Grain alignment mechanisms and grain properties in the massive quiescent filament G16.96+0.27 using dust polarization observations from JCMT/POL-2

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The polarization of starlight and polarized thermal dust emission induced by non-spherical dust grains aligned with the interstellar magnetic field (B-field) provides a powerful tool for tracing the B-field morphologies and strengths in molecular clouds and for constraining the grain properties and their alignment mechanisms. The mechanism behind the alignment of grains to produce polarization is not yet fully clear and act as one of the long-standing problems in astrophysics. However, the leading grain alignment theory is the alignment induced by RAdiative Torques (RATs) known as RAT alignment theory, which is supported by numerous observational studies in diffuse interstellar medium and molecular clouds. The study of the grain alignment mechanism in dense star-forming regions is limited and started only recently with the advancement in far-infrared, submillimeter and millimeter polarimetric instruments. To bring a comprehensive understanding of the grain alignment mechanisms by exploring different environments, a proper study in the dense star-forming regions is highly important. In this work, we investigate the grain alignment mechanisms in a massive, quiescent and filamentary Infrared Dark Cloud G16.96+0.27 using thermal dust polarization observation with JCMT/POL-2 at 850 µm. We observe the so-called phenomenon of polarization hole attributed to the decrease in polarization fraction in the denser regions associated with higher total emission intensity and gas density. We explore for any significant contribution of magnetic field tangling to cause the observed polarization hole. We find that the B-field tangling effect is minimal and the dominant factor to cause the polarization hole is the reduction in grain alignment efficiency in the denser regions, consistent with the RAT alignment mechanism. To test RAT theory, we calculate various quantities describing grain alignment, including minimum size of aligned grains, magnetic and magnetic relaxation parameter, and show that RAT mechanism can explain the observational data. Our study also reveals the potential evidence that the observed high polarization fractions of above 10% in the outer regions of the filament could be explained by the combined effect of the enhanced magnetic relaxation strength and suprathermal rotation of grains by RATs, supporting the magnetically-enhanced RAT (M-RAT) alignment mechanism. To bring a comprehensive analysis, we perform a detailed modeling of thermal dust polarization using DustPOL-py based on M-RAT theory and find that the modeling could successfully reproduce the observational data when maximum grain size is around 0.45 μm accompanied by an increase in the grain axial ratio, along with the consideration of variations in the magnetic field's inclination angle with the line of sight. Our modeling provides implications for anisotropic grain growth in the denser regions of the filament, and also provides insight into the evolution of the 3D B-field morphology over the filament. (This work has been published in ApJS.)