



a **YAGEO** company

KEMET-SMOLTEK Partnership
Carbon Nanofiber Capacitor Technology Development

Louise Duker, Chief Product Officer, SMOLTEK
Reggie Phillips, Director, Product Management, KEMET

PARTNERSHIP FOR COMMERCIALIZATION



KEMET is partnering with SMOLTEK to jointly develop and commercialize Carbon Nanofiber Capacitors.

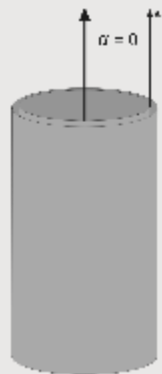
- Phase 1; Joint Development Agreement (JDA)
- Phase 2; Joint Venture (JV)

“This partnership is an excellent opportunity to commercialize a new technology that will be used in capacitors for applications where space is at a premium and high capacitance density is required”.

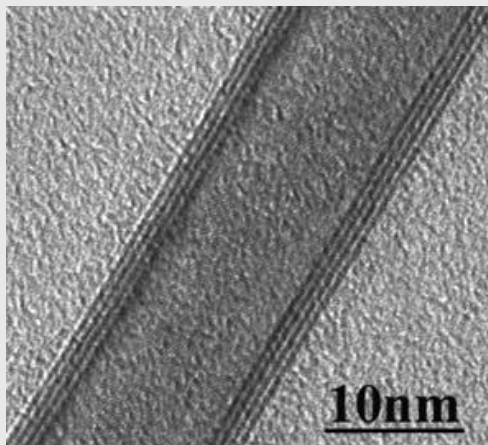
Dr. Philip Lessner, Senior Vice President of YAGEO Group states,

WHAT ARE CARBON NANOFIBERS (CNF)

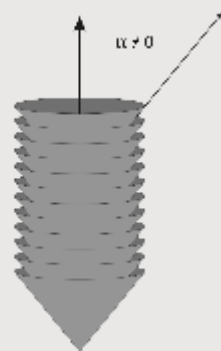
Carbon nanotubes (CNTs)



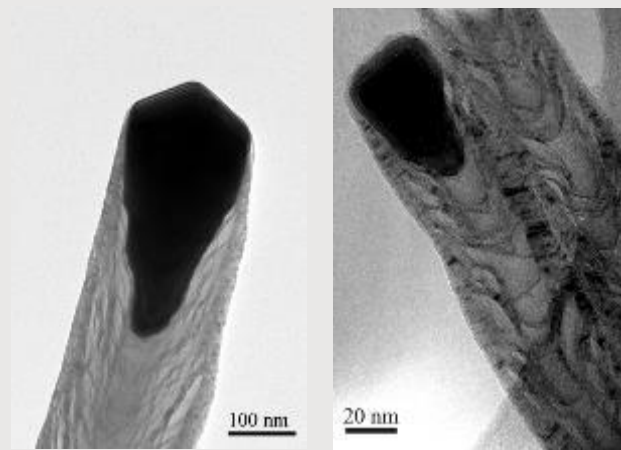
In carbon nanotubes the graphene sheets are parallel to the axis of the tube ($\alpha=0$). Carbon nanotubes could be metallic or semiconductor depending on their chirality.



Carbon nanofibers (CNFs)



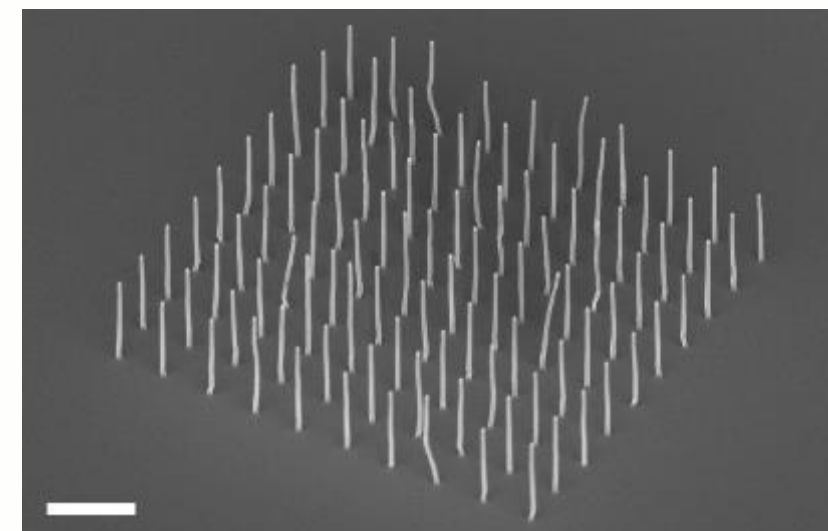
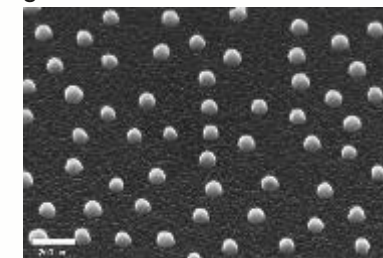
In carbon nanofibers the graphene sheets create a non-zero angle with the axis of the fibers ($\alpha \neq 0$), resembling stacked cones. Carbon nanofibers are always metallic and have similar electrical properties as graphite.



Carbon nanofibers are “grown” from catalyst seeds in a Direct Current Plasma Enhanced Chemical Vapor Deposition (DC-PECVD) process.

The catalytic process enables accurate control of the position, diameter, and the length of the CNFs.

Catalyst seeds before the growth

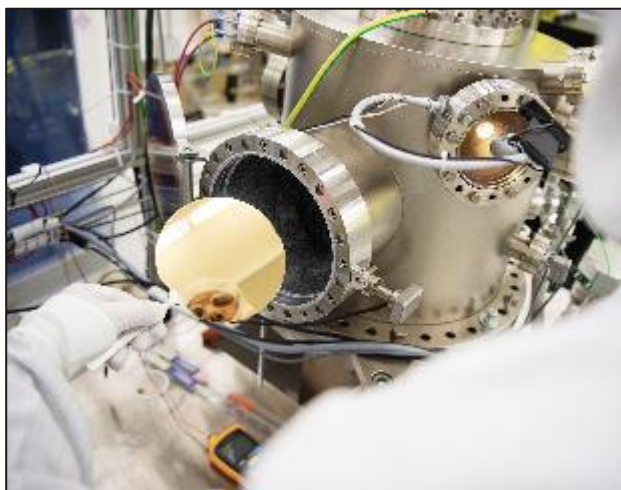


SMOLTEK PECVD TOOLS LINE-UP

SmolGROW is Smoltek's innovative and patent protected plasma-enhanced chemical vapor deposition (PE-CVD) technique to grow vertically aligned carbon nanofibers (VACNF) with exact diameter and length at exact locations. Smoltek has developed a number of growth equipment based on **SmolGROW** technique and is currently building the world's first growth equipment targeting high-volume production of carbon nanofibers on 8-inch wafers.

Smoltek's research tool

A 4-inch highly customizable and flexible tool which allows our R&D team to develop new recipes and test a wide range of process conditions



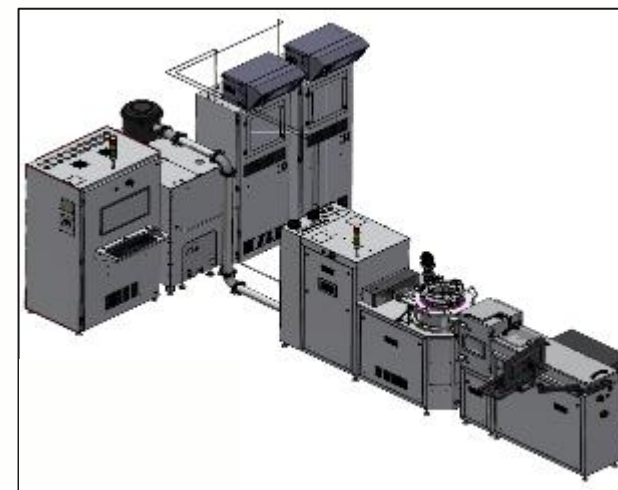
Smoltek's semi-automatic tool

An advanced PECVD tool designed for extremely high plasma and temperature uniformity over an entire 6-inch wafer enabling CNF-based device development







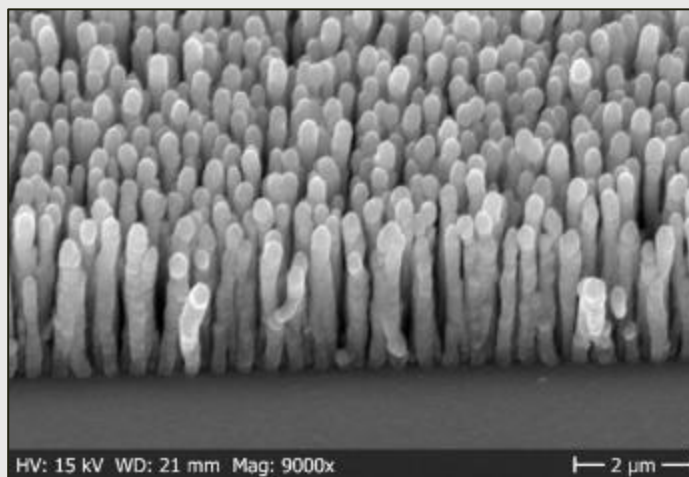
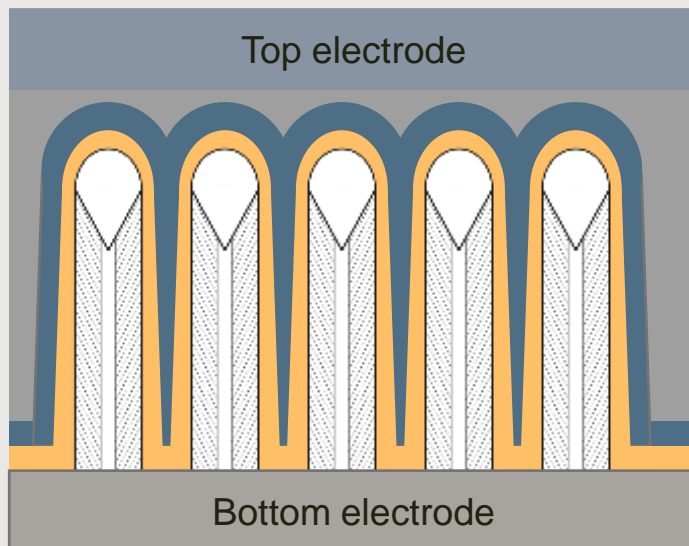
Smoltek's high-volume tool (2023)

Fully automated with advanced temperature and plasma control units providing extreme growth uniformity on 8-inch wafer size. Once operational, it produces up to 5k 8-inch wafers per month enabling true high-volume production



SMOLTEK CARBON NANOFIBER CAPACITOR

-  Top electrode metal
-  Conformal conductive liner
-  Conformal field oxide
-  Bottom electrode metal



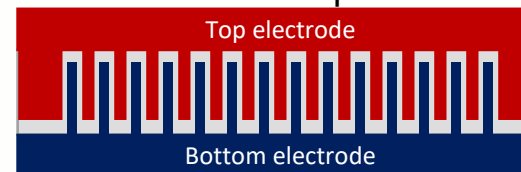
SEM image of carbon nanofibers coated with conformal field oxide and the conductive liner before the top electrode is deposited

parallel plate capacitor



$$C_{parallel} = \frac{\epsilon A_p}{d}$$

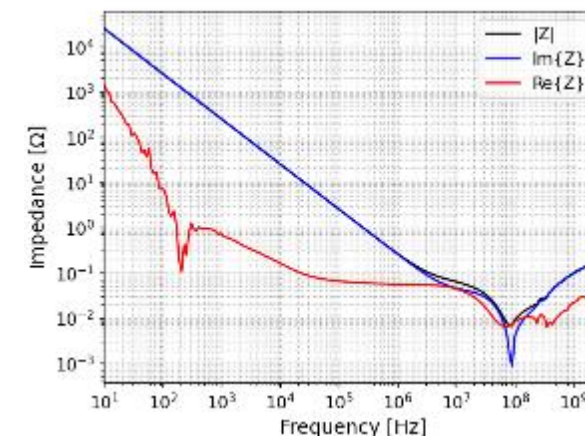
CNF-MIM capacitor



$$C_{CNF-MIM} = \frac{\epsilon A_c}{d}$$

$$A_c \gg A_p \rightarrow C_{CNF-MIM} \gg C_{parallel}$$

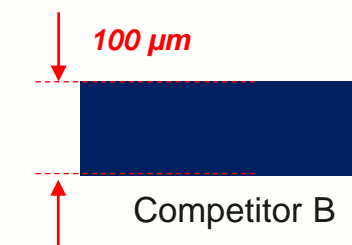
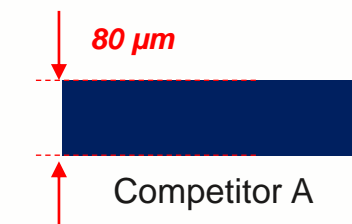
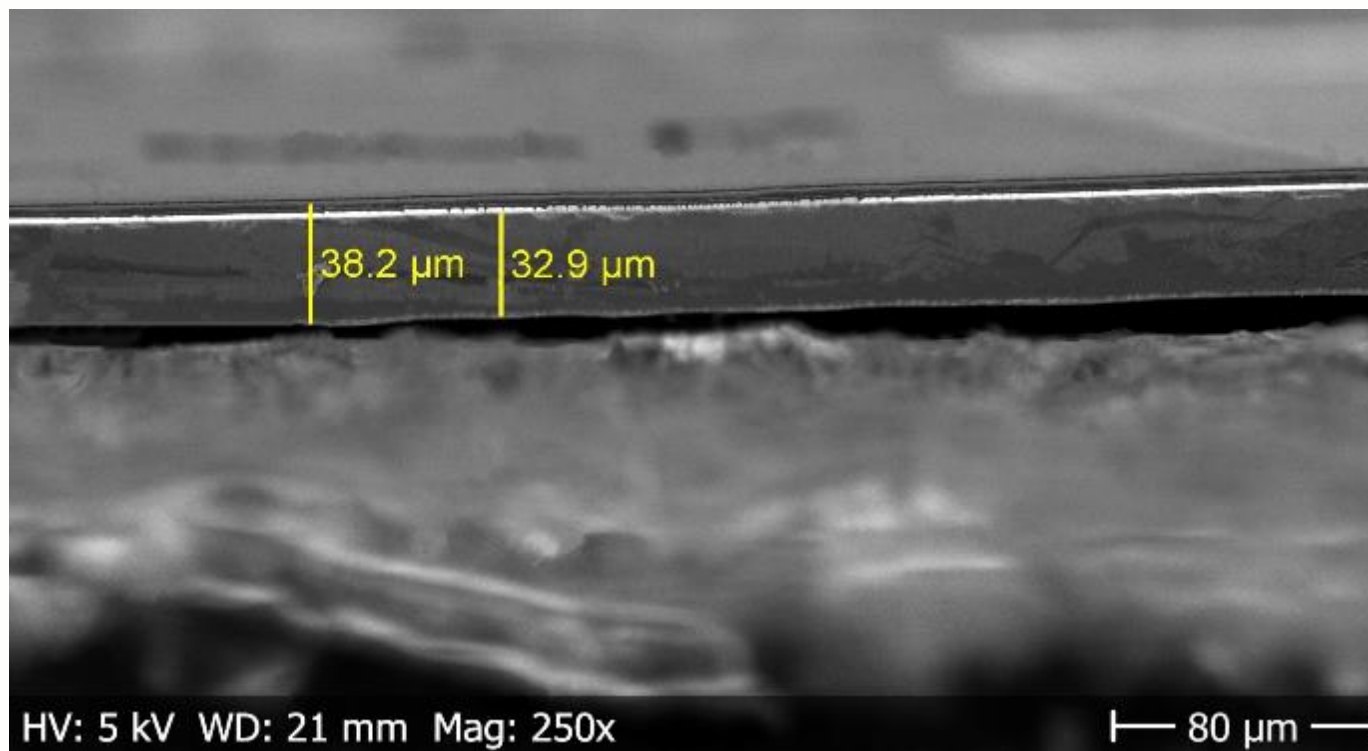
- C, ESR and ESL obtained from 2-port VNA measurements on a CNF-MIM device



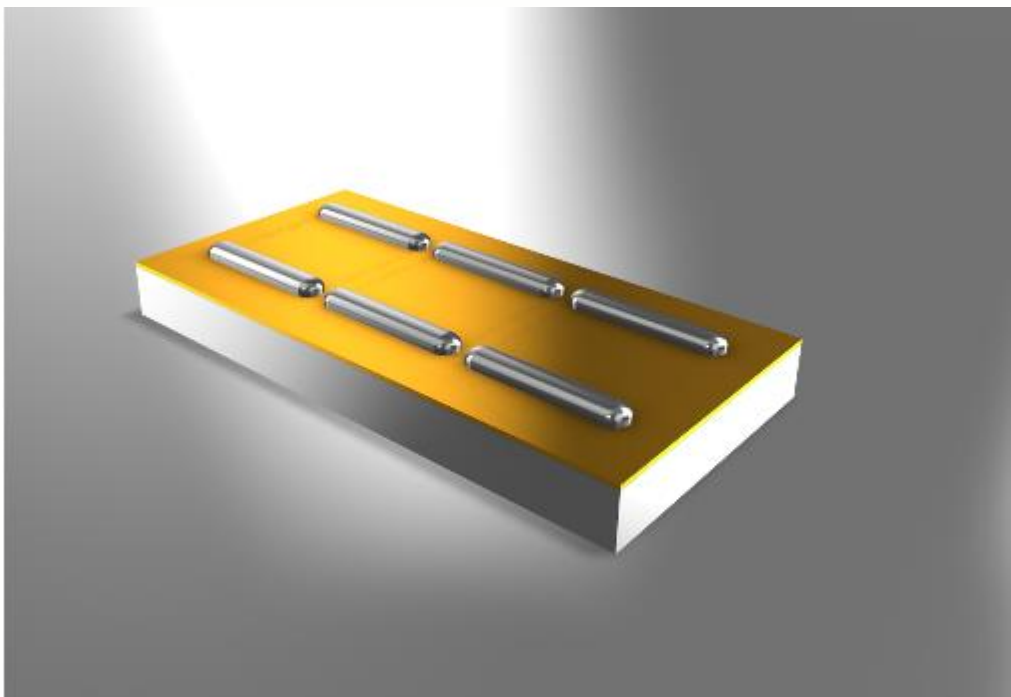
SMOLTEK ULTRA THIN CAPACITOR

Delivering the world's thinnest discrete capacitor

Based on the extraordinary and unparalleled surface area, we have developed ultra-thin Carbon Nanofiber capacitors having only 40µm in thickness while offering electrical performance on par with silicon capacitors.



CARBON NANOFIBER CAPACITOR COMMERCIALIZATION



Commercialization Roadmap

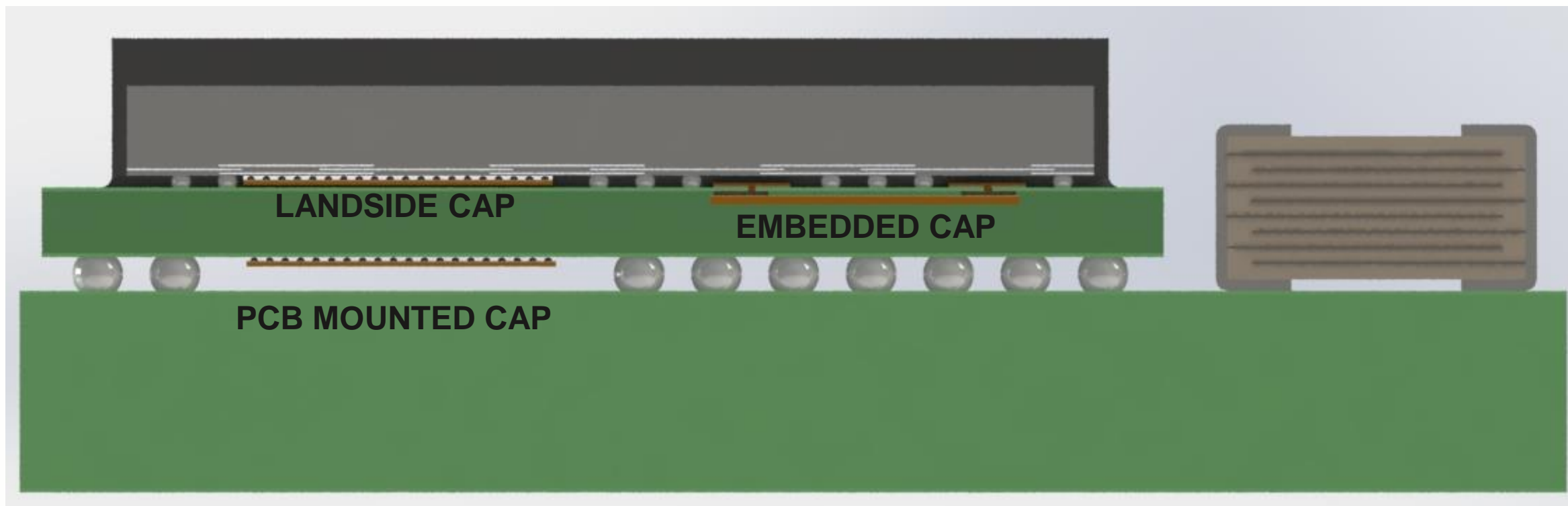
First prototype samples Q4 2023

- Targeting case size 0402
- Sub 100 μ m thick

Mass production 2025

- Targeting case sizes down to 01005
- Targeting down to 40 μ m

THE ULTRA LOW PROFILE ALLOWS FOR MULTIPLE PACKAGING OPTIONS



THANK YOU!

Louise Duker

Chief Product Officer
Smoltek Semi AB

+46 707 70 19 18
www.smoltek.com
louise.duker@smoltek.com
Kaserntorget 7
411 18 Gothenburg
Sweden

Reggie Phillips

Director, Product Management
KEMET Specialty Products
YAGEO GROUP

+1-864-228-4052
www.kemet.com
reggie.phillips@yageo.com
2835 KEMET Way
Simpsonville, SC 29681
USA

CONNECT with KEMET!

