# Heat transfer analysis during ultra-rapid annealing process of amorphous ribbon

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*Keywords: modern soft magnetic materials, ultra-rapid annealing, nanocrystallisation, amorphous ribbons*

## 1. Introduction

Soft magnetic materials play an essential role in the electrical energy ecosystem. Amorphous and nanocrystalline materials are one important group. Those material's low $H_c$ value is observed due to the structure containing iron nanocrystals embedded in the amorphous matrix. The nanocrystals have got diameter on the level of several nanometres. They are manufactured in two steps (melt spinning of amorphous alloy and subsequent heat treatment in controlled conditions of already wounded cores). Unfortunately, the presence of non-magnetic metals in the alloy composition is vital to obtain such a structure. Those elements enable to obtain optimal nanocrystalline structure, but this influences the material's maximum induction saturation value. Since several years a new approach to the nanocrystallization of soft magnetic materials is observed. Instead of isothermal heat treatment, ultra-rapid annealing (URA) is implemented. The seconds-long annealing at a higher temperature than the temperature of conventional nanocrystallization enables material with a higher amount of ferromagnetic elements and optimal structure. It results in materials with higher possible magnetization values.

## 2. Results and discussion

The work included experiments to measure the heating rate of a material in the form of a ribbon placed between heated copper blocks. The system shown in Figure 1 was used for the study. The results obtained made it possible to estimate the heating rate of the material placed between the heated copper masses. In addition, the cooling rate of the strip after it was removed from the device was analyzed.

Furthermore, the effect of annealing parameters (temperature and time) on the structure and magnetic properties was analyzed. An example of the result of changes in the shape of the hysteresis loop is shown in Figure 2.

This work describes a detailed structural study of amorphous $Fe_{75.3}Ni_{10}B_{14}Cu_{0.7}$ alloy. The influence of URA time (1 – 14 s) is analyzed, and the heat treatment temperature was 773 K (500 °C). The standard structural analysis methods, e.g. XRD, DSC, and magnetic measurements were implemented.

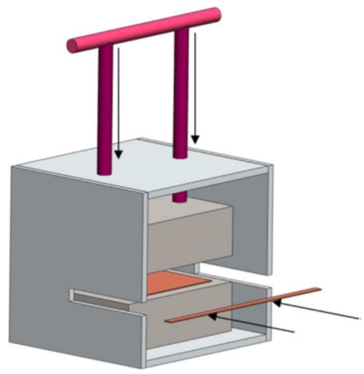

Figure 1: Schematic diagram of the ribbon insertion mechanism

The increase of annealing time conduced to not only increase of volume fraction of crystalline phase but also to the growth of α-Fe crystallites size. Moreover, after 5 s of annealing the additional $Fe_3B$ phase appeared while further elongation of annealing time up to 12 s affects in the formation the third phase indexed in accordance to $Fe_2B$ structure.

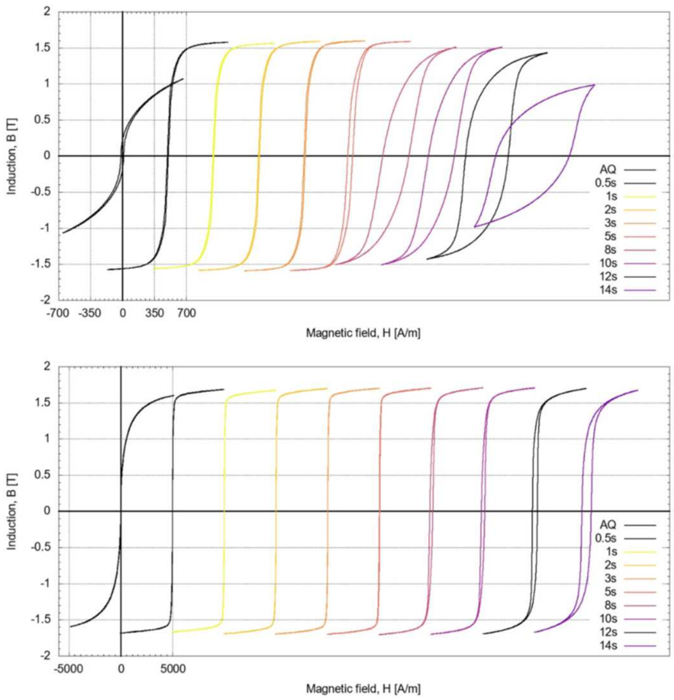


Figure 2: The histeresis loop evolution of material annealed for different time in the range of 1 to 14s