ARPA-E Power Technologies Workshop

<u>Breakout Group</u>:

Magnetics

(Chair: Charles Sullivan, Dartmouth University)

What are the critical performance metrics for magnetic <u>components</u> for high switching frequency (>10 MHz) converters at 10 W, 50 W, 250 W, 3kW, 300 kW?

- Core loss (eddy & hysteresis)

  Range from 200 mW/cm3 to several W/cm3….but need tie-in with thermal management. Ideally low loss for any flux direction (issue for laminations, anisotropic material.

- Winding loss (skin, proximity, gap, end)
  - Designs for low dc resistance, low 60 Hz resistance, low HF resistance.
  - Optimized for minimum total core + winding loss over operating cycle.
  - Long term: room temperature superconductors.
- Inductance
  - nH's to uH's: different circuits need different things.
- Size
  - In terms of power density (processed power not dissipated): W/cm2 for integrated, W/cm3 for discrete. Goals: near term 100s of W/cm2, long term 1000s of W/cm2 (integrated). Discrete: see Fred Lee's presentation
- Heat transfer
  - Challenge for miniaturization and for high power.
  - Not a problem with ultra-high efficiency.
  - Designs with active/fluid cooling
- Cost: $/kW: $20-$30 today for large (MW) 60 Hz; smaller scale is much more expensive per kW. Consider total cost of ownership.

EMI applications

- WBG -> high dv/dt: need to slow transitions for compatibility with motors, etc.
- Material development? Different set of metrics for material performance.
- Move from trial and error design to systematic design.
- Standard regulations address up to 30 MHz

What are the critical performance metrics for magnetic <u>materials</u> for high switching frequency (>10 MHz) converters at 10 W, 50 W, 250 W, 3kW, 300 kW?

- Conductivity

  As low as possible (electrical) : 100s of micro ohm cm now, but want higher resistivity: 1 milliohm cm is very good, higher even better

  Thermal conductivity: as high as possible
- Coercive field/Hysteresis: As low as possible---see component metrics
- Permeability

Ideally tunable (10 to 1000)

- Saturation flux density

As high as possible….
compare to ferrite as baseline (0.3 to 0.5 T)

Consider practical operation ac flux density as well as saturation

(compare to 30 mT ferrite baseline)

- Processibility:
  - Temperature of processing
  - Scalable: tie in with cost, ability to scale to multi kW
- Temperature stability:
  - Maintain properties at high temp: Curie temp, stability of permeability
- Frequency of interest for advanced designs is lower than 10 MHz for high power.

What are the unique critical performance metrics for materials for <u>integrated magnetic</u> <u>components</u> for high switching frequency (>10 MHz) converters at 10 W, 50 W, 250 W?

Same as last slide but bold = most important; italics = less important

- Conductivity
  - *As low as possible (electrical) : 100s of microohm cm now, but want higher resistivity: 1 milliohm cm is very good, higher even better*
  - *Thermal conductivity: as high as possible*
- Coercive field/Hysteresis
  - As low as possible
- Permeability
  - Ideally tunable (10 to 1000)
- Saturation flux density
  - **As high as possible….**
    compare to ferrite as baseline (0.3 to 0.5 T)
  - **Consider practical operation ac flux density as well as saturation**
  - (compare to 30 mT ferrite baseline)
- Processibility:
  - **Conformal deposition?**
  - **Temperature of processing**
  - **Stress**
  - Scalable: tie in with cost, ability to scale to multi kW
- Temperature stability:
  - Maintain properties at high temp: Curie temp, stability of permeability

For power converter technology (AC/DC & DC/AC), what are the <u>drivers</u> for integration?

- Packaging Costs
- Footprint
- Efficiency
- Ease of Use
- Cost
- Applications of interest:
  - Solid state lighting: footprint and cost
  - PV: efficiency, operation temperature, cost, (footprint)
  - Power supplies for electronics:
  - Grid scale power converters
  - Gate drive

For power converter technology (AC/DC & DC/AC), what are the <u>barriers</u> for integration?

- Performance
  - Now most have low power density and low efficiency.
  - Thickness of thin-film magnetic materials
- Yield: part of cost.
  - Achieving good magnetic properties over large area wafer.
- Thermal management

- Design complexity
- EMI, or fear of EMI
- Cost

A program could attempt to

- Lab tests of thin-film materials show much better performance than MnZn ferrites:
  - Power handling much higher because of high working flux density: 1 T vs. 20 mT.
  - Losses much lower for given operating conditions.
- Opportunity 1:
  - Scalable materials that offer the same performance in meso to macro scale.
    - “2.5 D material”: not thin film, not bulk
    - Similar considerations for coils
- Opportunity 2:
  - Develop component designs and commercialization of thin-film materials.

Technology Gap

	10 W	1000 W	100 kW	10 MW
50 kHz	N/A	Now: ferrite, amorphous	Now amorphous, ferrite, nanocrystalline	Future: existing and new materials
500 kHz	Now: ferrite	Now: ferrite Future: new materials	Future: new materials	
5 MHz	Now: thin-film	Future: new materials		
50 MHz	Future: thin-film and air core			