Iron-based superconductors have a great potential for high-field applications to superconducting wires/tapes employed in high-field magnets because they have a superior grain boundary property [1] along with large upper critical magnetic fields over 50 T and small anisotropy factors ($\gamma = 1 - 2$). To further investigate ultimate potential of iron-based superconductors thin films, Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ (BaFe$_2$As$_2$:Co) epitaxial films have been studied because of easy growth due to a low vapor pressure of Co dopant and a wide growth-temperature window; however, carrier scattering by the substituted Co within the carrier-conducting Fe planes is considered to deteriorate superconducting properties. On the other hand, BaFe$_2$(As$_{1-x}$P$_x$)$_2$ (BaFe$_2$As$_2$:P) has higher $T_c$ ($\sim$31 K) than that of BaFe$_2$As$_2$:Co ($\sim$22 K) and scattering by the substituents would be less important. Therefore, a BaFe$_2$As$_2$:P epitaxial film is a new research platform to high-field applications.

In this study, we have successfully grown BaFe$_2$As$_2$:P epitaxial films. These films exhibited high critical current density ($J_c$) over 2 MA/cm$^2$ at 4K under a self-field. The high $J_c$ over 1 MA/cm$^2$ was maintained even at 9T. The obtained $J_c$ at 9T (1.1 MA/cm$^2$), which is 20 times higher than that of BaFe$_2$As$_2$:Co at the same magnetic field, is the highest value in the iron-based superconductor thin films. Moreover, angular dependence of $J_c$ showed isotropic behavior in a low magnetic field of 1 T and only a single peak along the $H//ab$ direction in higher magnetic fields. These results imply coexistence of anisotropic strong pinning centers along the $ab$-plane such as stacking faults and isotropic weak pinning centers like point like defects. The high $J_c$ over 1 MA/cm$^2$ along with the low anisotropy indicates that BaFe$_2$As$_2$:P is the most promising material for high-field applications.