Ray Techniques Ltd.
NANODIAMOND TECHNOLOGIES
Ray Techniques Ltd, General Info

- **Company**: established in August 2009 in Jerusalem, Israel, VAT # 514305671
- **Scope**: nanodiamond (ND) technologies
- **Website**: www.nanodiamond.co.il
- **IP protection**: “Method and system for controlled synthesis of nanodiamonds” (USA, EU, Japan), “Disaggregation & mixing of ND” (know-how)
- **Products**: ND powders, colloids & compounds
- **Services**: ND formulation development
- **Sales**: initial stage, globally, mainly for research needs
- **Customers**: Universities, Rafael, Nanoresource, Van Damme Helicopters, etc.
- **H2020 projects**: Carbon based nanomaterials for Theranostic applications (CARTHER); Production of Advanced nano-Diamond Additives (PANDA)
- **Award**: Seal of Excellence for the project proposal PANDA phase 2
RAY Team, Executives

- **Olga Levinson**, co-founder, CEO, M.Sc. in Mechanical Engineering (Moscow Transport University) & Business Enterprise training (The Hebrew University of Jerusalem); general management, business strategy, R&D management, Nanocharacterization, scaling

- **Boris Zousman**, co-founder, CTO, M.Sc. in Electrical Engineering (Belarusian National Technical University); inventor of RAY technologies of ND synthesis & applications, expertise in TRIZ, R&D & Nano formulations

- **Galina Geyzersky**, CFO, BA in economics (Bar Ilan University), certified CPA, expertise in R&D funding programs and financial management
The Problem / The Mission

• The problems restricting Global ND Market
  • State-of-the-art ND are of **non-consistent quality** and complicated to use in industrial scale and expensive
  • No industrial technologies for ND disaggregation & mixing
  • Insufficient number of industrially validated ND formulations

• Our mission
  • Producing ND of highest purity & uniformity by proprietary method
  • Providing consumers in various fields of industry, energy, science & medicine with effective high-quality ready & easy to use ND in form of modified powders, colloids & masterbatches with disaggregated particles
  • Popularization of ND technologies & promotion of ND validation
What is Nanodiamond?

Diamond core (sp3) with average size of ~4 nano-meters having unique diamond properties

Hybrid surface structure with unpaired electrons

Active surface shell of various functional groups containing O, H and N

Functional groups enable to attach ND to molecules of a chosen material, to transfer it unique features of diamond and improve its properties & performance or to expand its functionality.
Three-dimensional cubic lattice of tetrahedral bonded carbon atoms determine unique properties of diamond:

- Extreme mechanical hardness **98 GPa** \{111\}
- Highest wear resistance
- Outstanding optical & electronic properties
  - Wide band gap \{300 K\}: **5.47 eV**
  - Refractive index: **2.419**
- Highest thermal conductivity: **2300 W/mK**
- Very high electrical insulation: **10^{13} \Omega cm**
- Highest sound propagation velocity
- Chemical and radiation resistance
- Biological compatibility and non-cytotoxicity
ND Applications

Existing ND applications

- Reinforcing polymer filler (glues & paints)
- Fine polishing abrasive (magnetic disks)
- Additive in coatings (galvanic & Electroless)
- Additive in lubricants (oils & greases)
- Catalysts in chemistry & power applications

Advanced ND applications are still under development:

- Thermal Management
- Energy storage
- Analytical chemistry
- Nano-composite materials with high radiation resistance
- Glass / polymer scratch protection
- High refractive index polymers
- Efficient catalysts
- Bio-Med: drug delivery, bio-imaging, tissue engineering
Promising Future ND Applications

- ND therapeutics
- Nano-electronic devices
- Quantum computers
- Cold neutron reflectors (revolution in scientific research & in energy in 20+ years)
- Cold fusion (perhaps fantasy)
Main Market Players (Adroit research)
1. Henan Yuxing Sino-Crystal Micron Diamond: synthesis, no dispersion
2. Diacel Corporation - ??? not mass production
3. Beijing Grish Hite: synthesis, no dispersion
4. Henan Union Abrasives: synthesis, no dispersion
5. Adamas Technologies (no synthesis)
6. NanoTech Lubricants (no synthesis, only lubs)
7. Carbodeon Ltd. Oy (no synthesis)
8. Microdiamant (microdiamonds, no ND synthesis)
9. NanoDiamond Products (no ND synthesis)
10. Ray Techniques (synthesis + dispersions)
11. Sinta: synthesis, no dispersion tech

Note: in contrast to ADROIT research, ND experts estimated ND Global Market <10 M USD annually
1. **Non-consistency of ND quality & reactivity** caused by current industrial methods for ND fabrication:
   - Detonation synthesis
   - Crashing of synthetic diamonds obtained by High Pressure High Temperature (HPHT) or by Chemical Vapor deposition (CVD)

2. **Almost no industrial technologies** for ND disaggregation & uniform mixing with various materials

3. **Slow uptake of nanomaterials by industry**: only few industrially validated ND formulations

4. **Not enough final ND formulations**: most advanced applications are still under development

5. **No standards** for the regulation of ND quality
Existing Technology of ND Synthesis

Problems:

- Polluting & dangerous technology
- Non-controllable
- ND of insufficient quality, complicated to use and expensive

- Detonation of explosives (TNT & RDX)
- ND isolation from detonation bland & purification by boiling in nitric acid, washing & drying
- Product: detonation ND powder (DND)

Detonation reactor in Sarov Russia, where ND were firstly found in 1963

Image from the book of Prof. V. Danilenko
Currently the biggest ND production is located in China.
The main ND consumption is in China, USA and Japan.
• Synthesis of high-quality nanodiamond (ND) powder

• ND surface modification (ND with controlled surface chemistry in powders and stable suspensions)

• Design novel ND-based composite materials with desired properties
RAY Technology of ND Synthesis

- In contrast to the existing technology the process is controllable, environment-friendly & non-hazardous
- Production at laboratory conditions
- Product of the best quality
- Patent protection
- Initial sales
ND Laser Synthesis Process

1. Preparation of carbon soot from pure graphite
2. Forming special targets from carbon soot & wax
3. Laser treatment of special targets in liquid
4. ND separation by flotation method, washing & drying

Nanodiamonds of high purity and homogeneity
New method of Synthesis: Light Hydro-Dynamic Pulse (LHDP)

LHDP synthesis of ND can be attributed to the form of Pulse Laser Ablation in Liquid (PLAL), which has been considered as non-economical method for ND synthesis.

2 novelties leaded to the output increase:
1) multi-component target instead of graphite;
2) focusing laser beam at some predicted distance from the target
The tiny size and the ball shape of ND

Another carbon structure Onion-like-Carbon (OLC) can be obtained by heating of ND, promising in EMI & energy storage
Advantages of Laser ND Synthesis

1. **Purity**
   - Incombustible residue ND obtained by laser synthesis (RayND): 0 (less than the accuracy of the instrument - 0.02 wt. %); for comparison: incombustible residue of DND: 0.4 - 2 wt. %
   - RayND powder is practically free of metals which is important for most advanced applications (electronics, neutrons, bio-medicine)

2. **Diamond structure sp3 on ND surface** in RayND up to 72 %; in DND 23 % of the surface area (XPS analysis)

3. **Homogeneity**: particle size distribution (PSD) in RayND is 2-10 nm with a peak at 4.3 nm; for comparison DND has PSD 2-20 nm with a peak at 4.5 nm; HPHT-ND have PSD 2-120 nm with a peak ~30-40 nm

4. **Controlled process → constancy of properties**
   - Possibility to provide desired ND features (crystalline size, optic properties, surface chemistry and desired reactivity)
## ND Production & Features

<table>
<thead>
<tr>
<th>ND production → ND features ↓</th>
<th>Detonation of TNT &amp; RDX explosives</th>
<th>Crashing / milling of HPHT or CVD microdiamonds</th>
<th>RAY: Light Hydro-Dynamic Pulse (LHDP) laser synth.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average size PSD</td>
<td>4-7 nm 2-20 (rarely 40-50 nm) Cell membrane, nucleus, BBB</td>
<td>20-50 nm, can be 10-20 nm 2-120 nm (can be 2-40 nm) Cell membrane, not nucleus, not BBB</td>
<td>4.3 nm; can be 3.5 nm 2-10 nm (can be 2-5 nm) Cell membrane, nucleus, BBB</td>
</tr>
<tr>
<td>Overcoming biological barriers</td>
<td>Purified: 0.1-1.2 wt. % Low</td>
<td>3 wt. %, purified: 0.2 wt. % Non-toxic</td>
<td>Non-detectable, &lt;0.02 wt.% Non-toxic</td>
</tr>
<tr>
<td>Purity (ash residue) Toxicity</td>
<td>Photoluminescence Bio-imaging</td>
<td>Drug carrying ability Gene delivery</td>
<td>Availability Price (industrial)</td>
</tr>
<tr>
<td></td>
<td>Low Rarely efficient</td>
<td>Very high Very efficient, but limited</td>
<td>Very high Possible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-detectable, &lt;0.02 wt.% Non-toxic</td>
<td>Not limited 1.4 – 4 € / g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High Efficient, not limited</td>
<td>Not limited 2 – 8 € / g</td>
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<td></td>
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<td>Now: up to 500 g monthly ≤ 1 € / g; (now: 15 € / g)</td>
</tr>
</tbody>
</table>

- ND produced by RAY are the most suitable for advanced applications.
- Further steps: validation of developed formulations, industrial implementation, scaling, FDA approvals, development of new ND applications
RAY has developed an industrial technology for mixing ND within various solvents & polymers. Special mechanical, thermal and chemical ND surface modification results in:

- Covalent bonding with matrix’ molecules (no surfactants!)
- ND disaggregation in diverse solvents
- Uniform distribution in basic material
- High efficiency of ND in the improving functional characteristics of basic materials & their performance
Why ND Modification is Needed?

ND aggregate on the copper grid
Size: ~1.5 micron

To produce stable ND colloids & composites ND should be disaggregated & homogeneously mixed within chosen matrix.

Modification of ND surface is know-how of the company
DLS analysis performed at HU with nanosizer Malvern, indicates high level of ND disaggregation in water (alone narrow peak at 4.9 nm)

RayND-SP: concentration 1.7 wt.%
Modified ND Powders & Slurries

**Modified ND Powders**
- Lyophobic (positive charge)
- Hydrophobic (alkylated)
- Hydrophilic (hydroxylated)
- Lyophilic (nitrogenized)
- Magnetic (Fe-doped)
- Magnetic (metal-free, outstanding magnetism)

**ND Water Based Slurries**
- Single particles @ 1.7 wt.%
- Hydroxyl groups @ 5 wt.% ND
- Nitrogenized @ 4 wt.% ND
- With surfactants @ 10 wt.%

**Stable ND Slurries in Solvents**
- Acetone @ 4 wt.% ND
- Isopropyl alcohol @ 4 wt.% ND
- Ethanol amine @ 5 wt.% ND
- N-methyl-2-pyrrolidine @ 5 wt.% ND
- Toluene @ 7 wt.% ND
- Cyclohexane @ 7 wt.% ND
- Xylene @ 7 wt.% ND
- Dimethylformamide @ 10 wt.% ND
- 2-Butoxyethanol @ 10 wt.% ND

**ND Oil Slurries**
- Polyester oil @ 3 wt. % ND
- Petroleum distillate @ 5 wt.% ND
Specially modified ND powders and slurries are compatible with some polymers and solvents. They form stable suspensions with nearly disaggregated ND by regular mixing, not requiring additional treatment and/or development.
Antifriction compounds
- Thermal conductive insulating compounds
- Coolants
- Precursors for CVD diamond growth
- Additives to galvanic electrolytes
- Additives to polymers (epoxy, PU, PE, etc.)
Use ND lubricants for lapping/finishing results in significant decrease of the friction coefficient and high energy savings

- Service life of friction pairs increase by a factor of 3 and more
- Decrease in energy & fuel consumption, 7 - 10% savings
- Enhanced horsepower and airproof capacity of engines
- Increase in reliability & durability of parts & mechanisms
- Decrease in noise

Physical mechanism:

- Lapping of friction surfaces
- ND being 50 times harder than steal introduce within metal surfaces & create protective diamond nano-layer with high wear resistance
- ND in lubricant work as nano-bearings
RT-Lap-A Lapping Grease Testing

- Performance testing was conducted by **Acuitas GmbH** (Switzerland)
- Application: motor bearings (2QTY Kaydon; 180ARO)
- RT-Lap was compared with special lubricating grease Klüberplex BEM 34-132

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>Coulomb Friction, Nm</th>
<th>Viscose Friction, nm/deg/sec</th>
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</thead>
<tbody>
<tr>
<td>BEM 34-132</td>
<td>3.50</td>
<td>0.070</td>
</tr>
<tr>
<td>RT-Lap</td>
<td>1.15</td>
<td>0.003</td>
</tr>
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</table>

**Conclusions:**
Treating bearings with RT-Lap & RT-Lub has resulted in:
- **Coulomb friction decreased by the factor of 3** (RT-Lap only)
- **Viscous friction decreased by the factor of 23** (RT-Lap and then RT-Lub)

Using ND antifriction treatment in engines, power generators and turbines should result in high increase in the energy productivity.
RAY thermal compounds contain ND particles uniformly distributed in polymer matrix.

**Advantages:**

- Low thermal resistance
- High electrical resistivity
- Stability of properties
- Low weight
- Easy to use and remove
- High range of operating temperatures
- Non-toxicity
- Low price

1. NanoHeat thermal grease for electronics
2. Heat conductive epoxy (15 -18 W/mK, thin layers)
3. Insulating heat conductive ceramics **(280 W/m*K)** (under development)
Lubricating Coolant for Wafer Dicing

Chipping and cracking caused by overheating when non-treated water for cooling is used

Lubricating coolant reduces hot & friction removing chips from the cutting zone

Advantages in comparison with the existing product:
1) Quality: less micro-cracks and surface layer tensions
2) Tools durability: blade resource increases in 4 times
3) Productivity: dicing speed can be increased significantly
4) Wafer cost: reduces considerably

<table>
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<tr>
<th>Coolant</th>
<th>Material</th>
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<tbody>
<tr>
<td>RT-Cool-Si</td>
<td>Silicon</td>
</tr>
<tr>
<td>RT-Cool-SiO2</td>
<td>Glass</td>
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</tbody>
</table>
**High quality CVD films grown using RayND precursor**

**Naval Research Laboratory & SAIC Inc., Washington:** RayND was tested for seeding in the growth of nano-crystalline diamond films of different thickness (0.3, 0.5 and 2.0 microns) in an ASTEX 1.5 KW microwave plasma deposition system. The grown films exhibit a high level of quality.

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>RayND-IPA-5</td>
<td>5 wt.% ND Isopropanol based slurry</td>
<td>Surfactant-free</td>
</tr>
</tbody>
</table>
ND Additives in Electroplating

Improvement in coating quality

1. Increase in wear resistance: 2-12 times
2. Increase in micro hardness:
   - Cr + ND: up to 1400-1500 kg/mm
   - Ni + ND: up to 800-900 kg/mm
   - Cu + ND: up to 160 kg/mm
   - Ag + ND: up to 180 kg/mm
   - Au + ND: up to 250 kg/mm
   - Al + ND: up to 600-700 kg/mm
3. Reduced porosity of the coating layer
4. Increase in elasticity
5. Improved corrosion resistance
6. 2-10 times increase in service life
ND Additives to Polymers

Proposed solution
1. Uniform dispersing specially modified ND within polymer matrix for improving adhesion, scratch & wear resistance, thermal conductivity, etc.
2. Synergic effect of using ND and other nanoparticles

Advantages
• Improved performance
• High reliability / durability: high aging resistance, chemical, corrosion, frost and radiation resistance, low thermal expansion (inducing stresses), ensure layer consistency, no cracking, enhance antifouling properties
• Environment: non-toxic (RoHS requirements, simple utilization)
• Manufacturability: assembly ease; no special requirements for storage; low bond-line thickness & layer uniformity
• Cost effectiveness: ensure low cost of material
4 Current Projects

1) **CARTHER**: Carbon-based nanomaterials for th**er**anostic application; H-2020 program MSCA-RISE-2014 in cooperation with INSA de Lyon (France), Aston University (Great Britain) and Taras Shevchenko National University of Kyiv

2) **PANDA**: Production of Advanced **Nano-Diamond Additives** for industry, energy, science & medicine; H-2020 program SME Instrument
CARTHER Project

The goal: systematic interdisciplinary study of carbon-based nanomaterials (particularly ND) for theranostic application:

- Efficiency & specific localization in cells depending on surface chemistry
- Luminescent properties, photo-induced electrical & thermal effects
- Photo-excitation cancer therapy
- Design imaging therapeutics agents
- Two unexpected results:

Dr. Geloen from INSA: all NDs have intrinsic therapy ability & can be applied in non-drug cancer treatment

New approach for non-drug cancer treatment has been proposed using non-toxic ND

RayND-M, specially modified non-toxic metal-free NDs have high fluorescence and ferromagnetism of un-known nature & can be applied at the same time in optical & magnetic bio-imaging & magnetic therapy
The goal: the development of full industrial technological chain for fabrication highly pure and uniform ND and efficient ND additives for

- Fine polishing (wafers, optical crystals, internal surfaces of thin tubes)
- Lubricants
- Various coatings
- Diverse polymer compounds (improving wear, aging, radiation and frost resistance, thermal conductivity and electrical resistivity, etc.)
- Catalysts and materials for energy storage (particularly, OLC)
- Biomedicine (cancer treatment, early diagnostics, cell imaging)

At phase 1: feasibility study for scaling + Business Plan for phase 2.
Phase 2: Seal of Excellence, new submission in June
Phase 3: business acceleration (meetings with corporates)
1. Aggressive marketing: the first step 5 project / product managers: 1) polymers, 2) polishing slurries and pastes, 3) additives lubricants, 4) additives to galvanic and other coatings, 5) Biomed

2. Establishing PANDA Manufacturing Line for upgrading purchased ND and producing **ready-to-use** additives in the form of modified powders, slurries and masterbatches

3. Establishing Laser ND Manufacturing Line (LaND) for providing Line #1 with raw material and bio-med research market

4. Development of novel ND-based products for various industries, patenting of final formulations & licensing

5. Participation in joint R&D programs in the field of ND applications with leading academia groups and industrial partners
Why Now?

• Growing demand in industry:
  • Rapid wafer & optical crystals polishing
  • Reducing weight & improving polymers
  • Heat dissipation in power & electronics
  • Reducing friction losses
  • Rapidly growing number of researches in various fields of ND applications

Fig. Increase in ND publications; Scopus search on “nanodiamond* + bio*” on 14.2.2019.

Time is ripe to start massive implementation of ND in industry & medicine!!!
RAY is Looking for Partners

- Consumers
- Subcontractors
- Joint ventures
- R&D partners
- SALES
- Investors
Considerations for Partners

- Unique RAY Technology
- Market demand in wide range of applications
- Already established contacts with leading players in the market
- Final products already developed and tested
- Promising preliminary results in new applications
- Various joint R&D opportunities => international research cooperation programs
- Unique RAY team expertise enabling implementation of various technological projects
- Unique combination DIAMOND + NANO + Israeli Start-up
Thank you for your attention!

**Nanodiamond** edited by Prof. Oliver Williams, RSC Nanoscience & Nanotechnology, London, 2014

**Chapter 5**: Pure nanodiamonds produced by laser-assisted technique, B. Zousman and O. Levinson, Ray Techniques Ltd.

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olga.levinson@nanodiamond.co.il
Appendix 1. Selected Publications

- B. Zousman and O. Levinson, Novel thermal interface materials based on Ray nanodiamonds; NanoFormulation 2011, ICMAT 2011, p. 43
- A. Priev, O. Levinson, B. Zousman and Y. Barenholz, Nanodiamond based diagnostic kits for rapid ultrasonic immunoassay; NanoFormulation 2011, ICMAT 2011, p. 115
- B. Zousman and O. Levinson, Monodispersed Nanodiamonds Produced by Laser Ablation; MRS 2012, Vol. 1452, p. 38
- A.M. Panich, A.I. Shames, B. Zousman, O. Levinson; Magnetic resonance study of nanodiamonds prepared by laser-assisted technique; Diamond & Related Materials, 23 (2012) p.150
- E. Perevedentseva, D. Peer, V. Uvarov, B. Zousman and O. Levinson; Nanodiamonds of laser synthesis for biomedical applications; JNN, 2015