Introduction

The focal plane of the NICER instrument is designed to monitor celestial soft X-ray sources (0.2 – 12 keV) and includes 56 nearly identical Silicon Drift Detectors (SDDs). Two SDDs from the flight candidates lot were selected for a calibration at a synchrotron. One of the two calibrated detectors was later installed into the flight instrument focal plane. The calibration was performed at PTB in Berlin at BESSY-II storage ring and included comprehensive testing with multiple monochromatic energies at 2 monochromators, as well as with undispersed radiation at “white light” beamline. As a result of these experiments we measured detector Quantum Efficiency, determined shapes of spectral redistribution function at multiple input energies, and discovered several unexpected features in the detector behavior.

Quantum efficiency measurement at SX700 monochromator beamline

Two detectors, designated as reference ones, were mounted on the same backplate and installed into the output of SX700 plane-grating monochromator beamline. Beam size was confined by an aperture to a 0.7 mm x 0.7 mm, much smaller than 2 mm opening of SDD collimator. X-ray flux was first measured by a previously calibrated photodiode (PD), placed in front of an SDD, then SDDs were exposed, one at a time. Large gap in dynamic ranges between photon counting SDD and photocurrent measuring PD was bridged by reducing stored electron current after reference measurement with PD. Scaling continuously monitored ring current allowed to determine detector QE.

Fig. 1: Quantum efficiency of the detector 02, later installed in Flight Focal Plane. Red diamonds are the results of QE measurement at BESSY. Blue line is a simulation which assumes that detector QE is a product of transmission of the optical blocking filter (OBF) in front of the detector and “trigger efficiency” curve (see panel to the right). Transmission of the OBF was also measured at BESSY in a separate experiment. Experimental data points are in a very good agreement with the model.

Spectral redistribution function

In order to extract spectral information from the detected signal, one needs to know detector spectral redistribution function at any given energy. We measured detector response at multiple monochromatic energies at both SX700 beamline (0.2 keV – 1.7 keV), and Four Crystal Monochromator (FCM) beamline at higher energies, up to 11.5 keV. The measurement results were used as input to the modified simulator described by Scholze&Prokop [1] to generate response function at any given energy. Simulation results agree very well with experimental data, as shown in the examples below and they are being used as the basis of the NICER Detector Response Matrix.

Fig. 2: Experimental spectra at monochromatic illumination at 2959 eV, 4511 eV and 5898 eV (black) and computer simulation of the response at the corresponding energies (red). The simulation is based on the detector physics and considers details of photon interactions with silicon.


“Trigger efficiency” effect in X-ray response

While analyzing BESSY data, we discovered that low energy X-ray response of the detector system has a cut-off shaped as an error function. The origin of the effect was traced to the noise in the electronics triggering algorithm. It can be clearly seen on the left plot, showing SDD response at different detection threshold levels to unattenuated synchrotron beam with very strong low energy component. Decreasing threshold value extends low energy response, but increases intensity of the noise peak. Another example, on the right, is a cut-off of the low energy tail of an X-ray peak in the detector response to the monochromatic illumination.

Fig. 5: Detector response to “white light” at BESSY - unattenuated synchrotron spectrum that has strong low energy component. Curves illustrate linear slice of the low energy quantum efficiency with threshold value settings, as well as exponential growth of noise peak intensity at lower thresholds.

Fig. 6: Detector response to monochromatic illumination during long exposure at 2959 eV coming from Four Crystal Monochromator at BESSY. Best fit to a sum of gaussian and error function produces parameters of the shape of the “trigger efficiency” curve.

Pile-up effects

NICER detectors can exhibit pile-up at high level of input flux, as can be seen in the insert spectrum on the left. The readout electronics has slow and fast channels and that presents an unusual way to detect piled-up events. Red points represent scatter plot of fast channel amplitude vs. slow one for all detected events. Since piled-up photons do not arrive simultaneously, their behavior differs depending on the difference of the arrival times. If the time difference is smaller than the fast peaking time (84 ns), they form the vertical branch; if longer than that, they form the horizontal branch. This presents an interesting new mechanism to reject significant fraction of the piled-up events.

Timing

Calibration of timing properties was not planned, but, rather, it was unexpectedly discovered that BESSY-II measurements present a powerful tool to study timing resolution and delays between fast and slow channels. Electrons in storage ring make a full revolution in 800ns and are injected in a series of short “bunches”. NICER detector’s response folded over that period can reveals that pattern, as shown on the left.

Summary

• NICER detectors were subjected to a multitude of tests at BESSY-II in order to measure Quantum Efficiency, Spectral Redistribution function, and other parameters.

• In addition to having accurately measured basic SDD characteristics, we have discovered a number of unexpected features in the detector’s behavior, as described above.

• Overall, calibration campaign at BESSY-II proved to be very successful, with many of the new-found effects being very difficult to reveal by other means.