We numerically demonstrate that a pronounced dipole-quadrupole (DQ) Fano resonance (FR) induced lateral force can be exerted on a dielectric particle 80 nm in radius (R-sphere = 80 nm) that is placed 5 nm above an asymmetric bow-tie nanoantenna array based on Au/Ge2Sb2Te5 dual layers. The DQ-FR-induced lateral force achieves a broad tuning range in the mid-infrared region by changing the states of the Ge2Sb2Te5 dielectric layer between amorphous and crystalline and in turn pushes the nanoparticle sideways in the opposite direction for a given wavelength. The mechanism of lateral force reversal is revealed through optical singularity in the Poynting vector. A thermal-electric simulation is adopted to investigate the temporal change of the Ge2Sb2Te5 film's temperature, which demonstrates the possibility of transiting the Ge2Sb2Te5 state by electrical heating. Our mechanism by tailoring the DQ-FR-induced lateral force presents clear advantages over the conventional nanoparticle manipulation techniques: it possesses a pronounced sideways force under a low incident light intensity of 10 mW/mμm2, a fast switching time of 2.6 μs, and a large tunable wavelength range. It results in a better freedom in flexible nanomechanical control and may provide a new means of biomedical sensing and nano-optical conveyor belts.