Chapter 5
A Novel Matrix-Type Semiconductor X-ray Detector

5.1 Characteristic Properties

For the purpose of the measurements of temporally and spatially resolved electron temperatures during a single plasma discharge alone, a new matrix-type semiconductor X-ray detector is proposed and fabricated.

The X-ray detection systems including the matrix-type semiconductor detector are also shown in figure 5-1(a). Schematic drawings of detector locations and viewing lines of sight of semiconductor X-ray detectors are illustrated with the labels of C and A in the central cell and the anchor region, respectively. Central cell X-rays are observed by the use of the matrix-type semiconductor detector [figure 5-1(b)]. Incident X-rays are imaged on the matrix detector through six pinholes (3 mm in diameter) aligned in line against the corresponding six detector rows, respectively. The spatial resolution of each detector row is 3 cm in the midplane of the plasmas, and the total overlapped viewing area for the six detectors in the axial direction (parallel to $\boldsymbol{B}$) covers 6 cm in the midplane [see figure 5-1(a)]. This length is sufficiently short as compared with the electron mean free path; thus, the matrix detector having these six detector rows views over nearly the same region in the axial direction of the plasmas.

The matrix detector is fabricated on a 300 μm thick n-type silicon wafer [figure 5-1(b)]. The active area of each channel is 0.5×0.5 cm^2, and the total area of the detector is 3.6×4.1 cm^2. Each detector unit is essentially a p-n junction photodiode. The detector surface is covered with a 160 nm thick aluminium layer for cutting out visible light. The detector is characterized by the formation of six rows with different thicknesses of thin dead layers (SiO_2) with 1, 15, 242, 1, 110, and 495 nm on its surface [see labels from (i) to (vi) in figure 5-1(b), respectively]. The values of the depletion layer thickness d_{dep} range 21.9 μm for the first three rows and 28.9 μm for the remainder in the present plasma experiments, respectively. The diffusion length for X-ray produced carriers in the field-free substrate region located behind the depletion layer ranges 150 μm for the matrix detector [8,9,58]. Each detector row has seven channels (columns) for measuring plasma X-ray radial profiles so as to obtain X-ray tomographically reconstructed data.

A tomographically reconstructed data set in various X-ray energy ranges is simultaneously obtained from each detector row having a different ultra-thin "SiO_2 X-ray absorber". Consequently temporal evolution of energy resolved X-ray or T_e profiles is conveniently attained during a single plasma discharge alone [59].

The total detector response of each detector row labelled in figure 5-1(b) normalized by the incident X-ray energy is plotted in figure 5-1(c), respectively, for comparison with those of standard semiconductor detector systems [1,2,8,9,58-60].

For checking the spatial profiles of X-ray emission and plasmas, fifty channel microchannel plate X-ray detector [4-6], a sixteen channel semiconductor detector array having an active area of each channel of 0.2×0.5 cm^2, d_{dep} of 20 μm, and an 8 nm thick dead layer with a 0.5 μm thick polymer filter [see the dotted curve for the X-ray response in figure 5-1(c)], as well as standard two sets of H_α detector arrays and microwave interferometers are employed in the central cell. These X-ray detectors are placed at a 135° separation from the matrix detector. These data give information on the confirmation of a plasma rotation having an $\boldsymbol{E}\times\boldsymbol{B}$ drift velocity on the basis of tandem mirror positive potentials (see chapter 6). A similar type of the sixteen channel semiconductor detector array is also employed for X-ray tomographic reconstructions in the anchor region so as to investigate the electron behaviour and characteristics in comparison with those in the central cell [see A in figure 5-1(a)].

5.2 Plasma Electron-Temperature Measurements Using a Novel Matrix-Type Semiconductor Detector

The temporal evolution of the radial profiles of line-integrated X-ray intensities (brightness) in the central cell of GAMMA 10 is obtained during a single plasma discharge by the use of X-ray signals in six different energy ranges from the six different detector rows of the matrix detector. Figure 5-2(a) exemplifies lower-energy X rays all though the plasma radii r_c, while higher-energy X rays in Fig. 5-2(b) are locally emitted from the core-plasma region. Accordingly, as a quick outlook for the two data sets, the information on a peak-on-axis T_e profile is anticipated. For more detailed analyses, the thick-solid and the dashed curves in Fig. 5-1(c) provide the detector responses in the cases of Figs. 5-2(a) and (b), respectively. These line-integrated data are then tomographically reconstructed for attaining spatially resolved X-ray emissivity in plasmas. Similarly the six data sets from the matrix detector are employed for T_e analyses.

Figure 5-3 summarizes the first analyzed result of temporally and spatially resolved T_e in a single plasma discharge alone by the use of the above-described method and data (Fig. 5-2). As one can find the X-ray increase during the injection period of ECH 1 and 2 in Fig. 5-2, the analyzed values of T_e, in fact, increase by 60% (Fig. 5-3) due to ECH.