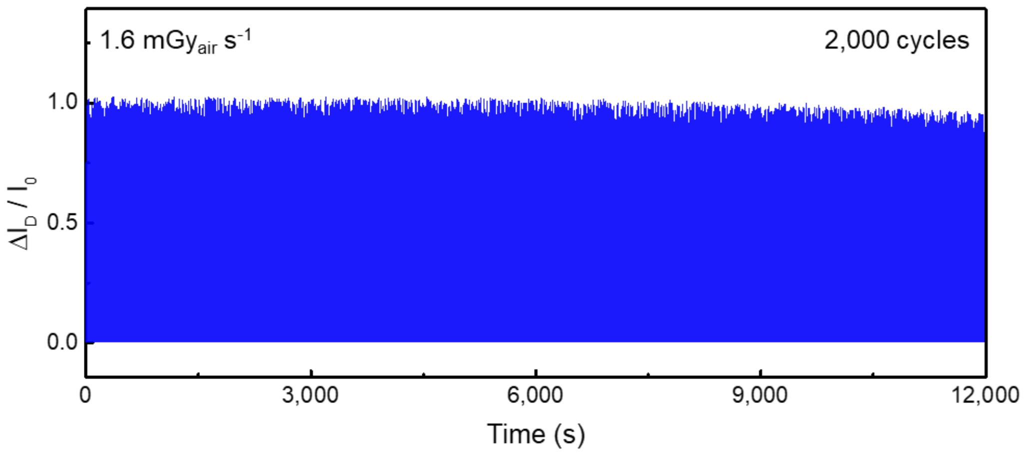

Figure S9. Real-time detection of the relative change in drain current ($\Delta I_D/I_0$) during the repetitive X-ray irradiation (1.6 mGy$_{air}$ s^{-1}) for 2,000 cycles.

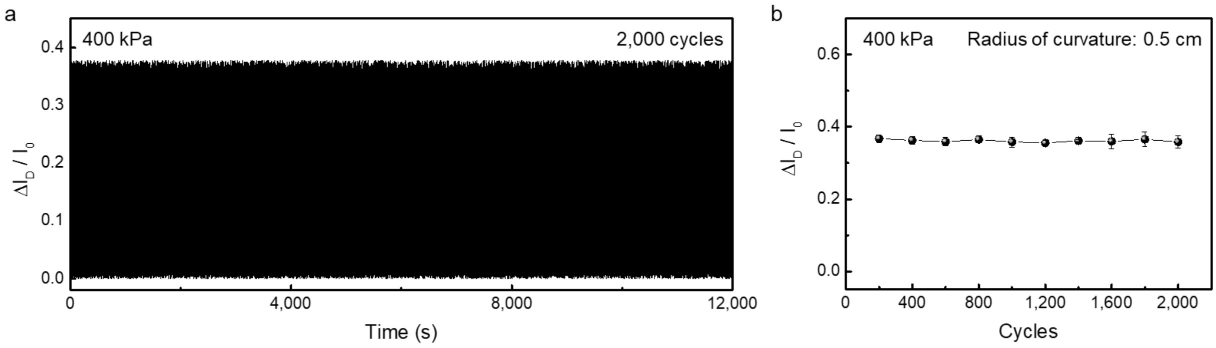

Figure S10. The mechanical stability of the multiplexed detector. a) $\Delta I_D/I_0$ during the repetitive application of 2,000 cycles at a pressure of 400 kPa. b) $\Delta I_D/I_0$ after 2,000 cycles of bending (0.5 cm of radius of curvature).

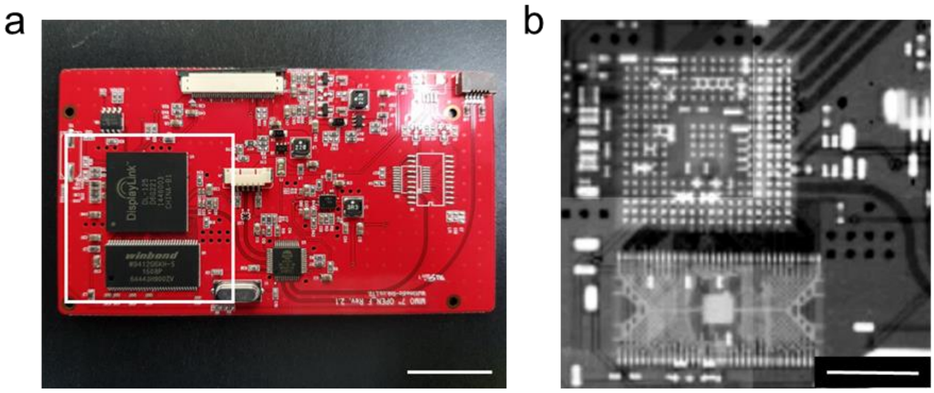

Figure S11. The X-ray image of the printed circuit board (PCB). a) A photograph of commercial PCB with 4 × 4 cm of sensing area (white box in the photograph). Scale bar, 2 cm. Because the sensing area of the multiplexed detector was 2 × 2 cm, the area corresponding to the white box in the photograph (4 × 4 cm) was divided into four sections and imaged separately. b) Combined X-ray image of commercial PCB. Scale bar, 1 cm.

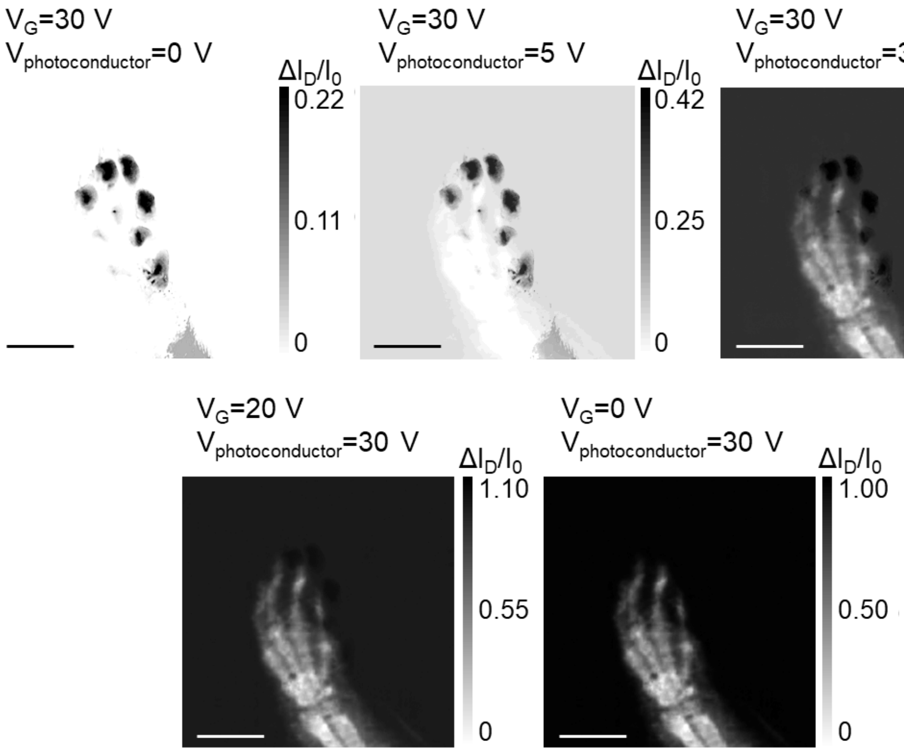

Figure S12. Contour plots of the distribution of $\Delta I_D/I_0$ according to the different bias condition (V_G and $V_{photoconductor}$). V_G and $V_{photoconductor}$ were applied stepwise for each condition (0, 20, 30 V for V_G and 0, 5, 30 V for $V_{photoconductor}$), and V_D was maintained at 2 V. Here the voltage of the X-ray tube was kept at 50 kV with a dose rate of 1.6 mGy_{air} s^{-1} for 500 ms. Scale bars are 0.5 mm.

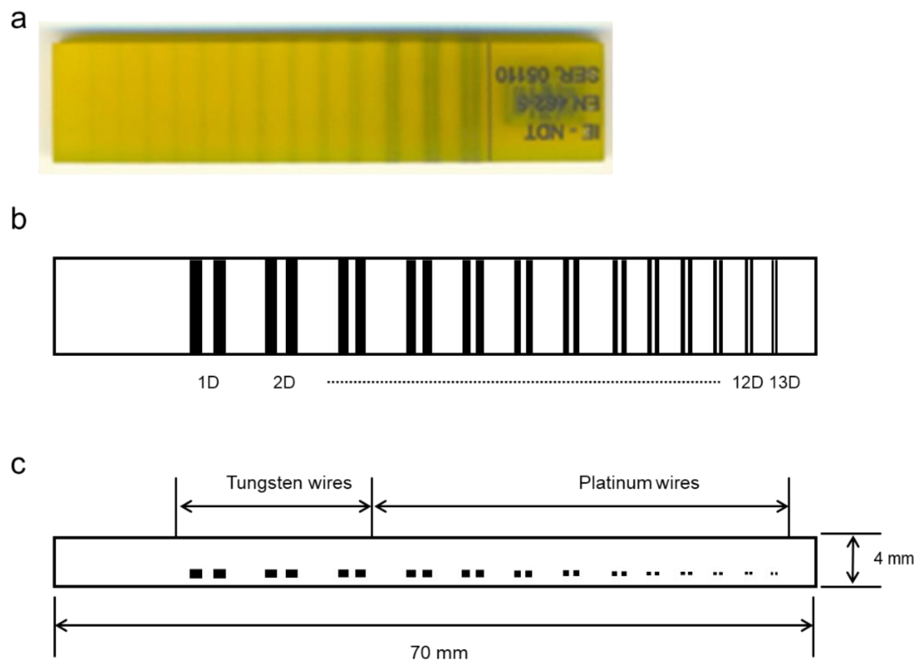

Figure S13. Typical standard information of the Duplex IQI sample. a) Photograph of Duplex IQI sample. b-c) Schematic structures of the top and bottom view of the Duplex IQI sample.

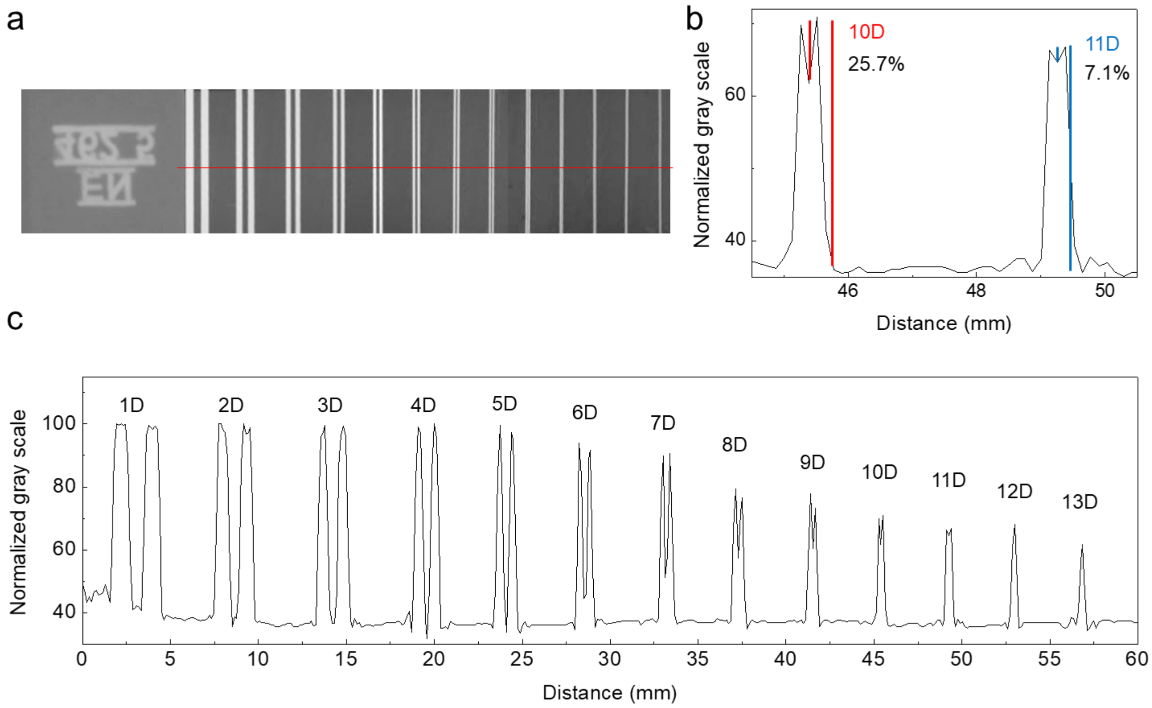

Figure S14. Measurement of a spatial resolution. a) X-ray image of the Duplex IQI sample taken by the multiplexed detector. b) Normalized gray scale of the element number of 10D and 11D obtained by a line profile tool. The element of 10D (diameter and spacing of 100 μm) exhibits a dip value of 25.7%, whereas that of the element 11D exhibits a dip value of 7.1%. c) A line profile of all elements from 1D to 13D.

Element No	1D	2D	3D	4D	5D	6D	7D	8D	9D	10D	11D	12D	13D
Diameter and spacing (mm)	0.800	0.630	0.500	0.400	0.320	0.250	0.200	0.160	0.130	0.100	0.080	0.063	0.050

Table S1. Dimension of the Duplex IQI sample. The double wire IQI (Duplex IQI, EN 462-5) consists of the 13 pairs of wire (element number from 1D to 13D) housed rigid plastic and the wires are exactly spaced to correspond to the diameter of each pair.

Captions of Supporting Movies

Movie S1. The real-time *in-vivo* mapping of the pressure distribution and anatomical structure of the rat's foot obtained by the multiplexed detector with a calibration process.

References

[1] G. W. Grodstein, *X-Ray Attenuation Coefficients from 10 Kev to 100 Mev*, U.S. Department Of Commerce, National Bureau Of Standards, **1957**.