Softmagnetic materials in todays power electronic designs

Multipurpose nanocrystalline cores reduce size

Iron-based nanocrystalline materials enjoyed more and more acceptance in modern power electronic designs. This is a result of the improved reliability of the production process and the availability from several sources worldwide

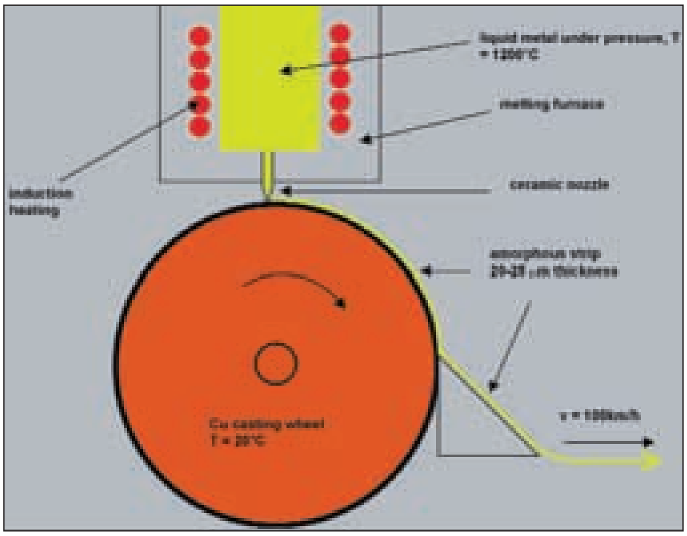

Figure 1: *Principle of rapid quenching technology*

■ Nanocrystalline softmagnetics like Fe73,5Cu1Nb3Si15,5B7 are best characterized by a unique combination of extraordinary softmagnetic properties (see *table 1*), a reliable and cheap production process based on low cost raw materials. They are superior to permalloys, ferrites or even amorphous cobalt based alloys in a rapidly growing range of applications.

During the production process, a stream of molten metal at about 1200°C is directly sprayed through a narrow ceramic nozzle onto a water-cooled, fast-rotating copper roller (*figure 1*). At a speed of more than 100 km/h a continuous amorphous ribbon of only 20-25 micrometer in thickness is obtained. After toroids are wound from these ribbons a specific annealing procedure under the presence of transversal and/or longitudinal magnetic field takes place. During the heat treatment, the amorhpous structure obtained initially forms ultra-fine crystals with a typical grain size of only 10 nm – this is why the material is called nanocrystalline. The result is a new generation of material with extraordinary softmagnetic properties: for the first time, the high flux swing of conventional silicon steel is combined with the low high frequency losses of ferrites.

By variation of the annealing parameters the required properties (i.e. shape of B/H-loop or permeability level) can be adjusted in a wide range (e.g. *figure 2*). As a result, the spectrum of applications in power electronics is big; e.g. chokes and transformers can be designed for:

switched mode power supplies; electrical welding power sources; X-ray generators; battery chargers; DC/DC converters; EMC mains filters for SMPS and inverter drives; electronical watthour meters; earth leakage circuit breakers and many more.

Independent from the application, the benefits gained from the use of nanocrystalline cores instead of ferrites or permalloys are: significant reduction of build volume of inductive components; less heat dissipation due to reduced number of turns; stable operation in a temperature range from –25 ... + 120°C; bigger safety margins and variable toroidal geometries without tool cost.

The main application for the new material so far is common mode chokes for EMI mains filters for any kind of switched mode power converters (including inverter drives). Here, the most significant reduction of build volume is achieved because both relevant material paramters (namely permeability and flux swing) are factors higher compared to the so far commonly used ferrite toroids (see *table 1*; PCIM 5/98 and 11/99). The other main-

Dr. Martin Ferch
Magnetec

Material	Alloy composition	Strip thickness [µm]	Losses (20kHz, 200mT) [W/kg]	Saturation B_{sat} [mT]	Magneto-striction λ_s [10^{-6}]	Permeability (50Hz) μ_4
standard crystalline permalloy	$Ni_{60}Fe_{40}$	50	45	1.200	10	20.000 – 30.000
advanced crystalline alloy	$Fe_{93,5}Si_{6,5}$	50	40	1.300	0,1	16.000
amorphous alloys I	$Fe_{76}(Si,B)_{24}$	25	18	1.500	25	6.500 – 8.000
high performance ferrites	MnZn	-	17	500	-	1.000 – 15.000
advanced crystalline permalloy	$Ni_{80}Fe_{20}$	30	14	800	1	100.000-300.000
amorphous alloys IIa	$Co_{73}(Si,B)_{27}$	25	5	550	< 0,2	100.000-150.000
amorphous alloys IIb	$Co_{77}(Si,B)_{23}$	25	5,5	820	< 0,2	2.000 – 4.500
amorphous alloys IIc	$Co_{80}(Si,B)_{20}$	25	6,5	1.000	< 0,2	1.000 – 2.500
nanocrystalline alloys	$Fe_{73}(Si,B)_{24}$	20	4	1.200	0,1	20.000-200.000

Table 1: *comparison of softmagnetic materials properties*

stream applications are power transformers in push-pull converters from a few 100 W up to several 100 kW, spike killers and trigger transformers for IGBT-driven converters, cores for passive earth leakage circuit breakers and current transformers in elecronical watthour meters (PCIM 5/97). There will be many more in the forthcoming future – in particular in conjunction with new topologies of power converters in the kilowatt range (PCIM 4/97).

Nanocrystalline cores are available in form of toroidal or stadium shaped tape-wound cores.

The material itself is brittle and requires a protection against mechanical forces which is either provided by plastic core boxes or a suitable coating. Once coated or boxed, the cores are extremely robust and the magnetic properties are almost independent from temperature.

On one hand, the strip material limits the variety of mechanical core shapes but on the other hand variable toroidal core geometries can be obtained without tooling costs. The cores can be stacked before the wire winding without problems. The available core sizes range from less than 10 mm up to more than 160 mm in outer diameter. Basically, air-gapped or cut-core versions should also be possible but this option is not yet available as a standard on the market.

Nanocrystalline cores were introduced into the market already in 1992/93 but industrial scale production capacity was installed only recently. There are two major manufacturers for the rapidly quenched nano-ribbon, one in Japan and the other in Germany. It is foreseeable, that more producers will start the production too so that availability is no longer a problem. The estimated actual production capacity of nano-ribbon worldwide is in the order of about 50t/month and will be at least be doubled every year. Finished cores are produced by several companies today and there are certainly many more to come.

Due to increased production capacities and enhanced competition, prices have now reached reasonable levels so that there is no reason, why this extraordinary material – which may be described as being a ‚high frequency silicion steel‘ - should not continue its sucessful way into todays and future power electronic designs. ■

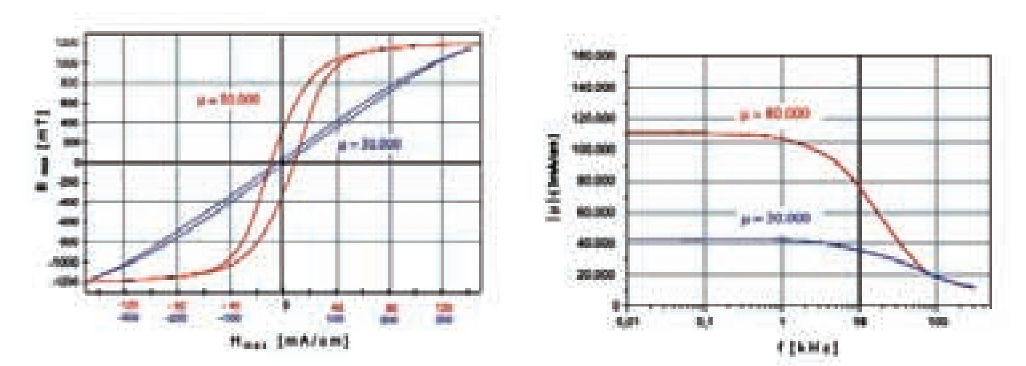

Figure 2: *Variable range of hysteresis loops and permeability levels*

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