The Promise & Progress
Single Walled Carbon Nanotubes

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OCSiAl GROUP
Redefining materials
Reinventing technologies
**SWCNT ARE EXCEPTIONAL**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>1.5-2.0 nm</td>
</tr>
<tr>
<td>Length</td>
<td>&gt; 5 μm</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>1 atom</td>
</tr>
<tr>
<td>Property</td>
<td>Value</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Excellent Conductor</td>
<td>5 Times Lighter than Copper</td>
</tr>
<tr>
<td>Stronger than steel</td>
<td>100 times</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>up to 1000 °C</td>
</tr>
<tr>
<td>The highest length to diameter ratio</td>
<td>up to 1 million times</td>
</tr>
<tr>
<td>Surface area</td>
<td>1 g = 2 basketball courts</td>
</tr>
</tbody>
</table>
ABOUT THE COMPANY

- OCSiAl is the largest commercial manufacture of SWCNTs
- OCSiAl has developed a breakthrough industrial scale synthesis of SWCNTs
- As of today, we are 200 people, 25 Ph.D. scientists and engineers
- Graphetron 1.0: the first in the world 10 ton/year SWCNT reactor
- 50 ton/year reactors are in design and construction stage
CONDUCTIVE CARBON BLACK vs TUBALL™
MULTI WALL NANOTUBES vs TUBALL™

MWCNT

TUBALL™

MWCNT

TUBALL™
DISPERSSION IN MATRIX

Concentration of particles ~0.1%

1 g = $10^{16}$ tubes
1 g = 50,000,000 km of tubes

SWCNT forms its own conductive 3D network at ultra low concentrations

A: Microparticles
B: Carbon nanofibers
C: SWCNT
SINGLE WALL CARBON NANOTUBES DELIVER IMPROVEMENTS AT 10 TO 1000 TIMES LOWER CONCENTRATIONS THAN OTHER CONDUCTIVE ADDITIVES
KEY FEATURE

- SWCNTs form electrically conductive 3D network in media at extremely low concentrations, typically <0.2%.

- TUBALL™ is superior to other SWCNTs and MWCNTs and provides orders of magnitude lower resistivity at very low concentrations (as low as 0.01%)

Fraunhofer study: SWCNTs and MWCNTs in silicon rubber (DowCorning Sylgard 184)
Electrical conductivity with CARBON BLACK

Electrical conductivity with TUBALL
SWCNT: THE FIRST UNIVERSAL ADDITIVE

- Add conductivity
- Keep the color
- Keep or enhance mechanical properties
SWCNT CAN IMPROVE 70% OF THE WORLD $3 TRILLION MATERIALS MARKET
TUBALL IN POLYPROPYLENE

2 wt % masterbatch

0.08 wt % compound
Volume resistivity $10^6 \, \Omega \cdot \text{cm}$
CONDUCTIVITY + STRENGTH

All samples at $10^4$ Ohm.cm and based on 0.1% TUBALL in PPH

Results were obtained by compression molding

Tensile strength at yield: +12%
Elongation at yield: -17%
Tensile modulus: +11%
Tensile strength at break: +6%
Elongation at break: -18%
TECHNOLOGY
THE SYNTHESIS OF CNT
FROM A FREE CATALYST PARTICLES

\[ T \sim 600-1000^\circ C \]

\[ N(C_xH_y) \]

\[ CH_4 \rightarrow C + 2H_2 \]
SCHEME OF METAL VAPORIZATION, CLUSTERING SWCNT SYNTHESIS

STEP 1
Metal vaporization

STEP 2
Metal is condensing into nanoparticles

STEP 3
Catalytic decomposition of hydrocarbon on metal nanoparticles and growth of nanostructures

US PATENT 8137653
«SYSTEM AND METHOD FOR PRODUCING CARBON NANOTUBES»
CORE PRODUCT
### TUBALL™ TECHNICAL DATASHEET

<table>
<thead>
<tr>
<th>SPECIFICATION</th>
<th>UNIT OF MEASURE</th>
<th>VALUE</th>
<th>METHOD OF EVALUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBON CONTENT</td>
<td>wt. %</td>
<td>&gt;85</td>
<td>TGA, EDX</td>
</tr>
<tr>
<td>CNT</td>
<td>wt. %</td>
<td>≥75</td>
<td>TEM, TGA</td>
</tr>
<tr>
<td>NUMBER OF LAYERS CNT</td>
<td>unit</td>
<td>1-2</td>
<td>TEM</td>
</tr>
<tr>
<td>OUTER MEAN DIAMETER CNT</td>
<td>nm</td>
<td>1.8±0.4</td>
<td>RAMAN, TEM</td>
</tr>
<tr>
<td>LENGTH OF CNT</td>
<td>μm</td>
<td>&gt;5</td>
<td>AFM</td>
</tr>
<tr>
<td>METAL IMPURITIES</td>
<td>wt. %</td>
<td>&lt;15</td>
<td>EDX, TGA</td>
</tr>
</tbody>
</table>
OCSiAI FIRST FACILITY:
TECHNOPARK IN NOVOSIBIRSK
FOUNDING IN 2010

$100 MLN
4,200 SQM
200+ EMPLOYEES
PROTOTYPING CENTER

- 150 pieces of equipment
- 6 key technologies
- 200 t/year capacity
PROTOTYPING TECHNOLOGIES

- RESEARCHING SWCNT PROPERTIES
- ENERGY
- ELASTOMERS
- TRANSPARENT COATINGS
- THERMOPLASTICS
- THERMOSET COMPOSITES
Based on the core technology of SWCNT synthesis, OCSiAl has developed a family of TUBALL™-based open-source technologies for applications in different industries.
OCSiAl 2016: BUSINESS MODEL

OCSiAl

-partners

CUSTOMERS

TUBALL production
TESTING support

PRODUCTION & SALES

TESTING AND PURCHASE

TUBALL®
100g

Neat PP CNT
2% masterbatch

RUBBER
BATT
COMP_E

COAT
INK
RUBBER
APPLICATION EXAMPLES FROM AROUND THE WORLD
CASE 1: ANTI-STICK COATING PANS WITH TUBALL
CASE 2: ANTI-STATIC PAINTS WITH COLOR

- **CONTROL**
  - aqueous acrylic paint
  - $10^{10} \, \Omega / \text{SQ}$
- **INSULATOR**
  - TUBALL™
  - 0.014 wt. %
  - $10^6 \, \Omega / \text{SQ}$
- **ANTI-STATIC AGENT**
  - 2 wt. %
  - $10^{10} \, \Omega / \text{SQ}$
  - $10^7 \, \Omega / \text{SQ}$
  - $10^5 \, \Omega / \text{SQ}$
- **BEST MWCNTs**
  - 0.25 wt. %
  - $10^5 \, \Omega / \text{SQ}$
CASE 3: **TRANSPARENT ANTI-STATIC LACQUERS**

**PERMANENT CONDUCTIVITY**

- **TUBALL™**
  - 10^8 Ω / sq
  - 0.02 wt. %

**INSULATOR**

- CONTROL: aqueous PU lacquer
CASE 4: TUBALL™ BASED DEVICE INTEGRATED INTO A T-SHIRT

- Semi-transparent flexible conductive PET, direct gravure and laser etching
- Surface resistance = 360 Ohm/sq
- Conductivity in a circuit with sensors and power source
- Good wear and water resistance can be washed many times while the initial performance maintains well
CASE 5: NATURAL & NITRILE ANTISTATIC LATEX GLOVES

NATURAL LATEX 0.03% TUBALL™ $10^5$ Ohm*m

NITRILE LATEX 0.05% TUBALL™ $10^4$ Ohm*m

- TUBALL™ introduced to industry in August 2015
- Large industrial gloves manufacturer used TUBALL™ to develop new line of antistatic protective nitrile gloves according to international requirements for protective wear
- Working with largest in the world gloves manufacturer

*Glove made by a customer with 0.05% TUBALL™
## ANTISTATIC LATEXES WITH TUBALL™

<table>
<thead>
<tr>
<th></th>
<th>CURRENTLY AVAILABLE</th>
<th>RESULTS WITH TUBALL™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific resistivity level*</td>
<td>$10^7 - 10^{11} \ \Omega \cdot m$</td>
<td>$10^4 - 10^8 \ \Omega \cdot m$</td>
</tr>
<tr>
<td>Concentration of conductive filler</td>
<td>&gt;5%</td>
<td>0.03 – 0.05%</td>
</tr>
<tr>
<td>Negative impact on mechanical properties</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Color</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Electrical resistivity measurements according to EN 1149 standard
ANTISTATIC GLOVES MARKET

**Dipped industrial**
- 4.3 mn pairs
- 160 mn $
- 30-40 $/pair
- CAGR 7 %
- 450 t
- 0.2 t TUBALL™

**Knitted gloves**
- 60 mn pairs
- 250 mn $
- 3-6 $/pair
- CAGR 7.4 %
- 1 500 t
- 0.8 t TUBALL™

**Disposable**
- 12 bln pairs
- 1.2 bln $
- 0.15 – 0.30 $/pair
- CAGR 13.3%
- 120 000 t
- 60 t TUBALL™
CASE 6: CONDUCTIVE SILICONES WITH TUBALL™

- Electrically conductive silicones applied for electronic and automotive applications
- Decreasing of loading level of conductive filler in silicon compound is one of the goal in industry
- TUBALL™ introduced to industry in August 2015
- February 2016 finish first evaluation with most largest silicon manufacturer (~20% of world capacity)

Customer: “This has not been possible before, the result is truly revolutionary”
<table>
<thead>
<tr>
<th></th>
<th>CURRENTLY AVAILABLE</th>
<th>RESULTS WITH TUBALL™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific resistivity level</td>
<td>$10^4 - 10^6 , \Omega \cdot m$</td>
<td>$10^1 - 10^6 , \Omega \cdot m$</td>
</tr>
<tr>
<td>Concentration of conductive filler</td>
<td>30-40%</td>
<td>0.05 – 0.3%</td>
</tr>
<tr>
<td><strong>Negative impact</strong> on mechanical properties</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Possibility</strong> to mix at “clean” facilities</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Color</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
CASE 7: NBR (HNBR) RUBBER O-RING COMPOUND

• Industrial introduction technology for adding of TUBALL™ based suspension to industrial process of rubber polymer production

• Customer samples of NBR with 0.05% TUBALL™ are currently produced by one of the leading rubber polymer manufacturer
NBR (HNBR) RUBBER O-RING COMPOUND

- +10% properties after heat aging
- +20% reduced property loss after rapid gas decompression
- + 33°C temperature before degradation of material (thermal resistance)
ADOPTION IN ENERGY FIELD

• Fast adoption in energy field: Li-ion, primary cells, lead acids, super caps
• Material introduced in April 2014
• >100 battery companies sampled, working with most largest battery manufactures
• CM Partner is the first battery customer to go public with using TUBALL™
• MOU and contract for 100kg of TUBALL™ signed on NanoKorea 2015
• Sunbike uses 0.04% of TUBALL and no carbon black in LFP cathode
• Demonstrated: higher energy density, higher rates and cycle life improvement

CASE 7: BIKE WITH TUBALL™ BASED BATTERY

Battery Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Type</td>
<td>Li - ion</td>
</tr>
<tr>
<td>Nominal Voltage</td>
<td>48V</td>
</tr>
<tr>
<td>Nominal Capacity</td>
<td>30Ah</td>
</tr>
<tr>
<td>Pack Energy</td>
<td>1.5kWh</td>
</tr>
<tr>
<td>Max Discharge Current</td>
<td>2C (60A)</td>
</tr>
<tr>
<td>Size (Wide x Length x High)</td>
<td>167 x 185 x 350</td>
</tr>
<tr>
<td>Weight</td>
<td>13 kg</td>
</tr>
<tr>
<td>Charging Time</td>
<td>3 Hour</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20~50°C</td>
</tr>
</tbody>
</table>
BENEFITS FOUND BY CM PARTNER

• Replaced 4% or carbon with 0.04% of TUBALL in LFP cathode

• More active material (>98% with TUBALL vs 92% with carbon black)

• Thinner cathodes → thinner cells by 1mm each → two more cells per pack → higher pack capacity

• Significantly improved cycle life (>1000 cycles with virtually no degradation)

• Better performance at high discharge rates (baseline formulation – 85% at 2C rate; TUBALL – 95% at 2C rate)
LI-ION SUCCESS STORIES

- Most common driver behind TUBALL adoption: energy density
- Everybody wants to increase % active
- Even in most optimized LCO chemistry for consumer electronics applications, companies always worked over many years to increase % active
- TUBALL adoption is inevitable

<table>
<thead>
<tr>
<th>Year</th>
<th>1990s</th>
<th>2010</th>
<th>2012</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCO</td>
<td>85%</td>
<td>96%</td>
<td>97.30%</td>
<td>98%</td>
<td>&gt;99%</td>
</tr>
<tr>
<td>Conductive additive</td>
<td>SuperP, KS6 5%</td>
<td>SuperP 2%</td>
<td>ECP Ketjen Black 1.2%</td>
<td>MWCNT 0.8%</td>
<td>TUBALL 0.04%</td>
</tr>
<tr>
<td>PVDF</td>
<td>10%</td>
<td>2%</td>
<td>1.50%</td>
<td>1.20%</td>
<td>0.80%</td>
</tr>
</tbody>
</table>
EXAMPLE WITH LFP

10Ah cell trial: 0.2% TUBALL BATT NMP PVDF

✓ Control:
  • Cathode: LFP:SP:KS-6:PVDF(5130) 90.5 : 4 : 2 : 3.5
  • Press density: 2.2 g/cc

✓ TUBALL Recipe:
  • Cathode Ratio: LFP : CNT : PVDF(5130) 98.4 : 0.1 : 1.5
  • Press density: 2.4 g/cc

Anode: Synthetic graphite (FT-1)
Electrolyte: 1.0 M LiPF6 /EC:DEC:DMC =30:20:50 2%VC

18% thinner cathodes
10% thinner cells

Better rate
IMPRESSING EXISTING CATHODE MATERIALS

- TUBALL: stable ~450°C in oxidizing environment
- Stable >1000°C in inert atmosphere

Introduction
- during synthesis
- during washing steps

Materials:
- LFP
- MnO₂
- Future: LTO, NCM, silicates, fluorides

Benefits:
- Extreme conductivity, high rate
- Mechanical reinforcement, cycle life
Future structures: Composite Si + SWCNT anode

CVD from SiH$_4$ excited by electron beam, temperature of deposition can be reduced to 200°C and Si deposits on SWCNTs as layers:

Cu foil + SWCNT 0.5 mg/cm$^2$

+ Si 0.13 mg/cm$^2$
Composite Si + SWCNT anode

- >2500 mAh/g achieved today
- 1st cycle efficiency >75%
- Next generation structures are under development

0.16 mg/cm² TUBALL™ and 0.5 mg/cm² Si

- Pouch cells, Li foil counter electrode, C/2 rates

Graph showing discharge capacity (mAh/g) vs. cycle number for different layers of Si:
- Two layers of Si
- Single thick layer of Si
- Single "thin" layer of Si

Sandwich structure diagram:
- TUBALL™
- 0.16 mg/cm² TUBALL™ and 0.5 mg/cm² Si

O C Si Al
CASE 10: LEAD ACID

Bar Ilan: lead acid batteries

Higher capacity at high rate (0.01% TUBALL)

Cycle Life data for 25 % DOD

4x longer cycle life (0.01% TUBALL)
CASE 12: CONDUCTIVE EPOXY FLOORS

The required volume resistivity of $10^6$ Ohm*m was reached in the epoxy flooring with the addition of only 0.009% of TUBALL.

No negative impact on viscosity and color of epoxy resin was observed.

The company has already gone commercial and currently promoting the new product line to consumers.
CASE 13: SMC-COMPOSITE

German company applied TUBALL to the gel-coat for antistatic pipes

A surface resistivity of $10^4 \, \Omega/$sq with 0.05% of TUBALL was achieved while maintaining the original color of the pigmented gelcoat.

No negative impact on mechanical properties was observed.
A company applied TUBALL to **BMC-composite** which are used for an electronics housings.

$10^4 \ \Omega\cdot\text{cm}$ of volume resistivity was achieved with only $0.02\%$ of TUBALL in the whole composite, corresponding to $0.20\%$ of TUBALL in the resin itself.

No significant increase of viscosity of the resin was observed.
CASE 15: CONDUCTIVE LIGHTWEIGHT MATERIALS

Tape based on TUBALL™ is a substitute product to metal shielding braid for cables and wires.

SOLUTION ADVANTAGES

- **WEIGHT REDUCTION** 10-15 times
- **GAUGE REDUCTION** 2 times

Tape (sheet) based on TUBALL™ allows reaching and exceeding the level of metals’ conductivity.
AEROSPACE INDUSTRY, where lowering the aircraft’s weight directly leads to fuel costs reduction and growth of working load.
CLIENTS 2015

Clients in total

482
1ST INDUSTRIAL TECHNOLOGY OF SWCNT PRODUCTION

1 TON OF TUBALL WAS PRODUCED & SOLD IN 2015

NEXT GENERATION OF SWCNT-BASED PRODUCTS WIN THE GLOBAL MARKET

WHAT IS YOUR APPLICATION?
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