Magnetic Properties of Amorphous CoNbZr Films Sputter-deposited in Magnetic Field*

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(Received February 9, 1990)

Synopsis

In an effort to improve soft magnetic properties of amorphous CoNbZr films at high frequency, we have investigated the effect of both magnetic field and sputtering deposition conditions on magnetic properties of the films. A uniform magnetic field from a pair of permanent magnets was applied during film deposition.

The magnetic field results in the in-plane uniaxial magnetic anisotropy in the films. Permeability(μ) of the films is dependent on the intensity of an applied field, and is independent of frequency more than 10 MHz. Argon(Ar) gas pressure and RF input power during film preparation can controll the magnitude of anisotropy and permeability. These films are consistent with the equation of μ=Bs/Hk : Bs: Saturation induction, Hk: anisotropy field.

1. Introduction

During the last decade there has been an extensive effort to investigate the soft magnetic properties of amorphous alloys like Co-Nb-Zr (1) for recording head applications. In the as-deposited state, however, these films exhibit low permeability and poor frequency response, even if their magnetostriction is almost zero, primarily due to a large uniaxial anisotropy induced during deposition.

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* The 1848th report of Institute for materials Research.

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Many deposition parameters in preparing amorphous films and several heat treatments have been considered to reduce the anisotropy of as-deposited films. The Ar gas pressure was found to be the most important deposition parameter for obtaining magnetically soft amorphous films, because deposition in low Ar pressure suppresses the formation of columnar structures. The rotating field annealed (RFA) films, also, are found to have extremely soft magnetic properties, compared to those reported for their as-deposited films(2).

The purpose of this research is to develop a thin-film deposition technique capable of controlling the anisotropy during deposition and to find the magnetically soft as-deposited film. In this paper, we report the effects of applying a magnetic field as well as various deposition conditions on the permeability untill higher frequency than 60 MHz.

2. Experimental

Thin films of CoNbZr were deposited onto Corning 0211 glass substrates using a ULVAC 2306E sputtering system. The substrates were placed on a water-cooled substrate holder under 6-in.-diam target of homogenous alloys of CoNbZr. The deposition conditions for these films are shown in Table 1. Input power, Ar pressure, and substrate bias were chosen to induce an amorphous state in thin films. A uniform magnetic field from a pair of permanent magnets was applied parallel to the surface of the substrates during film deposition(Fig. 1). All the samples were confirmed to be amorphous by X-ray diffraction method. Film thickness were measured using a profilometer. The composition of the samples was determined

Table 1. Deposition conditions

Background Pressure	$\leq 1\times10^{-6}$
External Magnetic Field	0 ~ 80 Oe
Target Composition	$Co_{80}Nb_{10}Zr_{10}$
Input Power	0.5 ~ 4.4W / cm^2
Ar Gas Preessure	2 ~ 30mTorr
Substrate Tampertature	water cooled

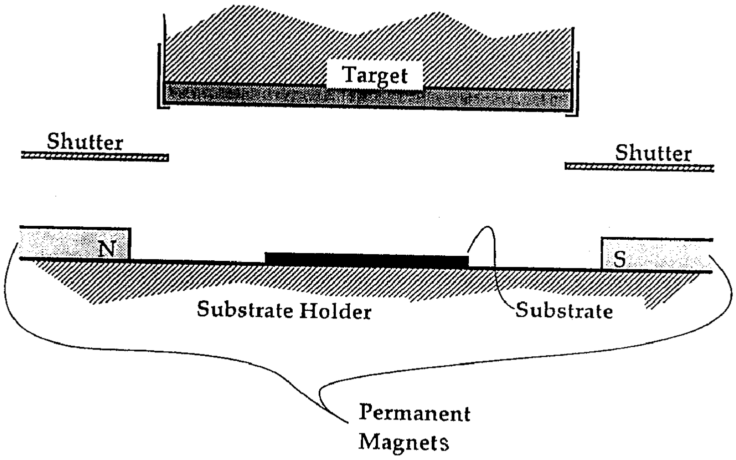

Fig. 1 Position of target,magnets and substrate during film deposition

by a electron-probe micro-analysis(EPMA). Magnetization vs field was measured with a vibrating-sample magnetometer(VSM) to give total magnetization, the magnetic anisotropy and coercive fields in easy and hard magnetization directions. Anisotropy field was determined by extrapolating the initial curve of hard axis magnetization to the saturation magnetization. Measurements of moment vs temperature in a magnetic balance gave information about the Curie temperature(Tc) and crystallization temperature(Tx). The frequency characteristics of the permeability were determined with an HP4192A(10kHz-10MHz) impedance analyzer, and the combination system of a figure-8-coil and digital sampling ociloscope (1-100MHz).

3. Results and Discussion

1) The Effect of Magnetic Field

Amorphous phase can be obtained in all films prepared with every deposition conditions ,and their major composition is $Co_{82}Nb_{11}Zr_7$. Figure 2 shows a typical example of measured hysteresis loops of CoNbZr films prepared under identical conditions (a) without and (b) with applied magnetic field of 20 Oe. Both of these samples exhibit excellent soft magnetic properties (Hc ≤0.1Oe). In the case of samples prepared without magnetic field, almost no difference can be observed among the loops measured with any in-plane directions . The sample of figure 2(b), which was deposited with a magnetic field, is found to have a large in-plane uniaxial magnetic anisotropy(Hk=5 Oe), induced by an applied magnetic field during deposition.

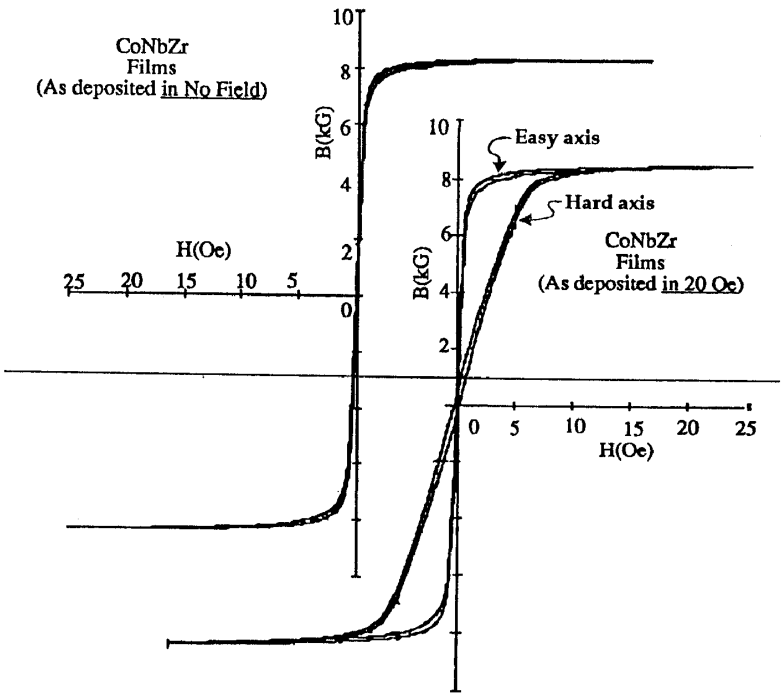

Fig 2. Typical hysteresis loops of deposited CoNbZr films

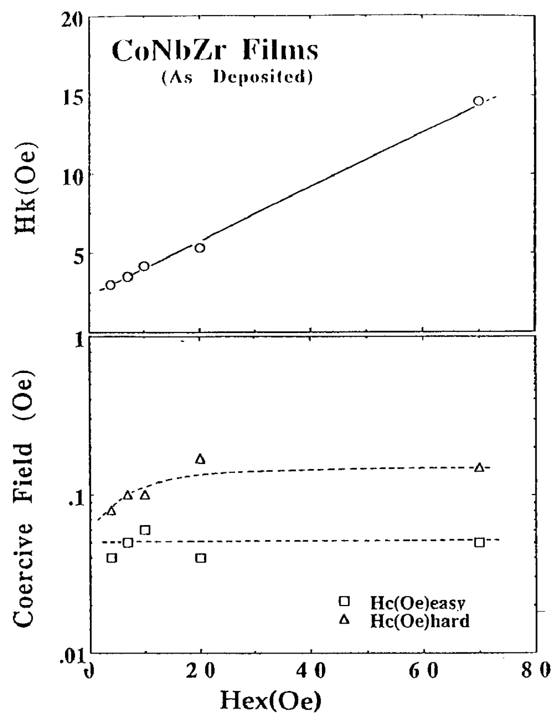

Fig. 3 Relationship between magnetic properties and external magnetic fields during depotion.

The deposition rate with magnetic field was found to be about 1.5 times larger than that without the field, and to increase with the magnitude of magnetic field. This result suggests that the magnetic field near the substrate not only induces the uniaxial anisotropy, but also condenses the density of Ar gas plasma near the target material.

Figure 3 shows the relationship between the coercive force (Hc) and anisotropy field (Hk) of the films and the magnitude of externally applied magnetic field during deposition. Both Hc in hard and easy directions are almost independent of applied field. It is noteworthy that the magnitude of uniaxial anisotropy can be easily controlled by varying the magnetic field. This result is the great advantage in having the potential of such films for magnetic recording heads and other high frequency devices. Because, to reduce the high frequency losses, this anisotropy is desirable in order to have rotational magnetization in the hard axis direction of the samples.(3),(4) And permeability at high frequency is known to be strongly dependent on the magnetude of uniaxial anisotropy. (We will discuss this issue later)

Figure 4 shows the frequency characteristics of the permeability measured along the hard and easy axis directions, where the values for the films prepared under no magnetic field is also shown for the comparison. Initial permeability more than 10,000 is obtained in lower frequency range than 10kHz in samples measured at easy magnetization direction, but decreases rapidly with increasing frequency. Almost the same tendency is observed in the films prepared with no magnetic field.

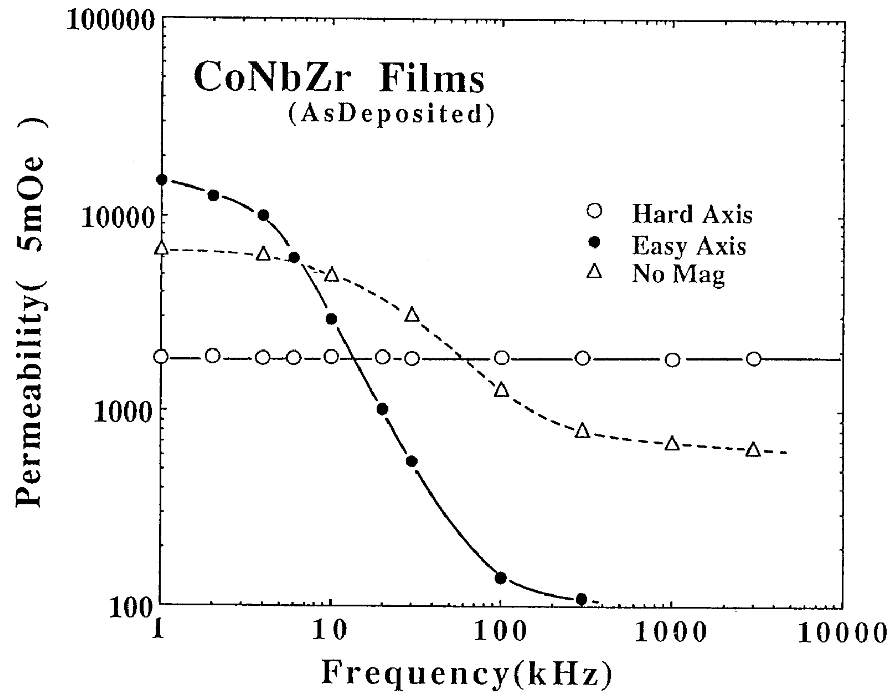

Fig. 4 Frequency characteristics of the permeability

Note that, in the case of measured at hard axis, the permeability of about 1600 is almost independent of frequency more than 10 MHz without any heat treatment.

To reveal the magnetic properties of the films with apparent uniaxial anisotropy, we measured the magnetic field characteristics of permeability at several frequencies measured along the hard axis direction (in Fig.5). Rotational permeability of 1800 is field independent up to 800 mOe.

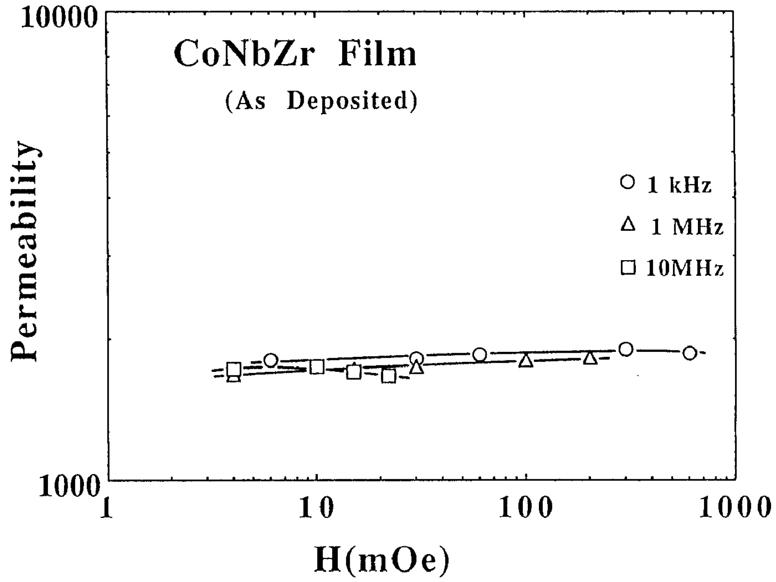

Fig. 5 Applying field characteristics of the permeability

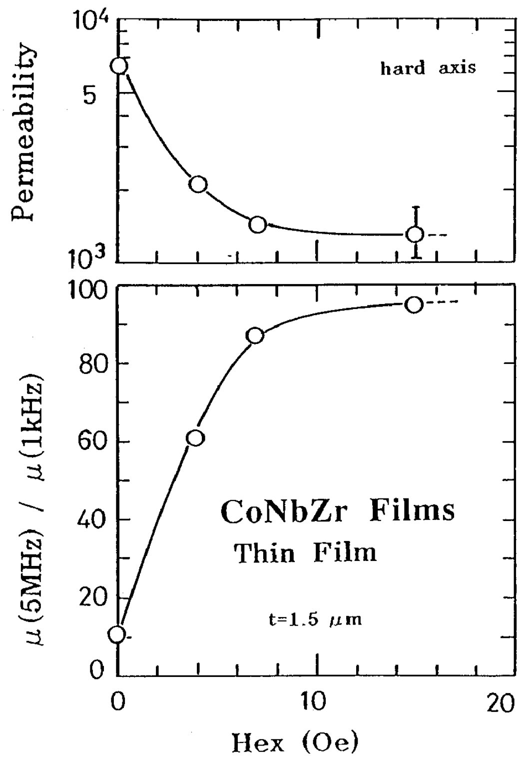

Fig. 6 Effect of external magnetic field on permeability and reduction ratio of μ

By varying the magnitude of externally applied field during deposition we could prepare samples where the permeability increased with decreasing the field (in Fig. 6). This result seems to be consisitent with the result of Hk in Fig.3, and this magnetization process is attributed to the rotational mechanizm.

Frequency characteristics of permeability is very important in the practical point of view. The reduction ratio of permeability, μ(5MHz)/μ(1kHz) is more than 8XZ0% in the case of Hex over 6 Oe. By considering the result of Fig.3, it can be seen that permeability along hard axis increases in low frequency ranges but decreases at high frequencies, as the uniaxial anisotropy becomes smaller. The reduction of permeability in high frequency, in general, is known to originate in classical eddy current loss and spin resonance which occurs due to the presence of an anisotropy field. In the case, however, it is attributed to the complex domain structures of films with very weak anisotropy(4),(5) in the frequency range like a 5MHz.

2) Effect of sputtering conditions during the deposition in magnetic field.

It is well known that the magnetic properties of the amorphous films is considerablly influenced by the sputtering conditions such as Ar presssure, rf input power,substrate temperature and so on. Fig. 7 shows the Ar pressure dependence, of Hk and uniaxial magnetic anisotropy energy(Ku) in constant magnetic field strength.

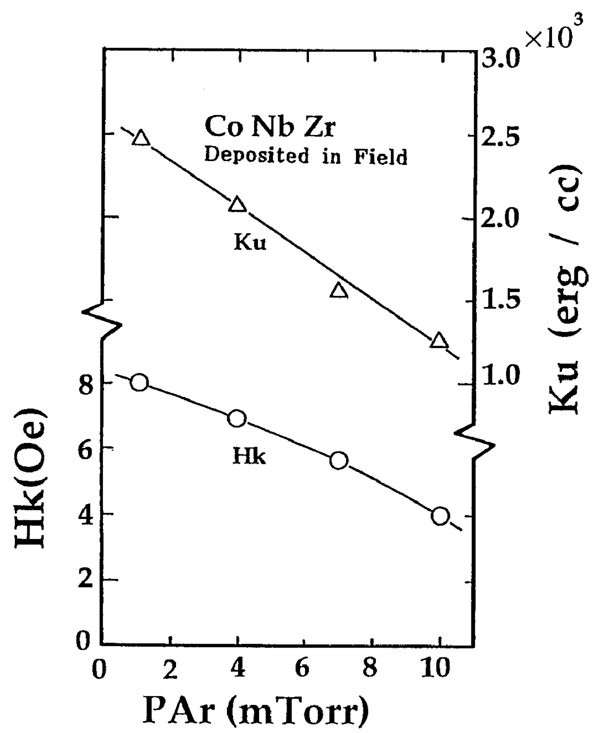

Fig. 7 Ar pressure dependency of Hk and Ku

Ku is calculated from the differnce between the magnetization curves in the parallel and perpendicular directions. We used the descending field branches of the hysterisis loops for this determination, on the grounds that magnetization changes occur primarily by rotation in these regions.

From this figure it can be said that not only Hex but also Ar pressure (P_{Ar}) can controll the magnitude of anisotropy. Not enough imformation has yet been obtained to explain the cause for the decrease of anisotropy. It might be related to the migration of sputtered atoms of which kinetic energy onto the substrate is strongly dependent on P_{Ar}. In the case of varying the P_{Ar} during deposition, on the other hand permeability increases with increasing P_{Ar} and has the maximum around 15mTorr. Fig. 8 shows the typical result of frequency dependence of μ measured along the hard axis. The difference in the data is probably due to a difference in Hk values. It should be noted that frequency independent rotational permeability of 1300 and 4000 up to frequency of 30MHz are obtained in as-deposited films. The considerable decrease of μ in higher MHz region may be mainly due to the dispersion of Hk. RF input power is also effective to controll the permeability of CoNbZr films. The higher the input power, the higher the μ can be obtained (Fig. 9). This effect seems to be explained in terms of the secondary electron bombardment and radiation heat from target at high input power. At higher power, CoNbZr films are in-situ annealed along the easy axis and thier anisotropy is reduced.

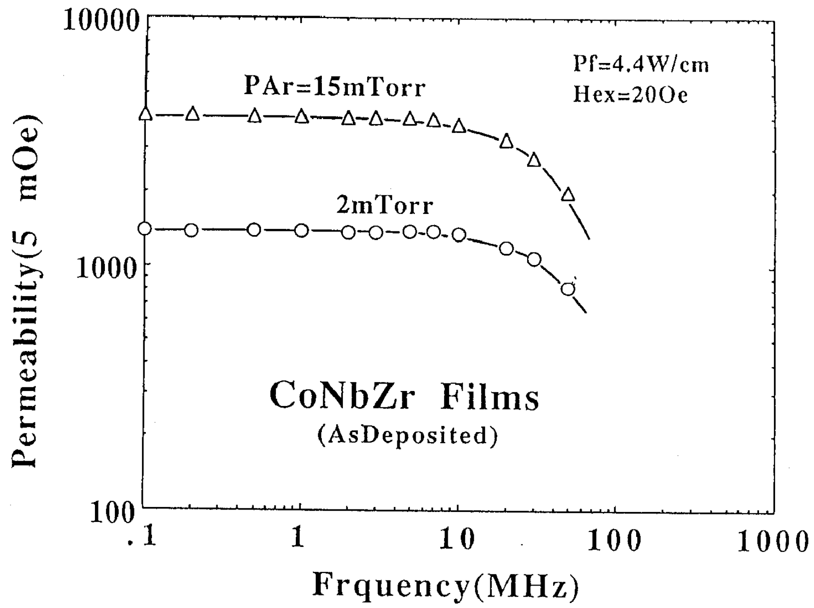

Fig. 8 Frequency dependence of μ at different Ar pressure.

reduced.

Fig. 10 shows the correlation between anisotropy field and initial permeability of all the films prepared in experimental conditions mentioned above. The solid line indicates the theoretical value (Bs/Hk) of hard axis initial permeability of the films with uniaxial anisotropy. Experimental results fit in with the theoritical value, however, experimental μ becomes smaller than that of theory in the smaller range of Hk than 2 Oe.

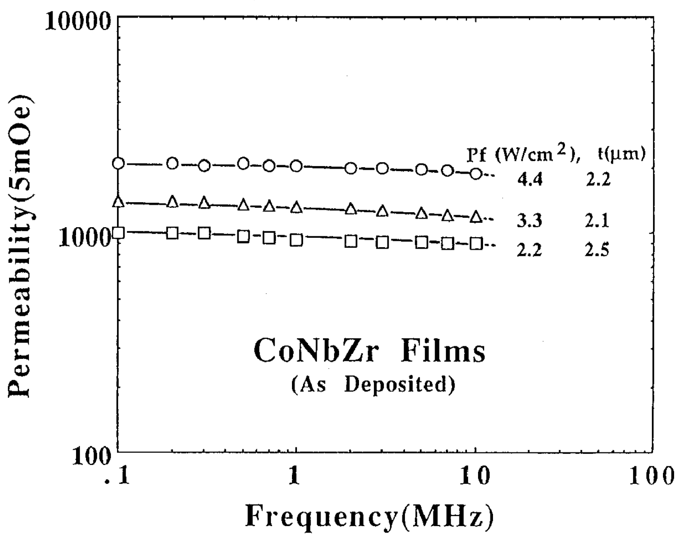

Fig. 9 Frequency dependence of μ at different rf input power.

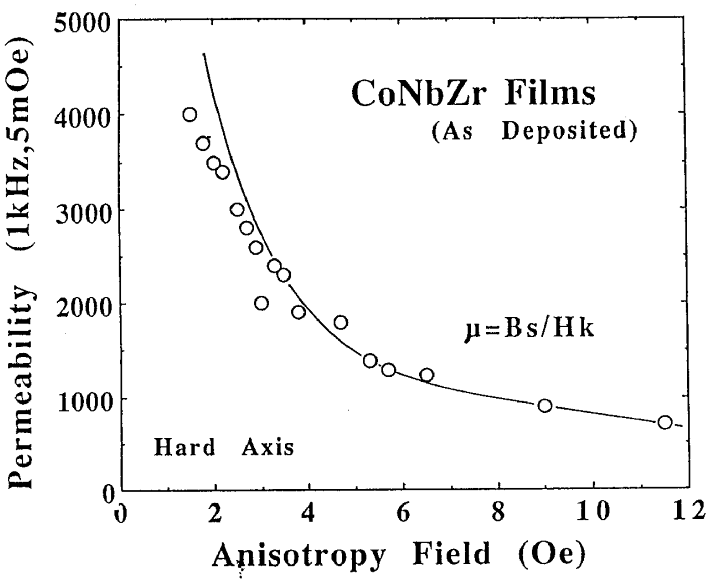

Fig. 10 Anisotropy and permeability

The domain structure of films with small anisotropy field is known to be more complicated than that in the case of large anisotropy.(4),(5) The difference between experimental and theoritical values in lower anisotropy field region may be attributed to the dispersion from the average easy axis, which originates in their complicated domain structure.

4. Summary

We have demonstrated the effect of magnetic field as well as deposition conditions on the soft magnetic properties of amorphous CoNbZr films. Magnetic field induces in-plane uniaxial magnetic anisotropy in the films and increases the deposition rate. Hk and μ of the films are controllable by variating the magnitude of applied magnetic field. It was found in the as-deposited films that the permeability of about 4000 is almost independent of frequency up to 30MHz.

In the case of constant magnetic field strength, μ increases with increasing P_{Ar} and has the maximum around 15 mTorr, and also increases with input power. An appropriate selection of magnetic field and deposition conditions brings the films with excellent soft magnetic properties without any heat treatment.

Acknowledgement

The authors are indebted to Prof. K. Murakami of Hachinohe Institute of Technology and Mr. T. Ban of Amorphous Magnetic Device Lab. for his constant encouragement in the course of this work.

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