Investigating the Effect of Various PVD Coatings on the Magnetic Properties of Electrical Steels

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Electrical steels are critical materials used in the cores of transformers, motors, and generators due to their soft magnetic properties. Reducing magnetic losses remains a key challenge, and surface coatings have emerged as a promising solution. In this study, various nitride-based (TiN, ZrN, CrN, AlTiN) and nanocomposite (AlCrBN, AlTiBN) coatings were deposited on conventional silicon steel substrates using cathodic arc physical vapor deposition (CAPVD) to enhance magnetic performance. The coated samples were characterized using vibrating sample magnetometry (VSM), magnetic domain imaging, electrical conductivity measurements, SEM/EDS, and XRD analyses. The results demonstrate that most coatings led to an increase in saturation magnetization (Bs) while preserving soft magnetic behaviour. These findings underscore the potential of CAPVD coatings in improving the efficiency of electrical steels for advanced electromagnetic applications.

Keywords: Electrical steel; CAPVD; Nitride-based coatings; Magnetic properties

1. Introduction

Electrical steels are a vital class of magnetic materials extensively used across the energy and industrial sectors. Their superior magnetic properties make them indispensable for components such as transformer cores, electric motors, and generators [1]. A key factor influencing these properties is the magneto-crystalline anisotropy energy, an intrinsic material characteristic that plays a major role in determining hysteresis losses. Reducing hysteresis losses is essential for improving the efficiency of electrical machines. This can be achieved not only through the development of advanced alloy compositions but also by applying functional surface coatings to existing commercial electrical steels. In particular, grain-oriented electrical steels (GOES) benefit from coatings that enhance electrical resistivity, improve surface roughness, and induce favorable tensile stress, all of which contribute to lower energy losses [2]. Previous studies have investigated the application of hard coatings such as CrN, CrAlN, TiN, and TiAlN; materials typically used to enhance the wear resistance and hardness of cutting tools; as a means to reduce losses in electrical steels [3].

PVD coatings generally offer superior adhesion, homogeneity, and morphology control. Monolayer, multilayer and graded structured coatings can be developed by PVD. The thickness of the films can be also well controlled by optimizing the process parameters. However, to date, the literature remains limited in exploring the use of such coatings specifically for improving the magnetic performance of electrical steels. This study aims to address this gap by examining the effects of various nitride-based coatings—including TiN, CrN, AlTiN, and ZrN—deposited via cathodic arc PVD (CAPVD) on conventional silicon steel. Additionally, the magnetic performance of nanocomposite coatings such as AlCrBN and AlTiBN is evaluated to explore further potential for loss reduction.

2. Results and discussion

Figure 1 presents the hysteresis curves of bare silicon steel alongside six different coated variants. The left image compares the magnetic behavior of nitride-based coated variations (TiN, CrN, AlTiN, and ZrN) with that of uncoated silicon steel, while the right panel presents results for nanocomposite coatings (AlCrBN and AlTiBN) in a similar comparison. All coated samples exhibit characteristic soft magnetic behavior, with generally notable improvements in saturation magnetization (Bs).

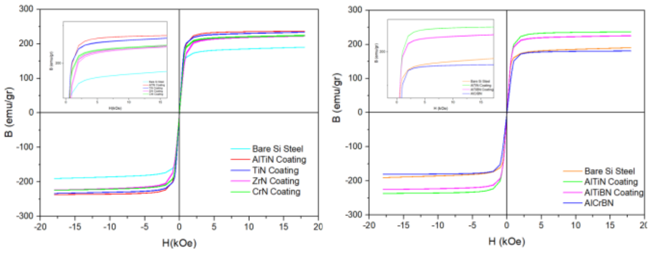

Figure 1: Left: Hysteresis loops of different nitride-based PVD coatings on bare silicon steel, right: Effect of boron addition on saturation magnetization of different PVD coatings on bare silicon steel

Among the nitride-based coatings, AlTiN-coated silicon steel demonstrates the highest saturation magnetization, reaching approximately 230 emu/g. In general, the application of these coatings enhances the Bs of the base material, indicating an improvement in magnetic performance. The only exception is the AlCrBN-coated sample, which shows a slight reduction in Bs compared to the bare silicon steel.

References

[1] Ouyang, G., Chen, X., Liang, Y., Macziewski, C., & Cui, J. (2019). Review of Fe-6.5 wt% Si high silicon steel—A promising soft magnetic material for sub-kHz application. Journal of Magnetism and Magnetic Materials, 481, 234-250.

[2] B. Weidenfeller and W. Riehemann, "Effects of surface treatments on the hysteresis losses of GO iron silicon steel," Journal of Magnetism and Magnetic Materials, vol.292, pp. 210-214, 2005.

[3] 86. Goel, V. (2016). Novel coating technologies for electrical steels (Doctoral dissertation, Cardiff University).

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