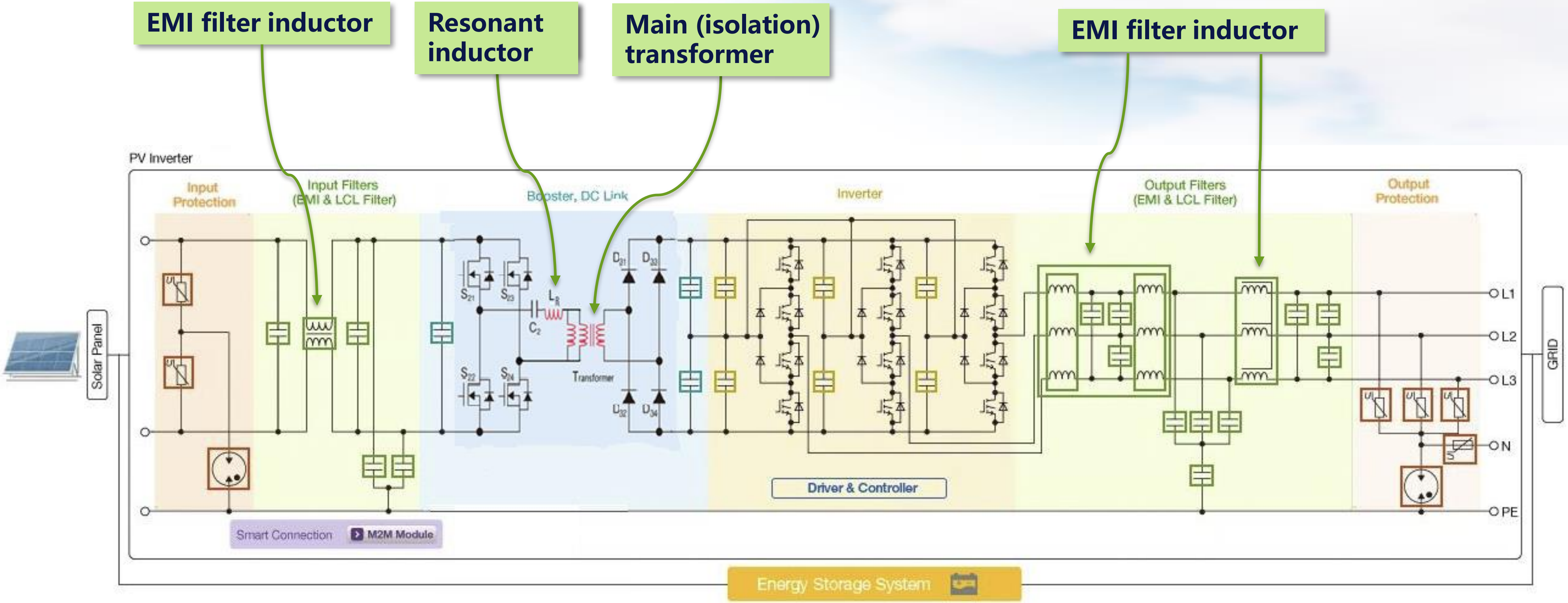
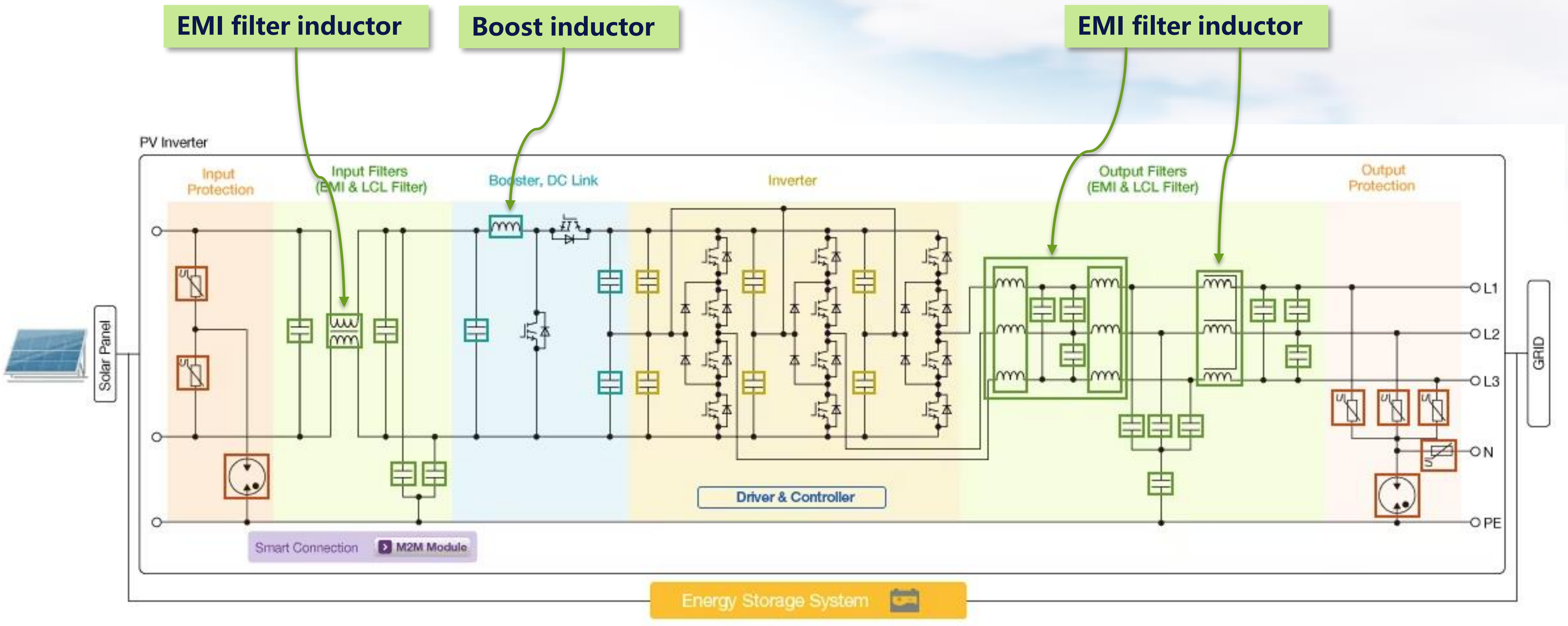
Technical Progress of NCD's Soft Magnetic Materials Used for Energy Related Fields

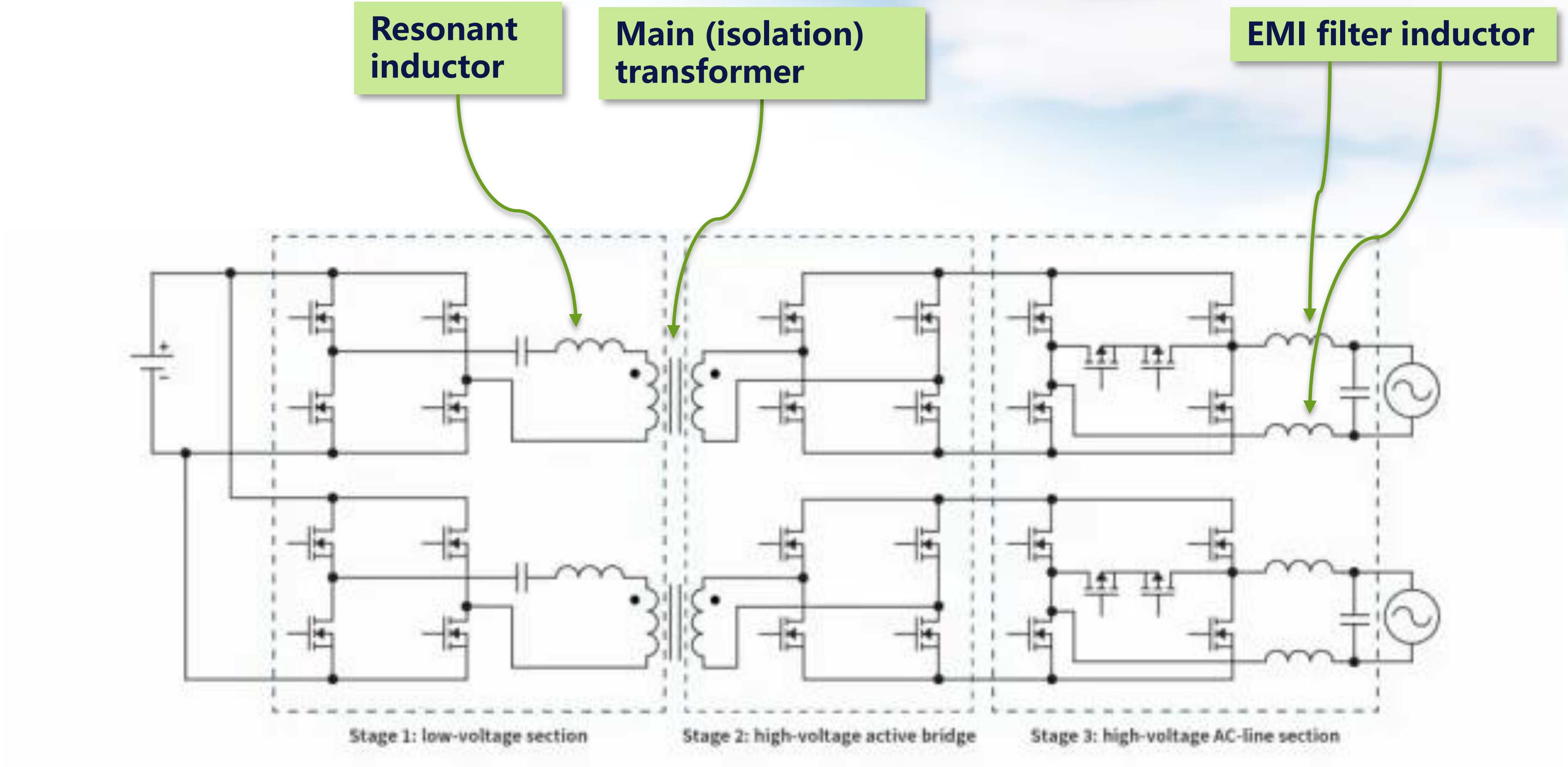
Soft magnetic components used in photovoltaic inverters (isolated type)



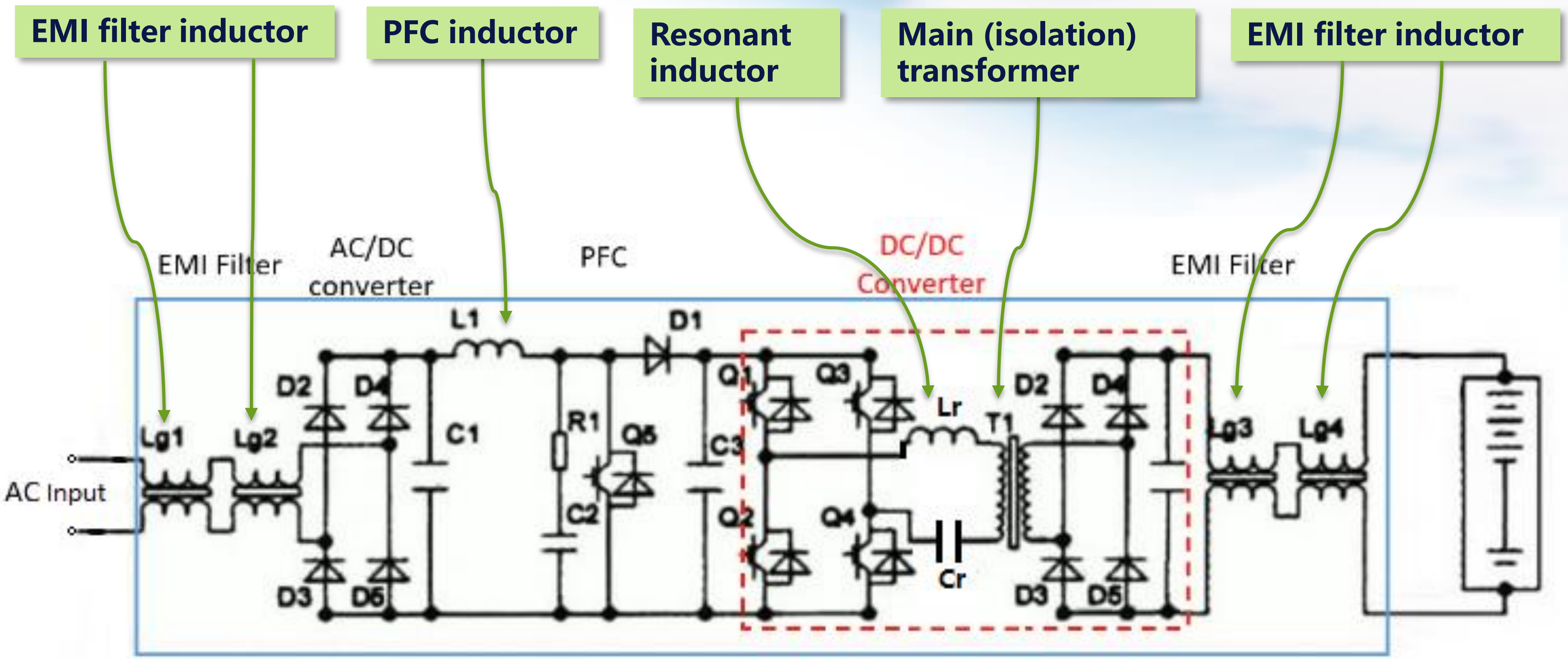
Soft magnetic components used in photovoltaic (PV) inverters (non-isolated type)



Soft magnetic components used in energy storage inverters

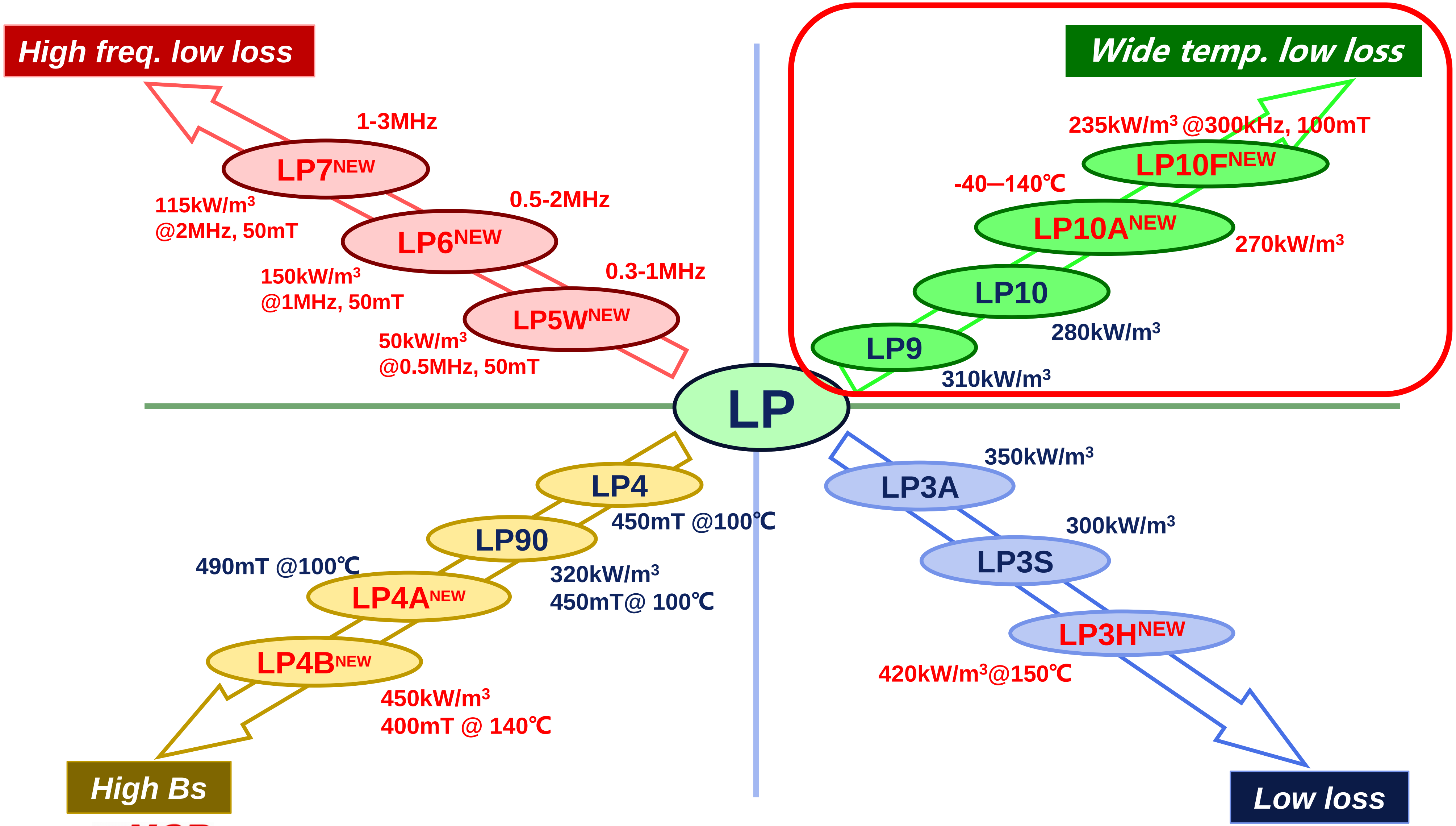


Soft magnetic components used in charging piles

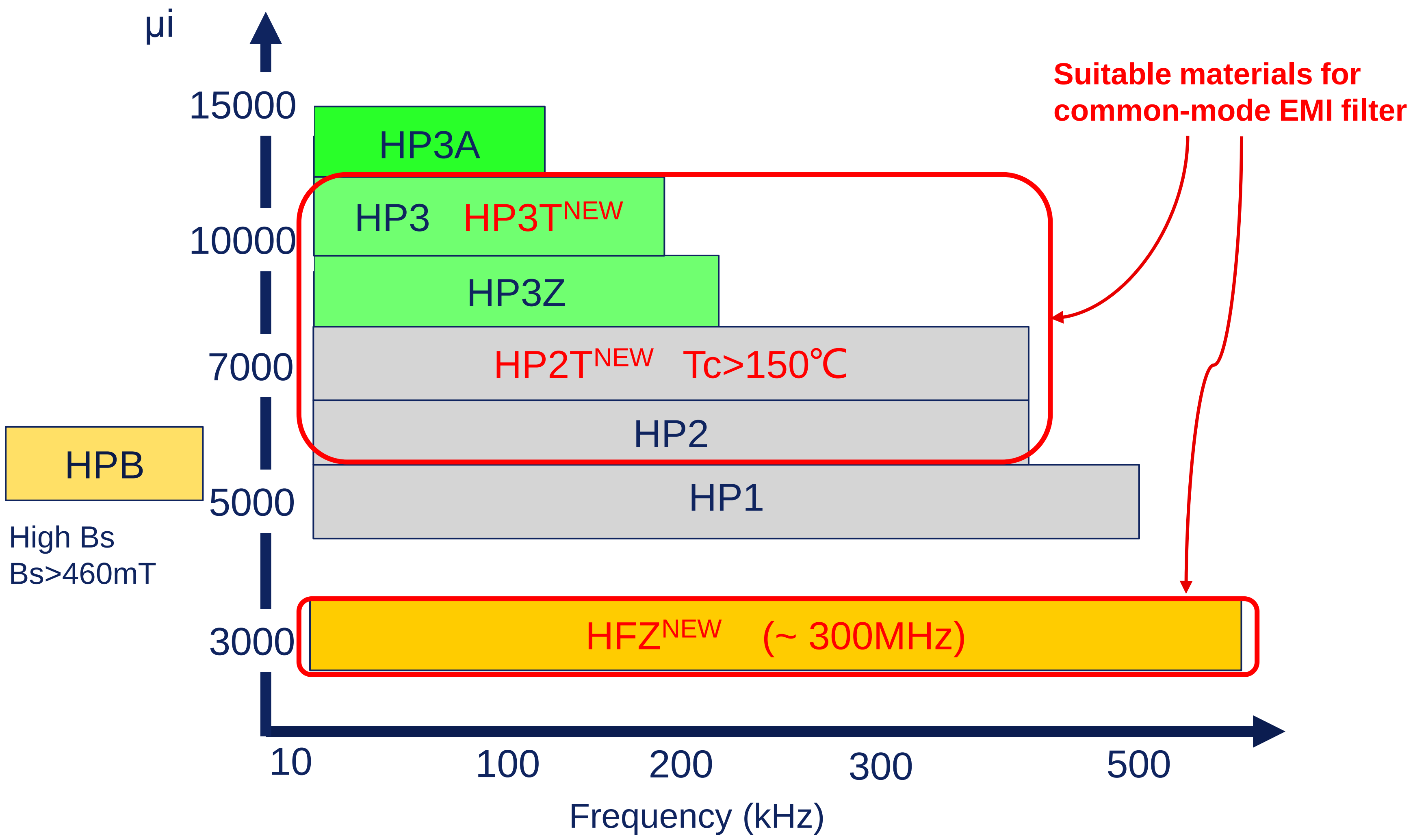


Low power loss (LP) ferrite material system

Suitable materials for main transformer and resonant inductor in isolated power conversion



High permeability (HP) ferrite material system



Magnetic powder core material system

材 料	μ	Bs (T)	Pc (kW/m^3) 50kHz/100mT	DC Bias (%) (L_{100Oe}/L_0)	Tc (℃)
NH	26-125	1.5	200	85	500
NHU	60-125	1.5	140	90	500
NS	26-125	1.03	220	46	600
NSW	26-90	1.03	140	57	600
NSW-L	26-90	1.03	110	57	600
NK	19-90	1.5	500	72	700
NKH	26-90	1.5	370	78	500
NHK	26-90	1.5	280	81	500
NSH	26-90	1.15	160	65	500
NHS	26-90	1.35	180	76	500
NKS	26-90	1.15	260	62	600

Suitable materials for PFC inductor

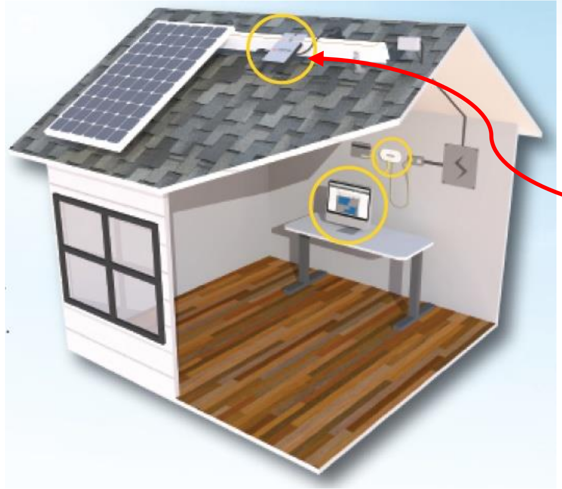
Suitable materials for boost inductor in non-isolated power conversion

Technical development of wide-temp. low loss ferrite materials

- The PV microinverters installed on outdoor roofs operate in a wider ambient temperature range than typical indoor applications. In different seasons, sunshine and load conditions, the operating temperature of soft magnetic components may be from -40 ° C to +80~90 ° C, requiring ferrite materials to have stable characteristics, especially low power loss in a wide temperature range, which affects the efficiency and reliability of the microinverters.

Input Data(DC)	M215-60-2LL-S22/23 M215-60-2LL-S22-NA/S23-NA(Ontario)	
Recommended maximum input power(STC)	260W	
Maximum input DC voltage	45V	
Peak power tracking range	22V-36V	
Operating range	16V-36V	
Min./Max. start voltage	26.4V/45V	
Max. DC short circuit current	15A	
Max. input current	10.5A	
Output Data(AC)	**@208 Vac**	**@240 Vac**
Maximum output power	215W	215W
Nominal output power	1.0A*	0.9A*
Nominal voltage/range	208V/183V-229V	240V/211V-264V
Extended voltage/range	208V/179V-232V	240V/206V-269V
Nominal frequency/range	60.0/59.3-60.5	60.0/59.3-60.5
Extended frequency/range	60.0/59.2-60.6	60.0/59.2-60.6
Power factor	>0.95	>0.95
Maximum units per 20A branch circuit	25 (three phase)	17 (single phase)
Maximum output fault current	1.05 Arms, over 3 cycles; 25.2 Apeak	1.74ms duration
		*Arms at nominal voltage
Efficiency		
CEC weighted efficiency		96.0%
Peak inverter efficiency		96.3%
Static MPPT efficiency (weighted, reference EN50530)		99.6%
Dynamic MPPT efficiency (fast irradiation changes, reference EN50530)		99.3%
Night time power consumption		46mW
Mechanical Data		
Ambient temperature range	-40ºC to +65 ºC	
Operating temperature range (internal)	-40ºC to +85 ºC	
Dimensions (WxHxD)	17.3cm x 16.4cm x 2.5cm (6.8" x 6.45" x 1.0")	
Weight	1.6 kg (3.5 lbs)	
Cooling	Natural convection - no fans	
Enclosure environmental rating	Outdoor - NEMA 6	
		*without mounting bracket
Features		
Compatibility	Pairs with most 60-cell PV modules	
Communication	Power line	
Warranty	25-year limited warranty	
Compliance	UL1741/IEEE1547, FCC Part 15 Class B CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	

Courtesy of Enphase



Ambient temperature range	-40ºC to +65 ºC
Operating temperature range (internal)	-40ºC to +85 ºC

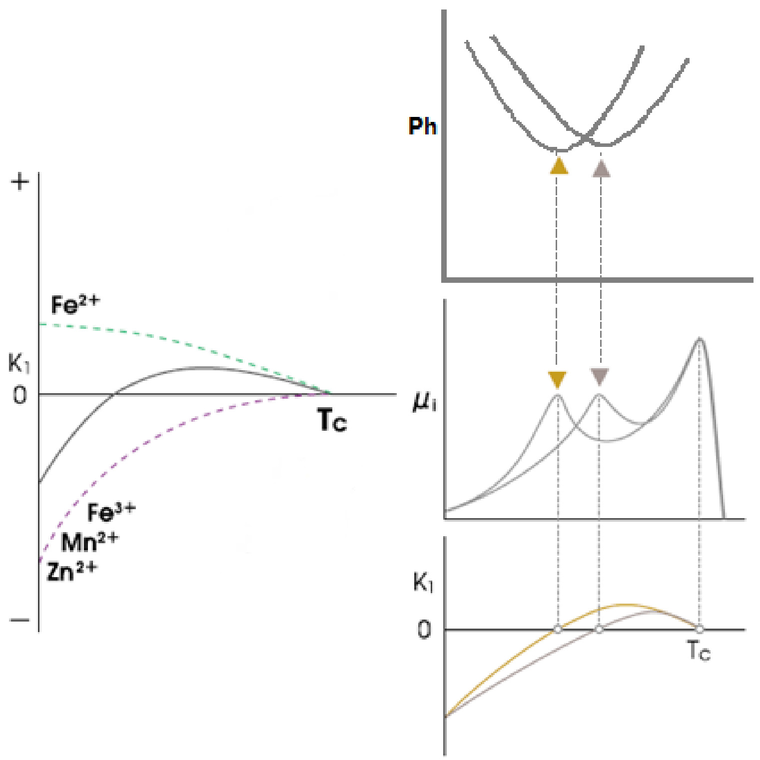
Technical development of wide-temp. low loss ferrite materials

- In view of the disadvantages that traditional power ferrites can only achieve low loss in a narrow temperature range, TDK developed PC95 wide temperature low loss MnZn ferrite material in 2000. The LP9 material corresponding to PC95 was developed in 2006 by NCD.

- With the continuous improvement of material performance requirements for photovoltaic, automotive and other applications, especially with the accelerated penetration of SiC and GaN wide-gap semiconductor devices, the first generation of wide-temperature low loss materials have high power loss in wider temperature ranges and higher frequencies. The market is in urgent need of new broad-temperature low loss materials with flatter temperature characteristic curves and higher application frequency.

Technical development of wide-temp. low loss ferrite materials

- One of the main reasons that the power loss of MnZn ferrite material varies with temperature is that the magneto-crystalline anisotropy constant K_1, which affects the hysteresis loss (P_h), changes with temperature. Low hysteresis loss and high permeability (μ_i) can only be achieved near a single temperature point where K_1 compensation is zero.

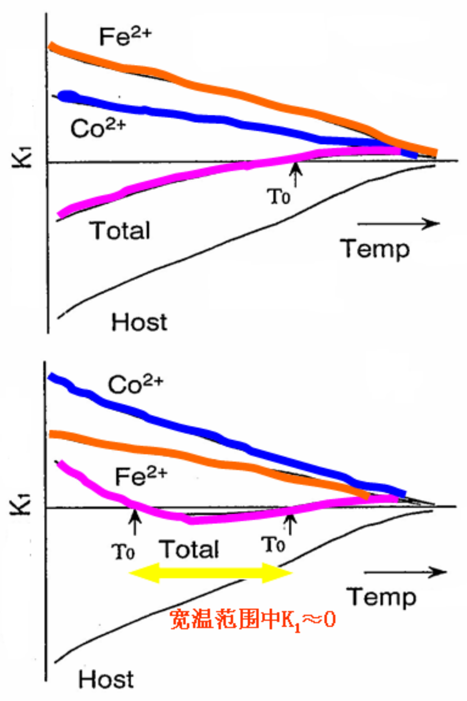


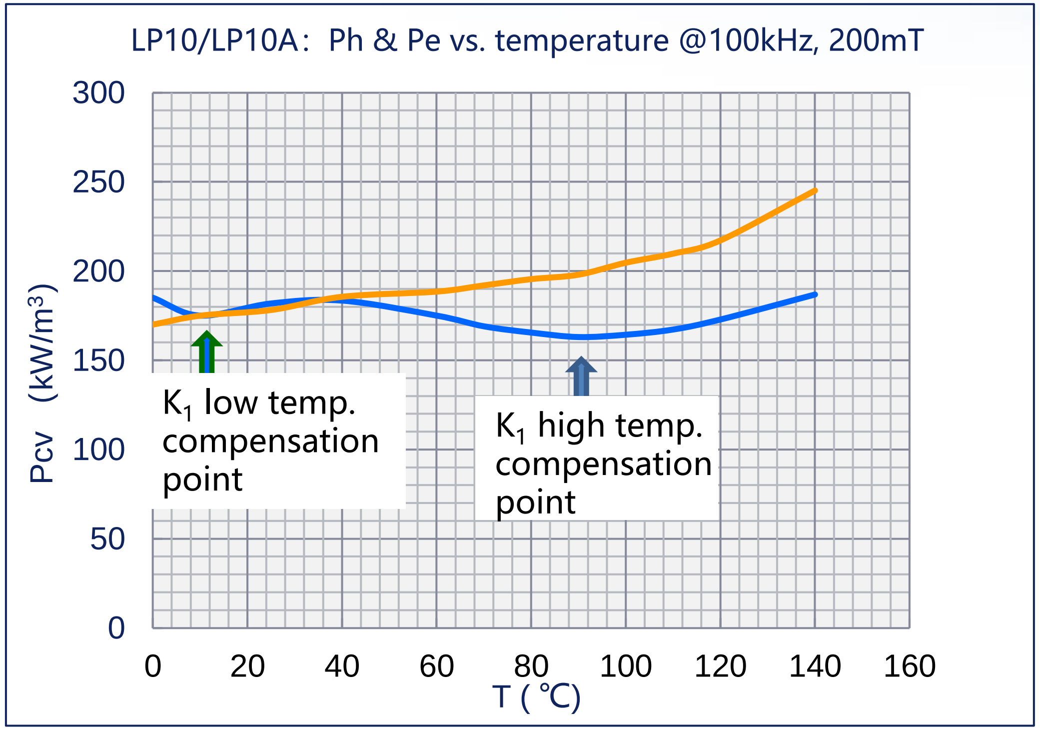
$P_c=P_h+P_e+P_r$

$P_h \propto |K_1|+\lambda_s\sigma$

Technical development of wide-temp. low loss ferrite materials

- Based on the study of the mechanism affecting the temperature dependence of K_1, through the technical innovation of the material principal component, additives, powder processing and sintering microstructure control, the temperature point where K_1 compensation is zero is changed from a single temperature point to high and low temperature two points, which greatly reduces the temperature dependence of the magneto-crystalline anisotropy of the material. On this basis, LP10 new material series have been successfully developed.



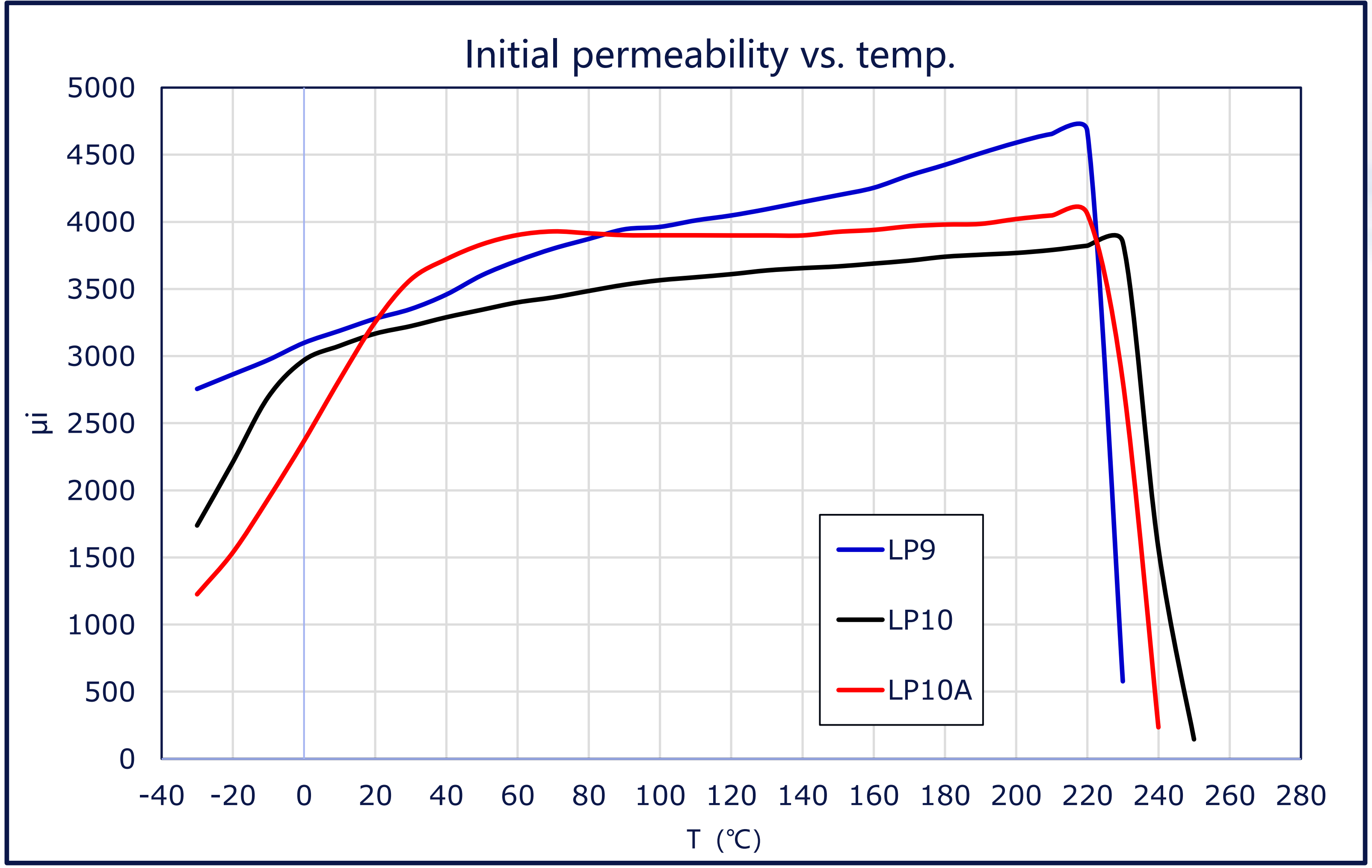


Technical development of wide-temp. low loss ferrite materials

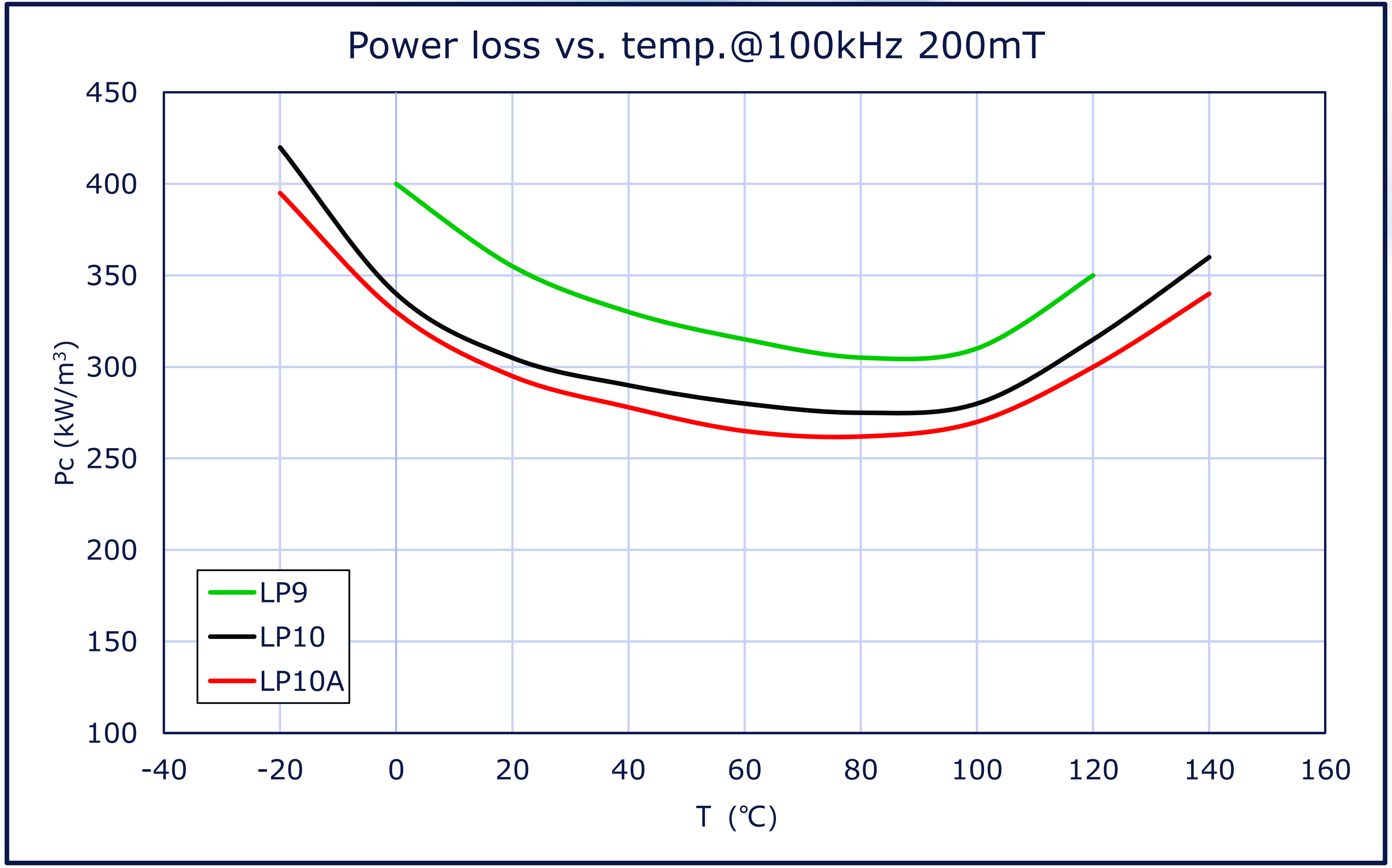
Characteristic	Symbol	Condition	LP9	LP10	LP10A
Initial permeability	μi		3300±25%	3300±25%	3300±25%
Saturation flux density*	Bs(mT) @1194A/m	25℃	530	540	540
		100℃	420	430	430
Power loss *	Pcv (kW/m^3) @100kHz, 200mT	25℃	350	300	290
		60℃	315	285	270
		80℃	305	275	265
		100℃	310	280	270
		120℃	350	320	300
		140℃	—	360	340
Curie temp.	Tc (℃)		>215	>230	>230
Density *	d (kg/m^3)		4.9×10^3	4.9×10^3	4.85×10^3

Test sample: OD25/ID15/HT10 ring-core *Typical value

Technical development of wide-temp. low loss ferrite materials

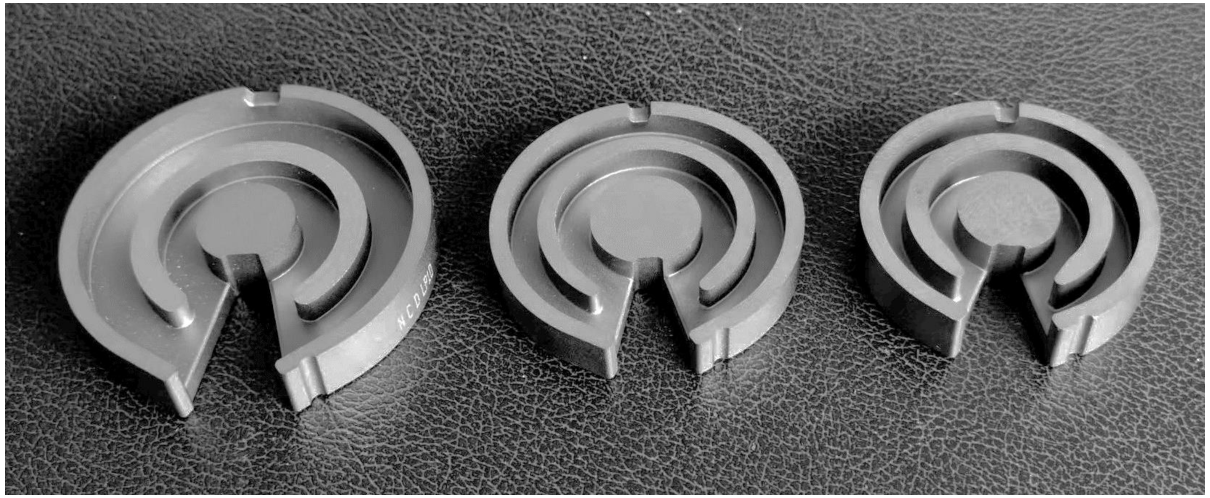


Technical development of wide-temp. low loss ferrite materials



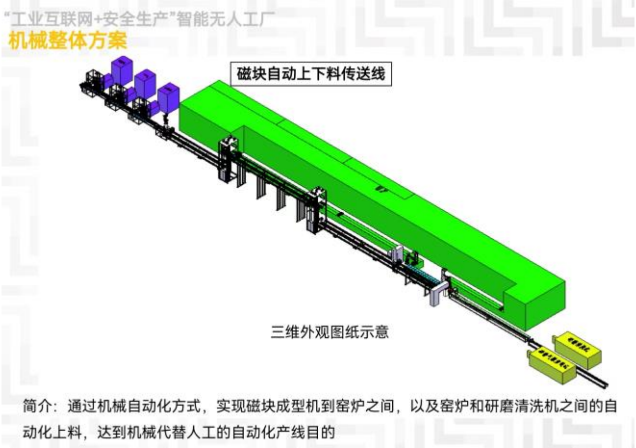
Development and mass production of ferrite P-core series used for main transformer in PV microinvertor

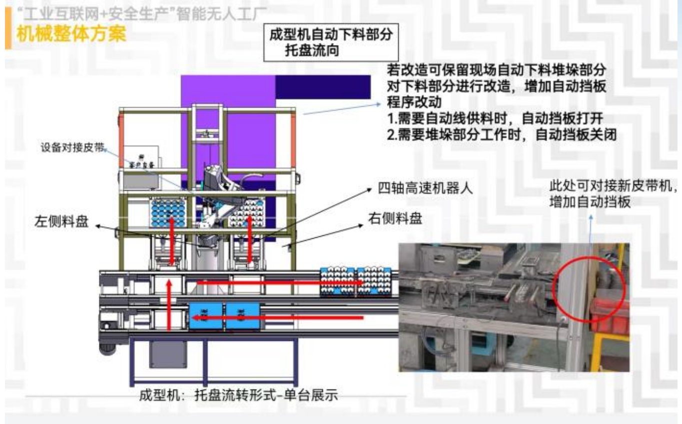
- Based on the development of high-performance LP10 material series, combined with automatic powder preparation, efficient rotary pressing, automatic green-core stowage, large-scale atmosphere controlled push-type kiln sintering, precision surface and air gap grinding and production management and quality management system based on MES, after years of efforts, NCD has become the largest Chinses supplier of the ferrite P-core series (P52/P52B/P61.7/P80.8) used by international leading enterprise of PV microinverters.

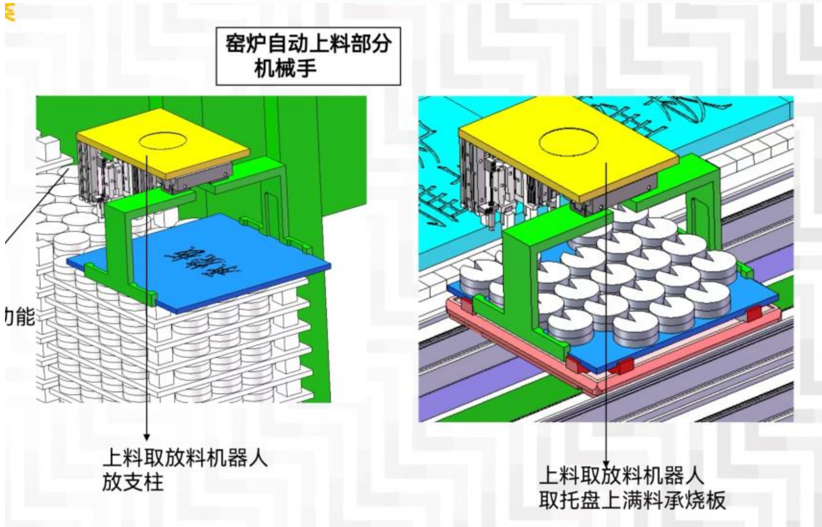


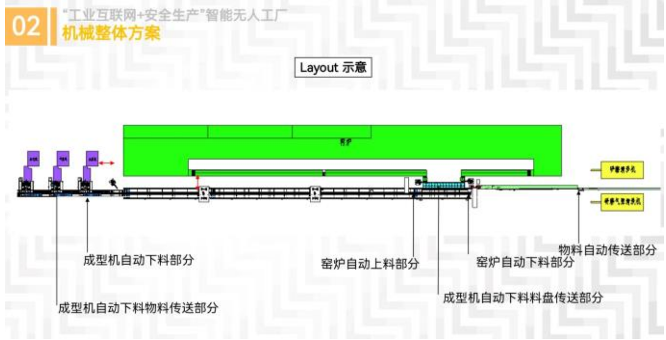
Development and mass production of ferrite P-core series used for main transformer in PV microinvertor

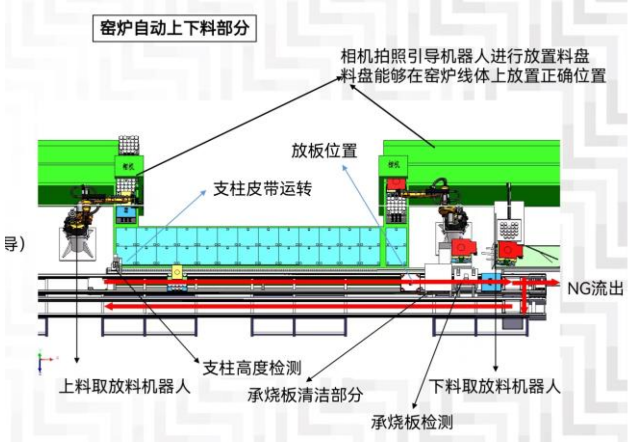
- NCD is implementing a construction project of the intelligent production line of P-core series. It is expected that after putting into operation in 2024, the molding - sintering - grinding processing process can be fully automated production, improve production efficiency and quality level, reduce labor costs, and double production capacity.











Improvement of materials for large ferrite core for energy storage and charging pile

● Challenges faced by soft ferrites

Higher frequency

- High-frequency is an effective means to achieve miniaturization, lightweight and low-cost magnetic components, so it is always a hot spot in the development of power conversion technology.
- The introduction of SiC device reduces the switching loss at high frequency and pushes up the design operating frequency of the circuits.

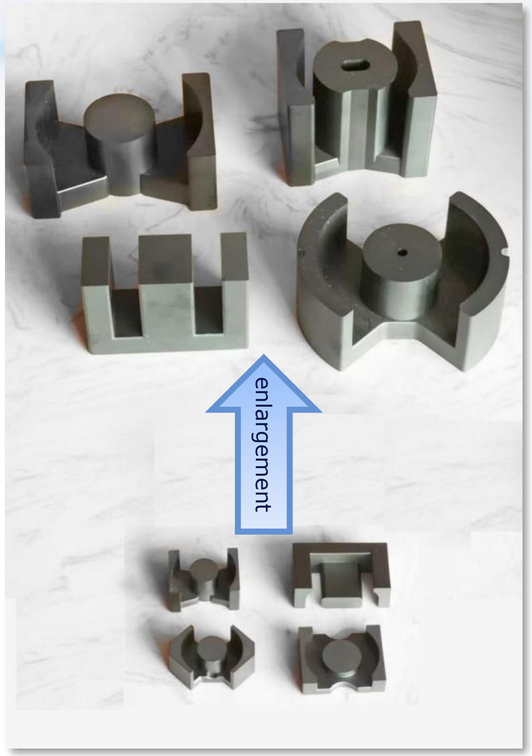
Higher temperature

- High ambient temperatures for outdoor PV microinverters and charging piles.
- High power densification increases the design working magnetic flux density of the core, causing greater magnetic loss, which leads to higher temperature rise.
- The high temperature stability of the SiC device and the high temperature resistance of the insulated wire skeleton (H class :180℃) push up the design operating temperature of the magnetic components.

Larger core size

- Power quality related devices (UPS, energy storage inverters) are high-powered.
- Large EMI filter magnetic components of distributed PV systems.
- DC fast charging pile with high power.

Large cores for energy related applications

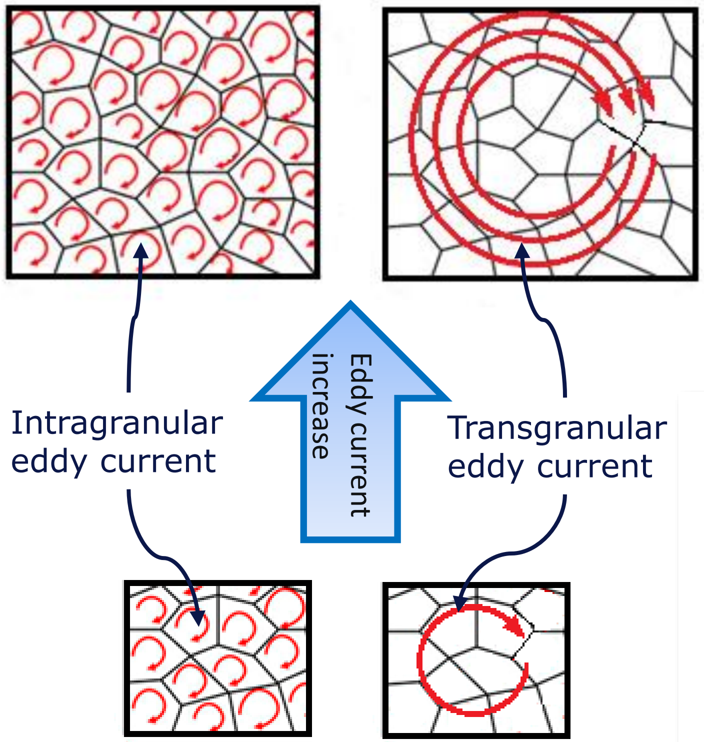


Small cores for communications and consumer electronics

Improvement of materials for large ferrite core for energy storage and charging pile

- **Challenge: With the increase of size, the performance of low-loss ferrite core deteriorates at high temperature and high frequency**

Large core



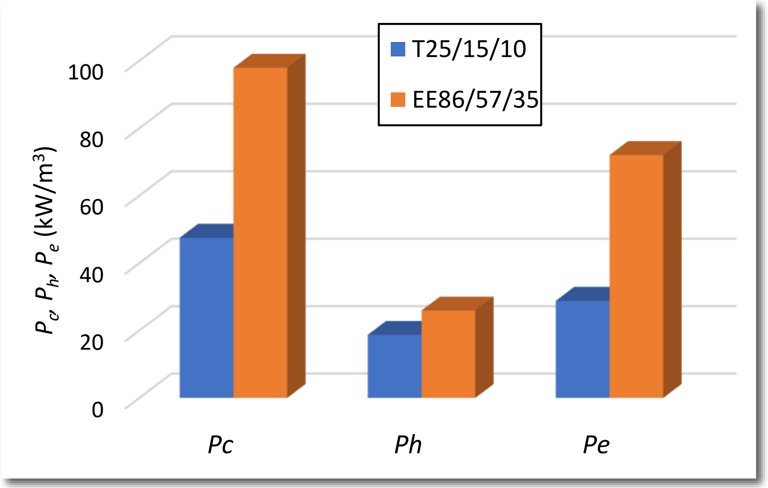
Small core

Composition of power loss: $P_c = P_h$ (hysteresis) + P_e (eddy current) + P_r (residue)

$$= f\oint B\,dH + C\, f^2 B_m^2 D^2/\rho + P_r$$

(Note: P_r below 500kHz can be ignored)

P_c, P_h, P_e @ 100kHz,100mT,100℃							
Item	P_c (kW/m^3)	P_h (kW/m^3)	P_e (kW/m^3)	P_h/P_c (%)	P_e/P_c (%)	A_e (mm^2)	V_e (mm^3)
T25/15/10	47.5	18.7	28.8	39.4	60.6	48.9	2940
EE86/57/35	97.9	25.9	72.0	26.5	73.5	965	234000

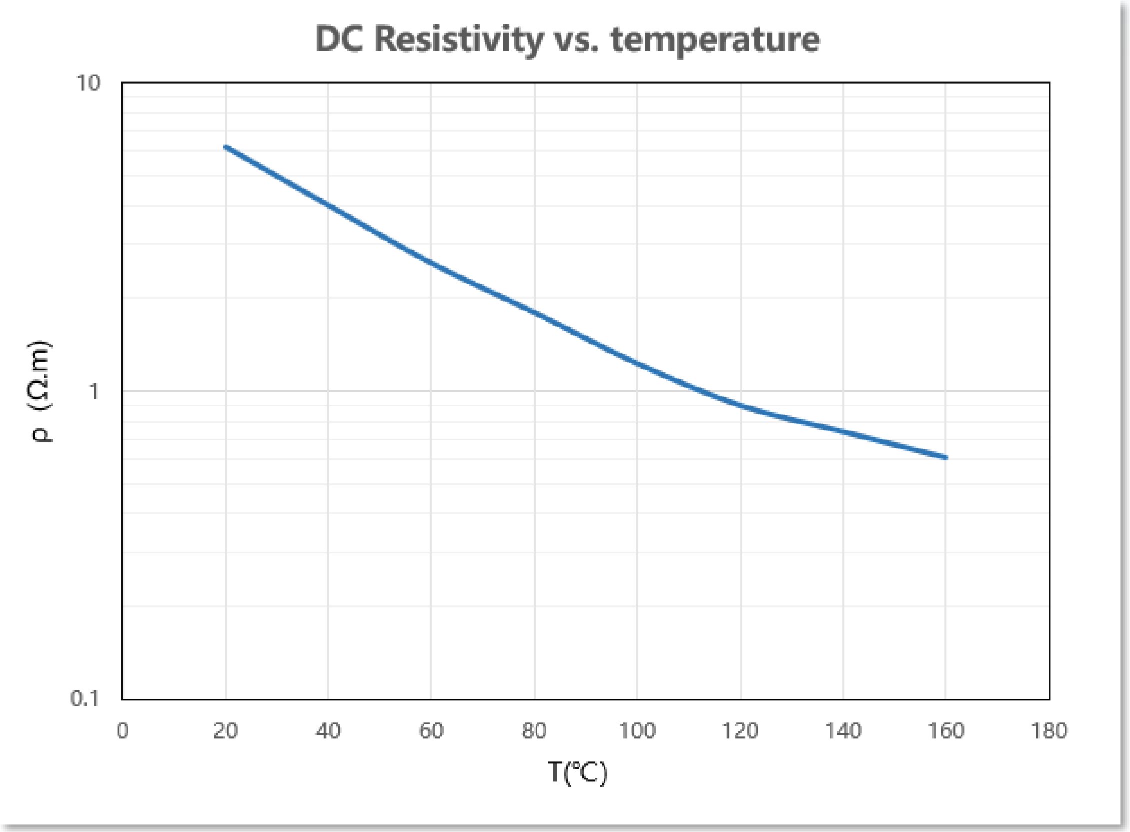


- With the increase of the magnetic core size, the eddy current path induced by the excitation field in the magnetic core increases, and the eddy current intensity, eddy current loss P_e and the proportion in the total magnetic loss P_e/P_c also increase.
- Due to the positive temperature characteristic of P_e, the total magnetic loss increases sharply with the rise of temperature, resulting in high temperature power loss deterioration of large cores.
- Since P_e is proportional to the square of the frequency, the power loss at high frequencies of large cores is more degraded.

Improvement of materials for large ferrite core for energy storage and charging pile

- **Eddy current mechanism study**

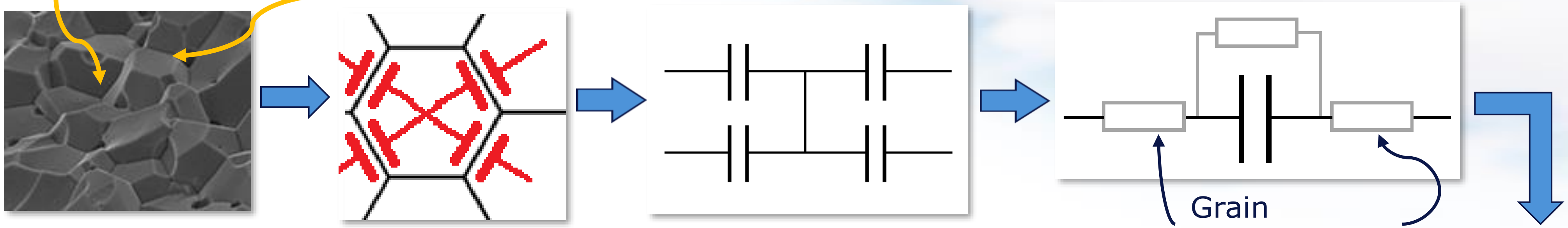
Eddy current loss $P_e = C\ f^2\ B_m^2\ D^2/\rho$

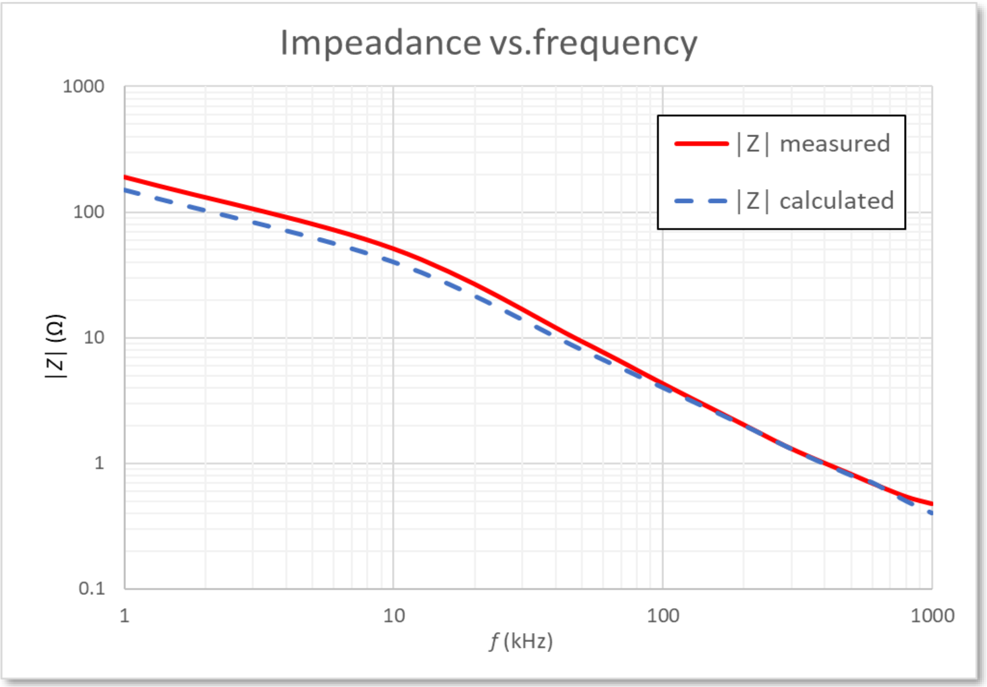


- Because eddy current has significant influence on high frequency and high temperature performance of large ferrite cores, the research focus is on eddy current suppression.
- For a particular core, C is a constant; Working conditions (f, B_m) are also determined by design. The only way to suppress eddy current loss is to reduce grain size D and increase resistivity ρ.
- In contrast to metallic materials, the resistivity of MnZn ferrite decreases with increasing temperature, showing a negative temperature characteristic similar to semiconductor, which is related to the electronic transition conduction mechanism between Fe^{2+} and Fe^{3+}. This is the reason why the eddy current loss of the core has a positive temperature characteristic.

Improvement of materials for large ferrite core used for energy storage and charging pile

- **Eddy current mechanism study**





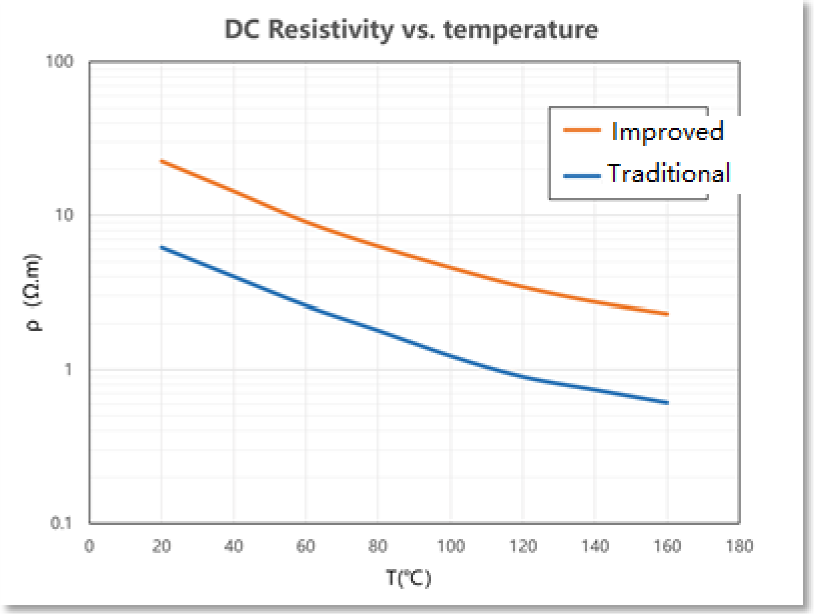
$$|Z| = R_g + \sqrt{\left(\frac{R_b}{1 + R_b^2\omega^2C^2}\right)^2 + \left(\frac{R_b^2\omega C}{1 + R_b^2\omega^2C^2}\right)^2}$$

- In polycrystalline ferrite, the grains with low resistance and the grain boundary with high resistance form a distributed capacitor array, and the frequency dispersion shows a capacitive reactance characteristic, that is, the impedance and AC resistance decrease with the increase of frequency. This capacitance effect is the main reason for the generation of transgranular eddy current, resulting in the eddy current effect further increasing with the increase of frequency.
- The increase of grain boundary and grain resistance and the decrease of dielectric constant of the material are beneficial to the suppression of eddy current and its loss.

Improvement of materials for large ferrite core used for energy storage and charging pile

- **R&D results: 300kHz wide temp. low loss MnZn ferrite**

EE 86/57/35: P_c, P_h, P_e @ 100kHz,100mT,100℃							
Item	P_c (kW/m^3)	P_h (kW/m^3)	P_e (kW/m^3)	P_h/P_c (%)	P_e/P_c (%)	A_e (mm^2)	V_e (mm^3)
Before improvement	97.9	25.9	72.0	26.5	73.5	965	234000
After improvement	79.1	27.8	51.3	35.1	64.9	965	234000



- Through a series of technical improvements, the resistivity of the material at 100℃ increased by 2.8 times; The grain is more uniform and refined.
- With the increase of resistivity and the decrease of grain size, eddy current inside the large magnetic core is effectively inhibited. The eddy current loss of the typical magnetic core EE86/57/35 at 100kHz, 100mT and 100℃ is reduced by 28.7%, the hysteresis loss is increased by 7.3%, and the total power consumption of the magnetic core is reduced by 19.2%。

Improvement of materials for large ferrite core used for energy storage and charging pile

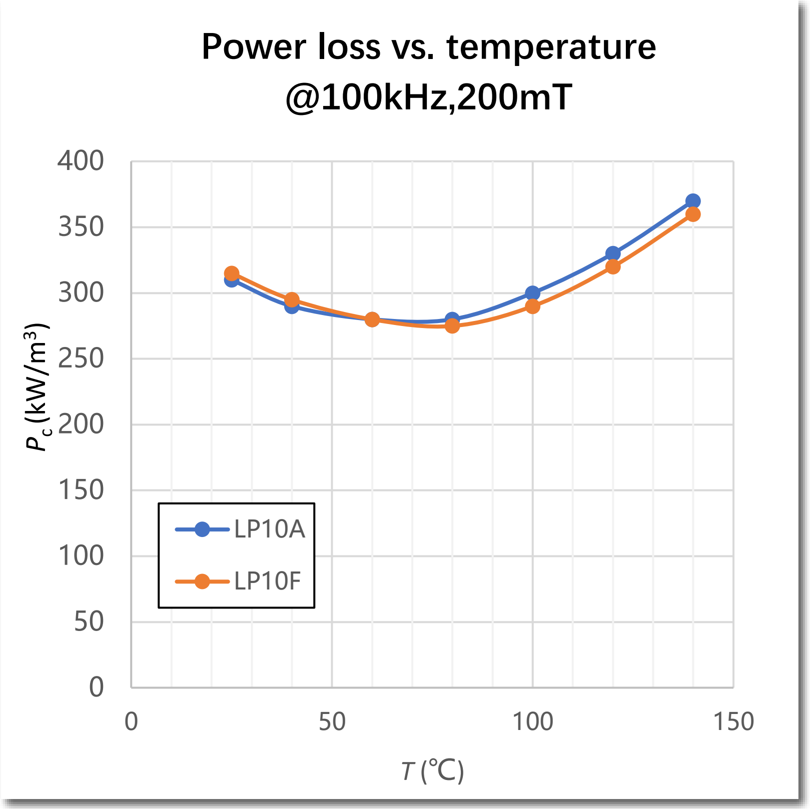
- **R&D results: 300kHz wide temp. low loss MnZn ferrite**

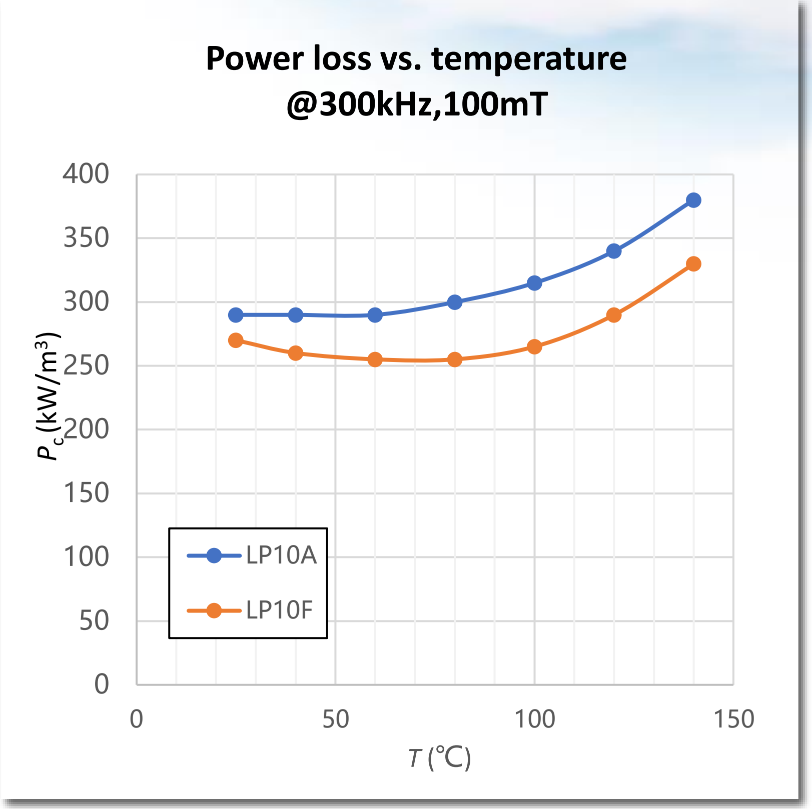
Characteristics	LP10A	LP10F new
Initial permeability μ_i	3300±25%	3000±25%
Saturation flux density B_s @1194A/m (mT)	540 (25℃)	530 (25℃)
	430 (100℃)	420 (100℃)
Curie temperature T_c (℃)	230min.	230min.
Density d (kg/m^3)	4.85×10^3	4.85×10^3
Resistivity ρ (Ω·m)	6	8
Power loss P_c @100kHz,200mT (kW/m^3)	290 (25℃)	——
	265 (80℃)	——
	300 (100℃)	——
	340 (120℃)	——
Power loss P_c @300kHz,100mT (kW/m^3)	——	250 (25℃)
	——	235 (100℃)
	——	270 (120℃)
	——	330 (140℃)

- Based on the above study work, NCD has developed a 300kHz wide-temperature low loss MnZn ferrite material LP10F, which is suitable for SiC device application scenarios.

Improvement of materials for large ferrite core used for energy storage and charging pile

- **R&D results: 300kHz wide temp. low loss MnZn ferrite**



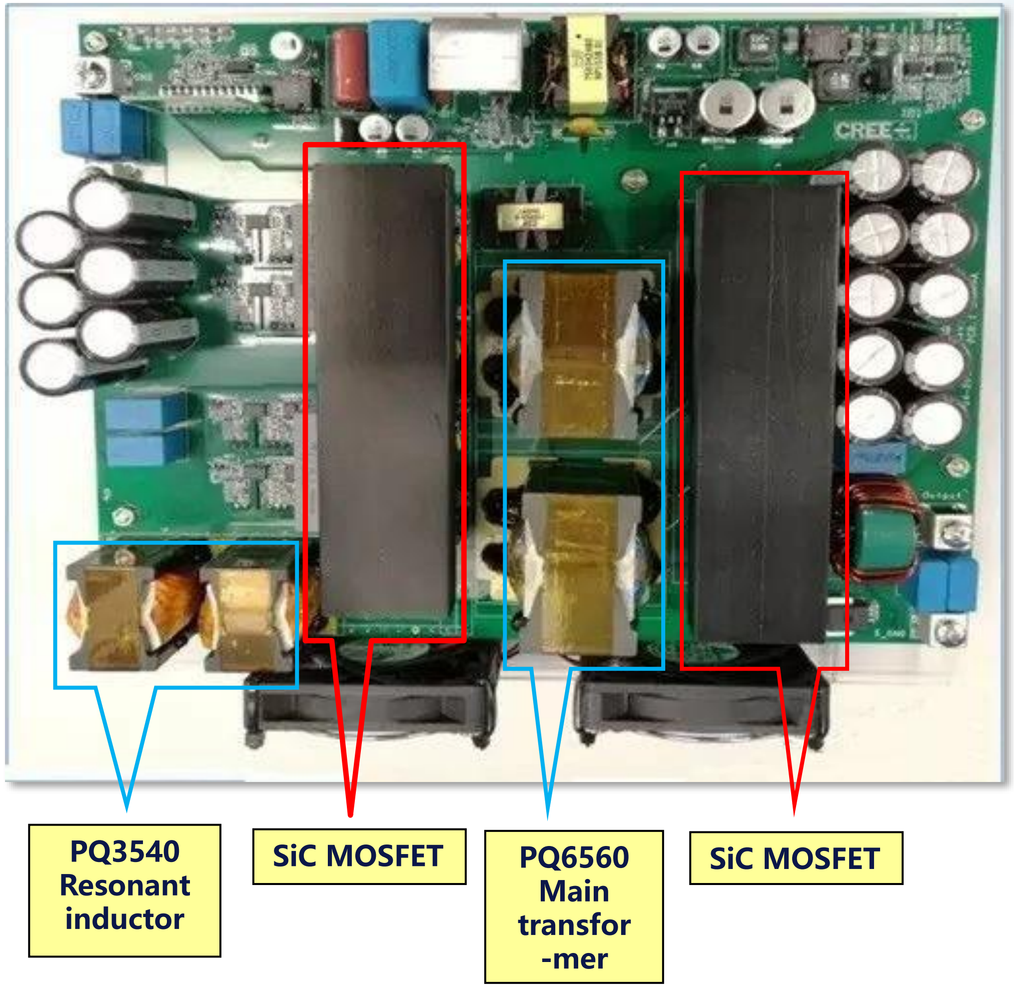


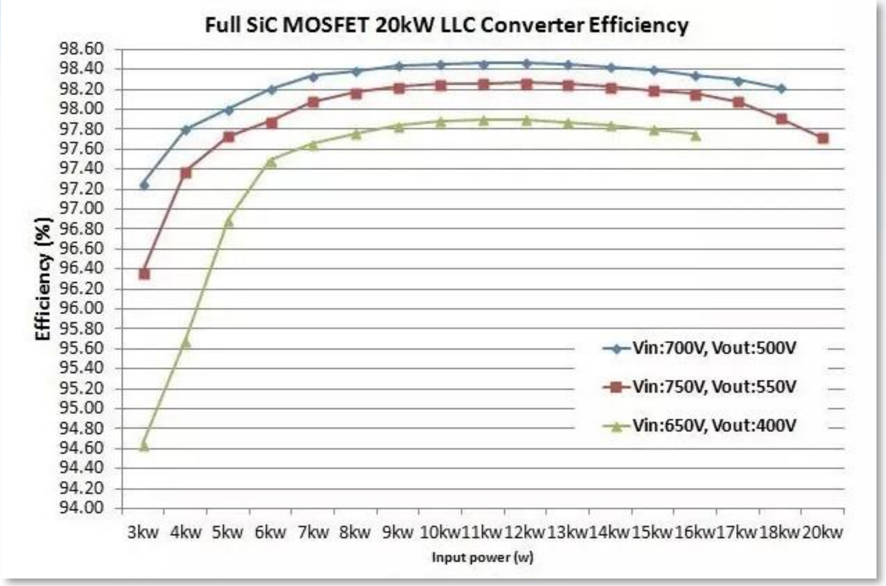
- Compared with the existing material LP10A, the power loss of LP10F is little different at 100kHz, but the difference is significant at 300kHz, indicating that the high frequency characteristics of the material are improved.
- It is mainly suitable for medium and high frequency, medium and high power scenarios using SiC devices, such as optical storage integration system, high power fast charging pile, etc.
- With the popularity of SiC device applications, it is expected that 300kHz low-power ferrite materials will gradually replace the current 100kHz materials and become the mainstream materials in the field of medium and high-power conversion.

Improvement of materials for large ferrite core used for energy storage and charging pile

- **R&D results: 300kHz wide temp. low loss MnZn ferrite**

Application example: 20kW DC/DC converter module based on SiC MOSFET and LLC circuit topology





- Switching frequency: 150~400kHz; Resonant frequency: 200kHz

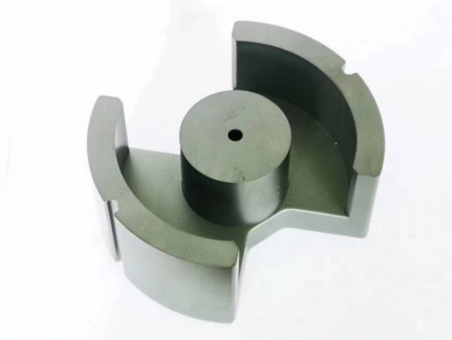
  Input voltage: 650~750V_{dc} ; Output voltage: 400~550V_{dc}

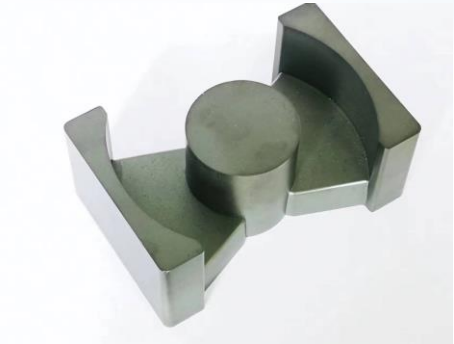
  Rated output power: 20kW; Maximum efficiency ≥98.4%

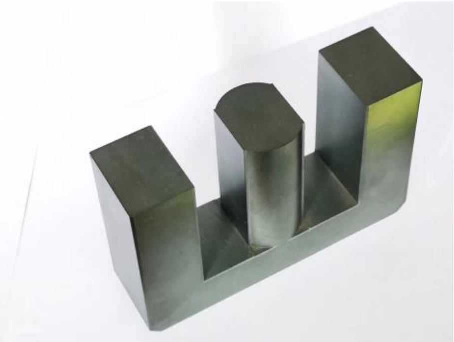
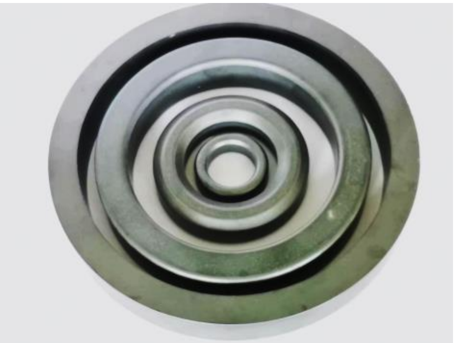
  Dimension: 275mm×220mm×65mm; Power density: 60W/inch^3

Improvement of materials for large ferrite core used for energy storage and charging pile

- NCD has accumulated many years of technology and experience in the R&D and manufacturing of large-size ferrite cores, and has advanced, efficient and large-scale production lines, with a wide variety of product specifications and excellent performance quality. For new products, CNC engraving can be used to quickly prepare samples. NCD can provide customers with effective cooperation and support from the design stage to mass production stage.



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Thank You

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