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Ag-graphene oxide composites for electric contact applications

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Outline

Project team

Product example: Tap-changers for transformers

Sliding electrical contacts

Tribological properties of GRMs

Ag-GRM composites for sliding contact applications – benefits and challenges

Concluding remarks

Graphene oxide - a new lubricant in industrial applications

Project start Sept 2015

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Dept. of Chemistry – Ångström
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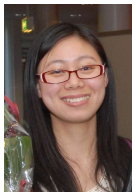
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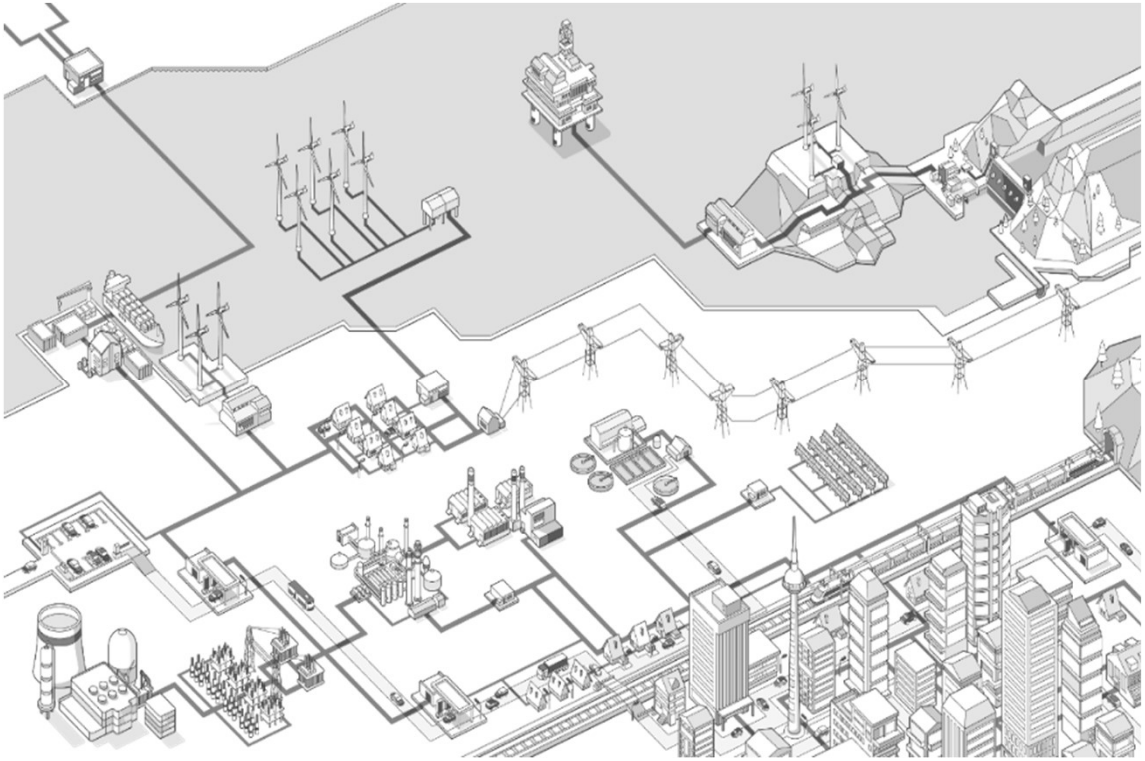
External frameworks / funding source

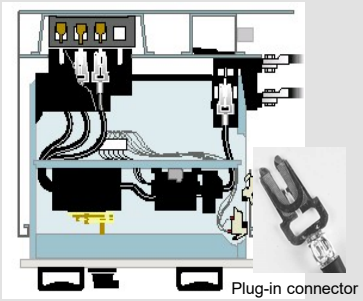
SIO GRAFEN

VINNOVA

Electrical contacts

Key components in the power grid

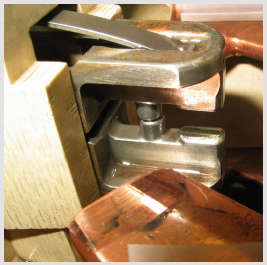




Low Voltage System

Stationary Contacts

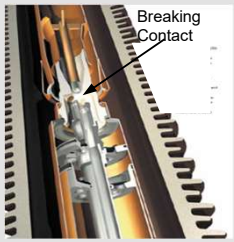
- Plug-in connectors
- Low Voltage Switchgear
- Medium Voltage Switchgear
- Terminals
- Bushings
- High Voltage Substations
- Power Electronic Packaging
- Varistors / Surge Arresters
- Cable joints



Tap-changer contact

Sliding Contacts

- Tap-changers
- Breakers
- Disconnectors
- Brushes
  - Electrical Motors
  - Robot Applications
  - Sensors

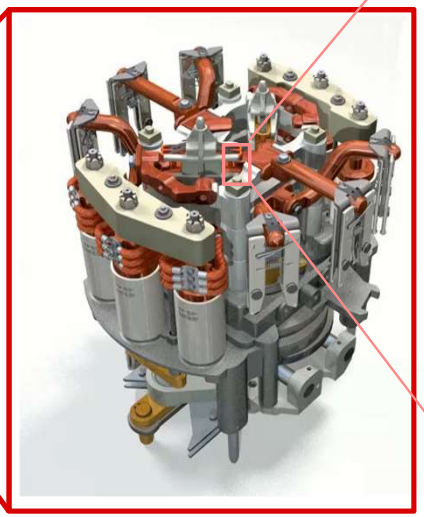


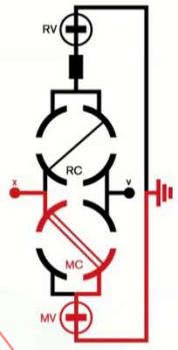
High Voltage Circuit Breaker

Breaking Contacts

- Circuit breakers (HV, MV, LV)
- Generator circuit breakers
- Disconnectors
- Vacuum interrupters
  - Contactors
  - Relays

Tap-changer





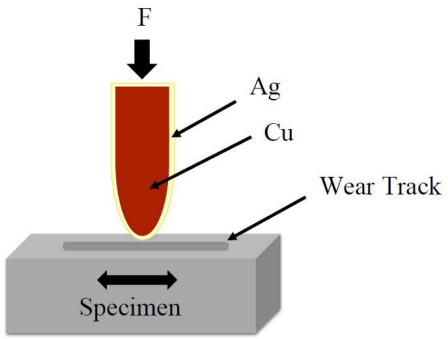
Sliding contact: Ag platelet on Cu finger

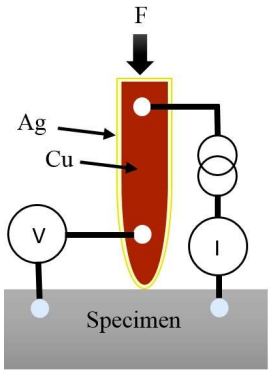
Stationary contact: Cu

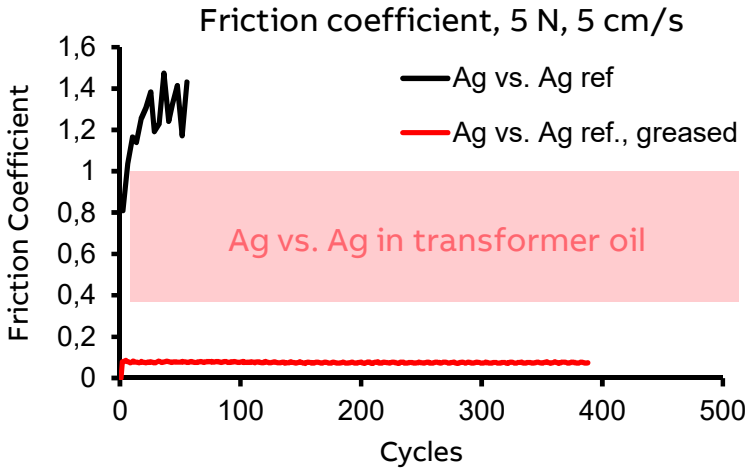
Working conditions: Contact loads up to 80N, contact speeds ca. 3 m/s, impact, vibrations, warm transformer oil with varying temp. (average ca. 80°C), life demand >1 M operations

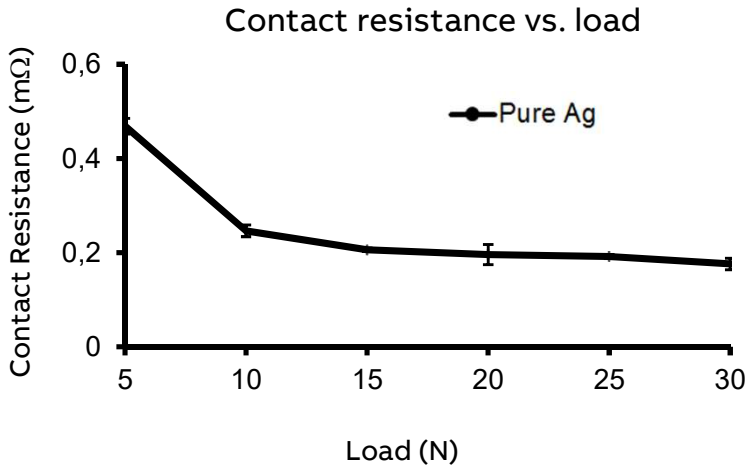
Sliding electrical contacts for power applications

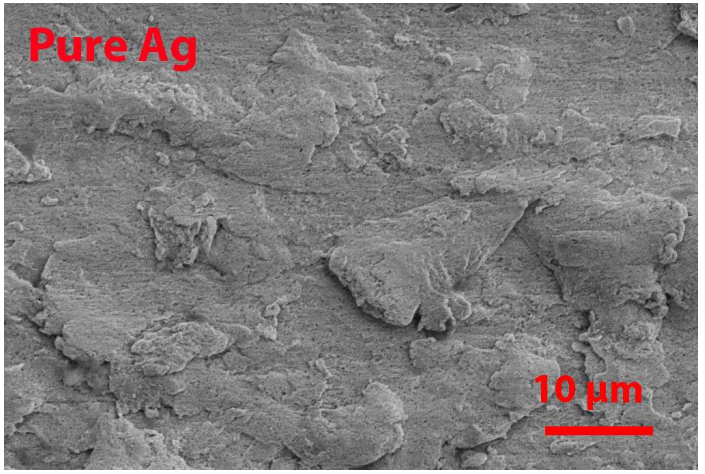
Ag – Ag contacts











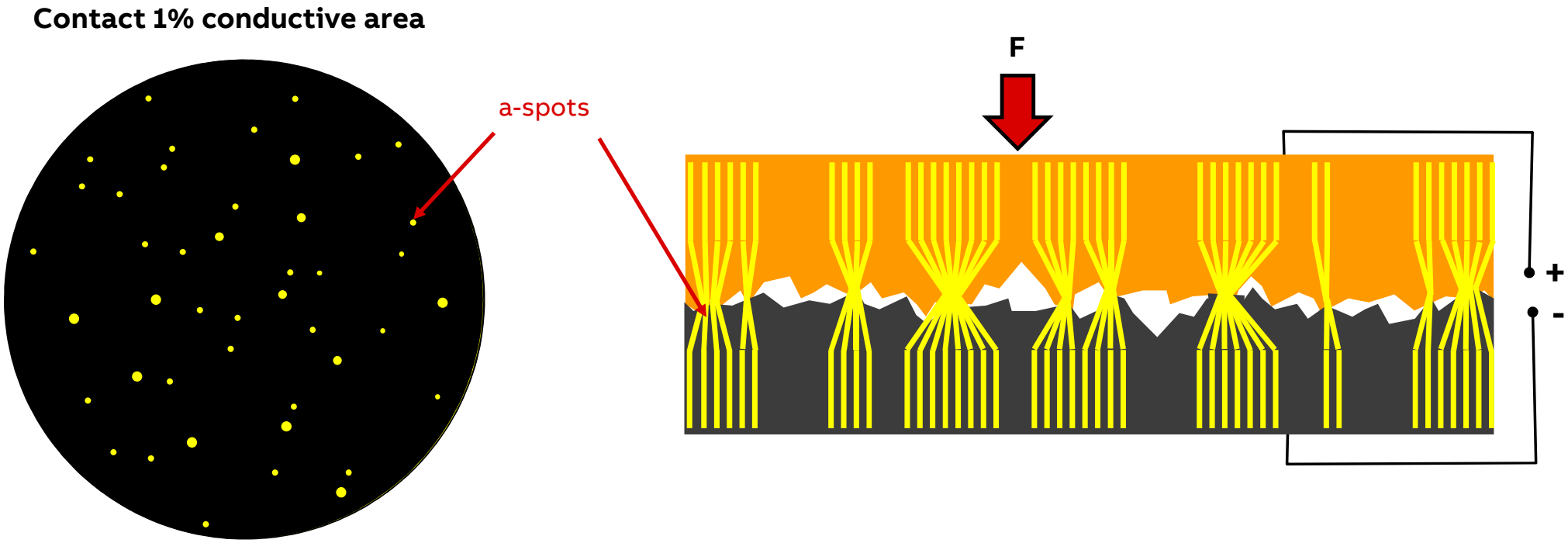
- Low resistivity
- Low contact resistance
- High oxidation resistance
- Adhesive wear, cladding
- High friction
  - Dry conditions: µ 1-1,5
  - Greased conditions: µ 0,08-0.2
  - In transformer oil: µ 0,3-0,9

Sliding electrical contacts for power applications

Examples of potential effects by improving tribological properties

1. Simpler and smaller designs due to reduced and more stable friction
2. Use of higher contact pressure, leading to lower resistive losses
3. Increased life-time (# of operations) of the device
4. Completely dry, self-lubricated systems in e.g. dry tap-changers/ transformers, lubricant-free disconnectors, breakers and switches → safer and more thermally stable
5. Reduction in particle generation due to less wear, thus minimizing risk for electrical overcharge
6. Cost reduction due to lower material costs

Sliding electrical contacts

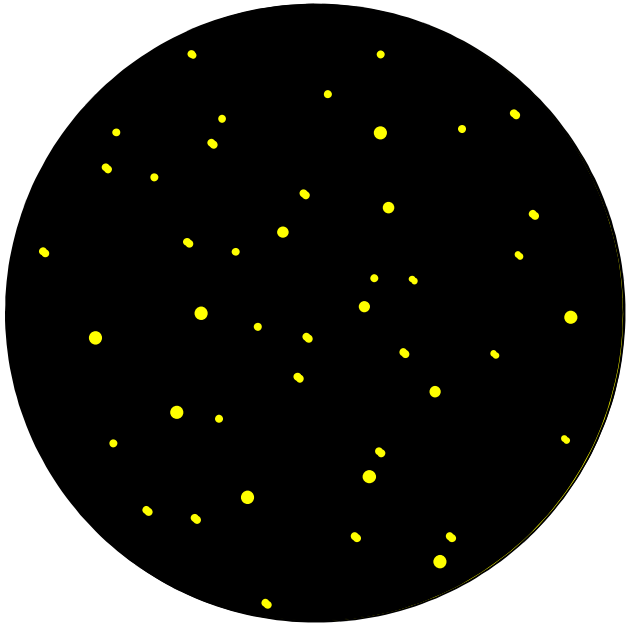


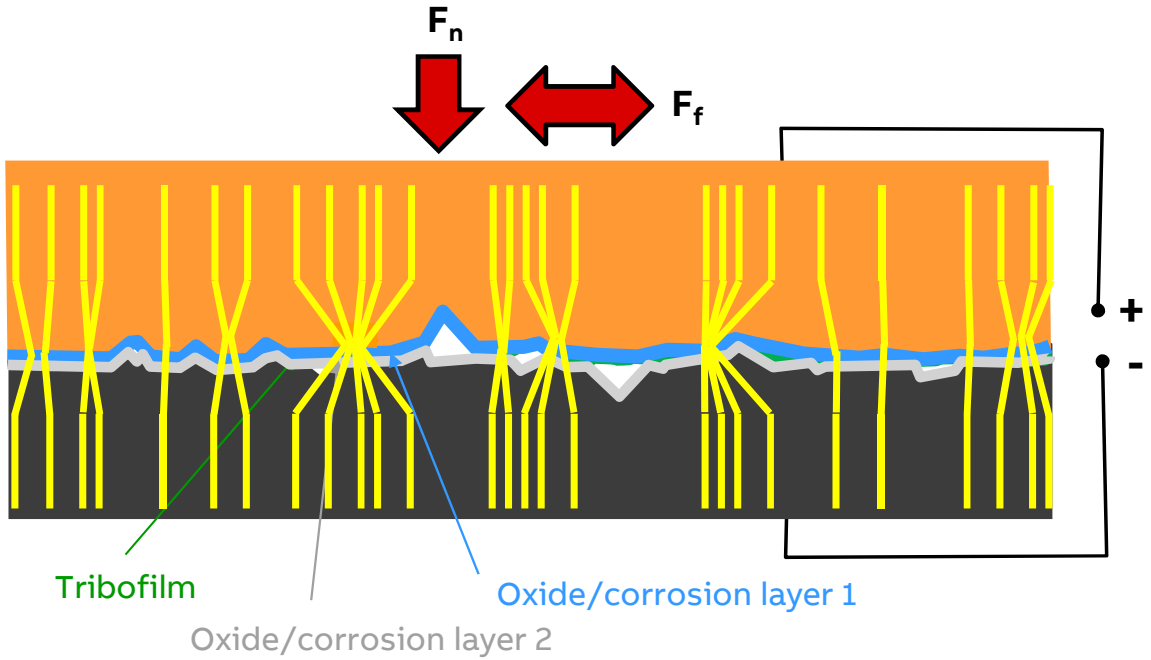
Good contact:	1 – 5 % of the interface is conducting
Bad contact:	< 1 ‰ of the interface is conducting

Sliding electrical contacts

Tribo-film formation

Contact 1% conductive area





Good contact:	1 – 5 % of the interface is conducting
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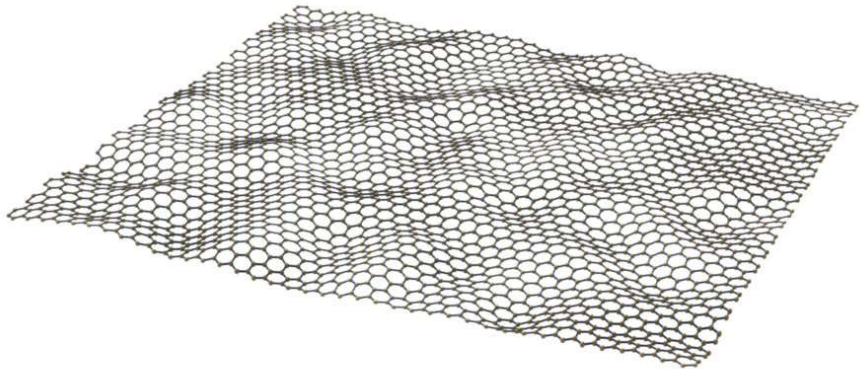
Sliding electrical contacts for power applications

GRMs as potential additive in Ag-based contacts



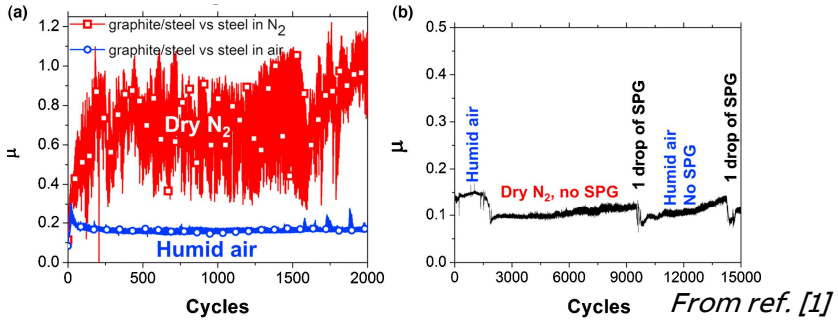
Why GRMs?

- Potentially excellent electrical and thermal properties
- High mechanical strength
- Good tribological properties in humid and dry environments (unlike graphite) [1]
- Chemical and thermal stability, corrosion protection
- Designability (GO)
- 2D material → thin

Ideal candidate for handling high loads, high speeds, high currents, high temperatures, different chemical environments etc. ?

Graphite/steel vs. steel

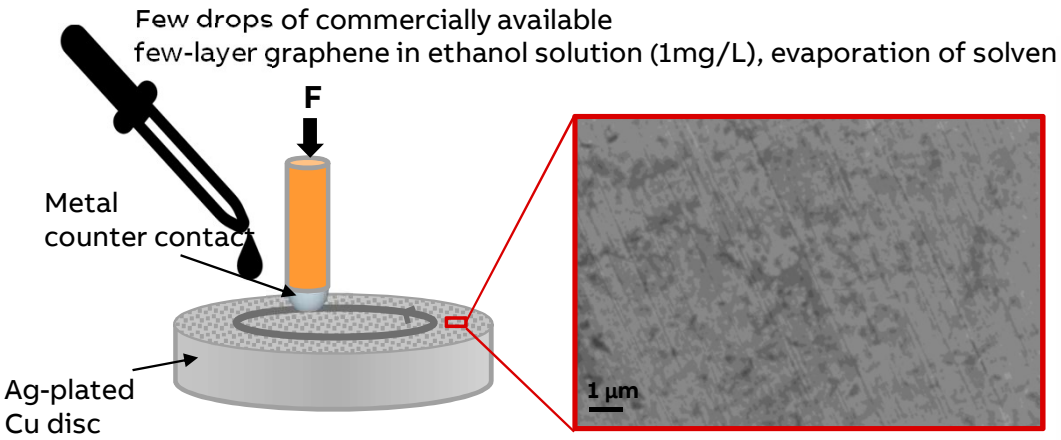
Graphene/steel vs. steel

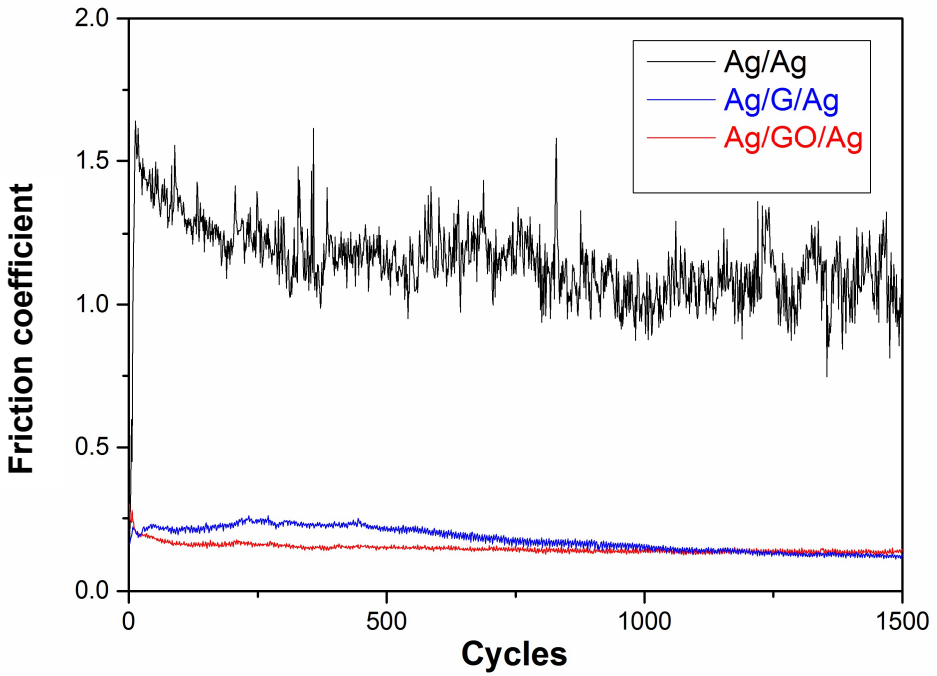


From ref. [1]

1. D. Berman, A. Erdemir, A.V. Sumant, 'Few layer graphene to reduce wear and friction on sliding steel surfaces', Carbon, 54 (2013) 454-459.

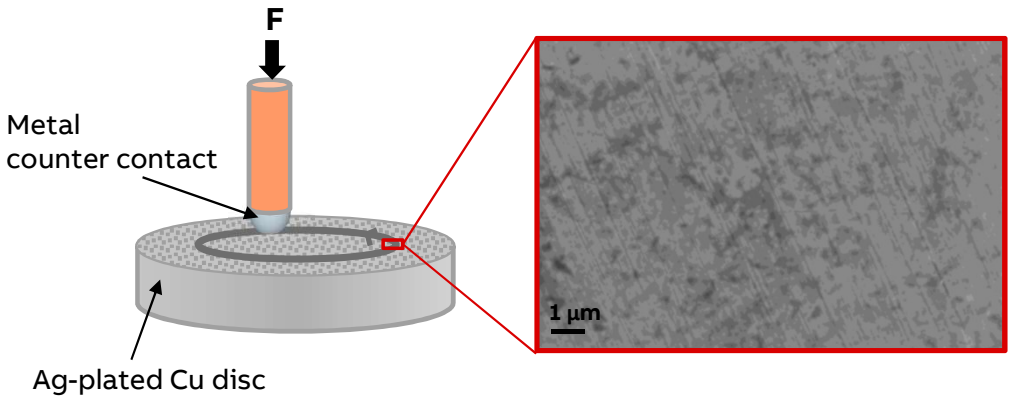
Tribological properties of GRMs



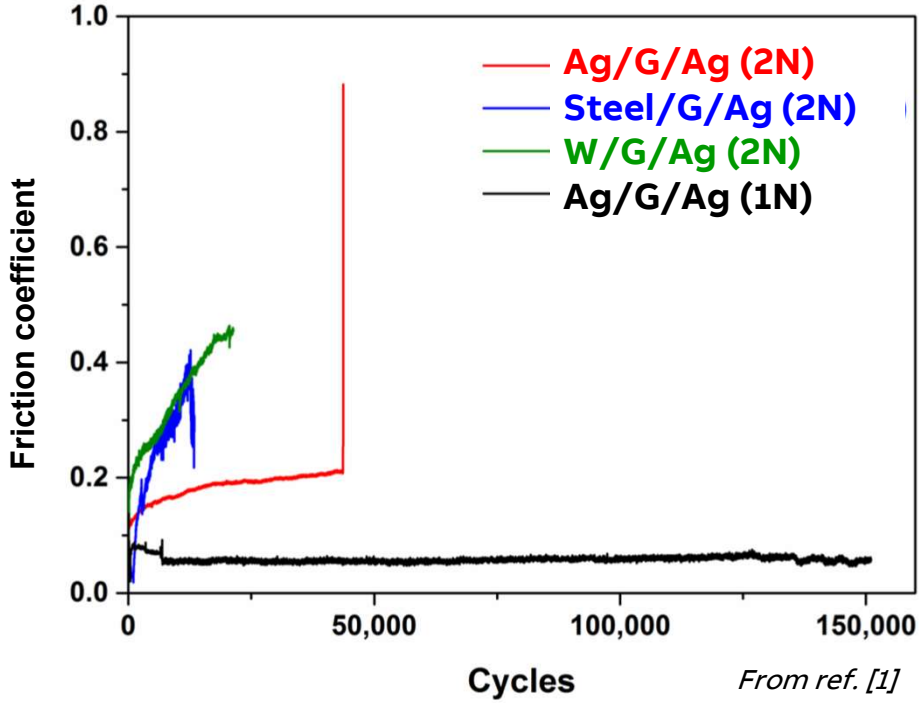


1. F. Mao, U. Wiklund, A.M. Andersson, U. Jansson, 'Graphene as a Lubricant on Ag for Electrical Contact Applications', J. Mater. Sci., 50 (2015) 6518.

Tribological properties of GRMs



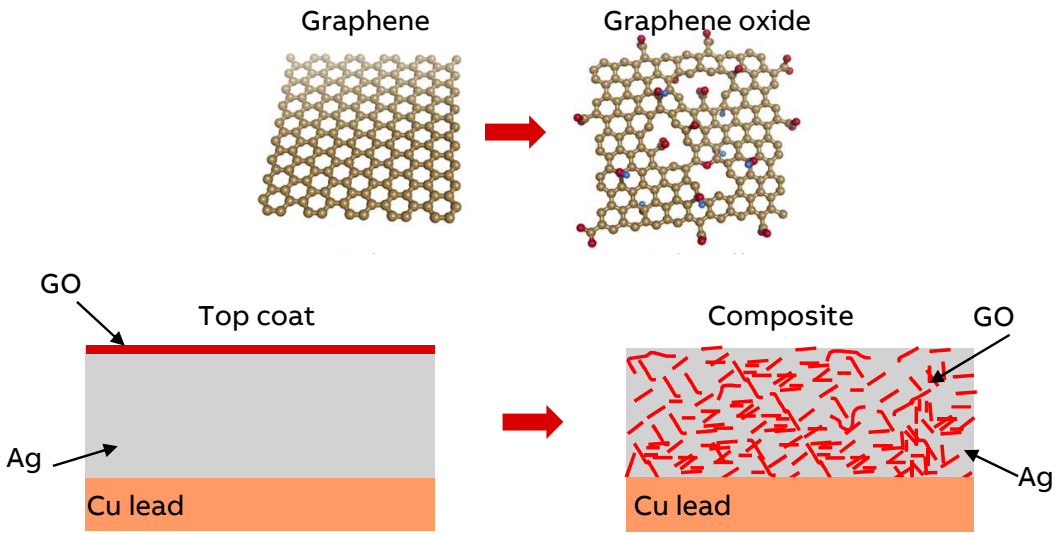
- Graphene and graphene oxide show similar behavior in air
- Lubricating effect of graphene strongly influenced by the metal in the counter surface → Me-C interactions
- Ag seems to be a very good match



From ref. [1]

F. Mao, U. Wiklund, A.M. Andersson, U. Jansson, 'Graphene as a Lubricant on Ag for Electrical Contact Applications', J. Mater. Sci., 50 (2015) 6518

Ag:GO composite sliding contact material for heavy-duty switching applications

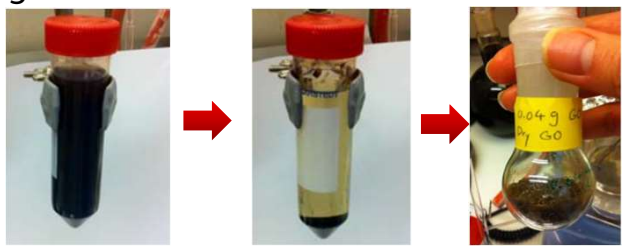


- GO lower cost, more industrially viable
- Composites enable continuous supply of GO (cf. gradual removal of topcoat)
- Possibility to build up a very thin tribofilm with few-layer GO
- Electrical properties of Ag pref. not interfered with
- Possibility for functionalization of GO to tune Ag-matrix and graphene sheet interaction

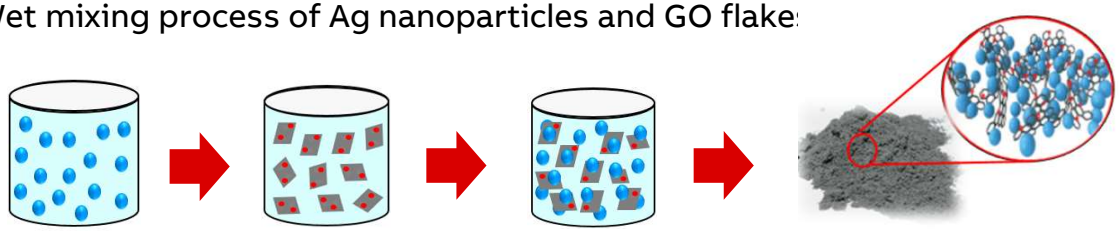
New protocol for a well-dispersed Ag/GO composite material

Cleaning and mixing process of Ag nanoparticles and GO flakes

Cleaning GO



Wet mixing process of Ag nanoparticles and GO flake



Ag nanoparticles/ Solvent

GO flakes/ Solvent

Ag + GO / Solvent

Ag/GO nanocomposite powder

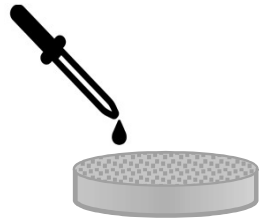
Sintering of Ag/GO composites

Pressing of the Ag/GO powder into a green-body composite

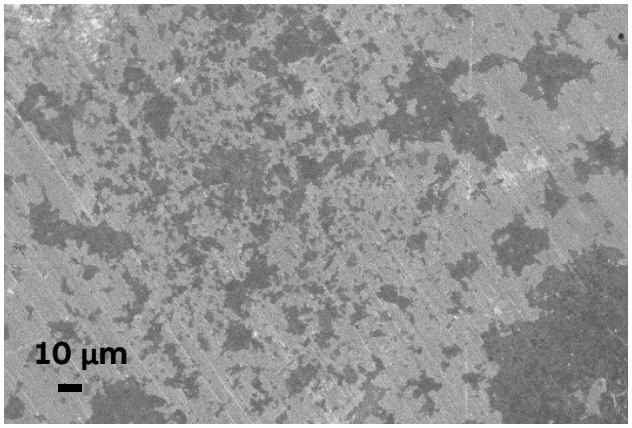
Sintering at specified temperature, time and atmosphere

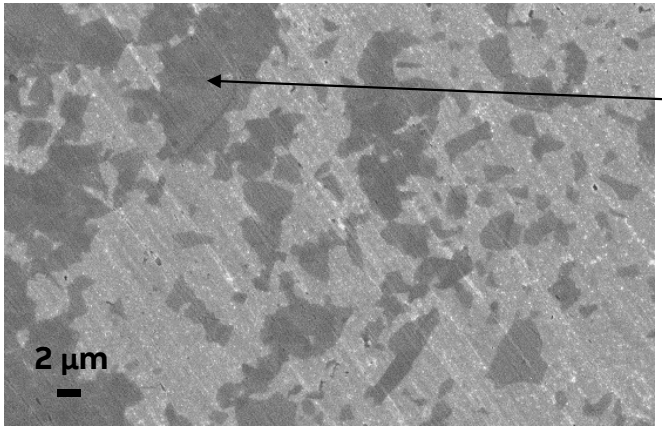
Sintered Ag/rGO composite

Flake distribution before and after cleaning



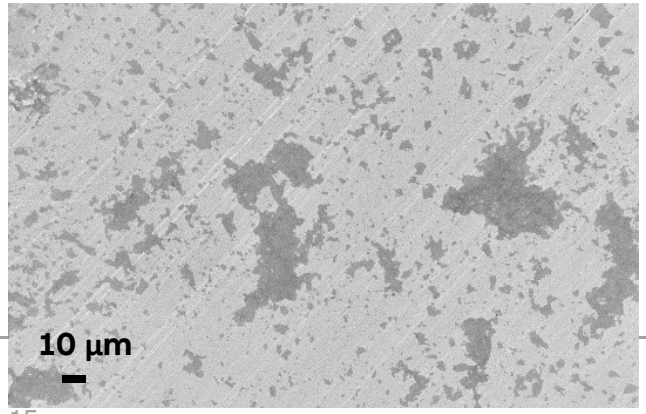
As-recieved

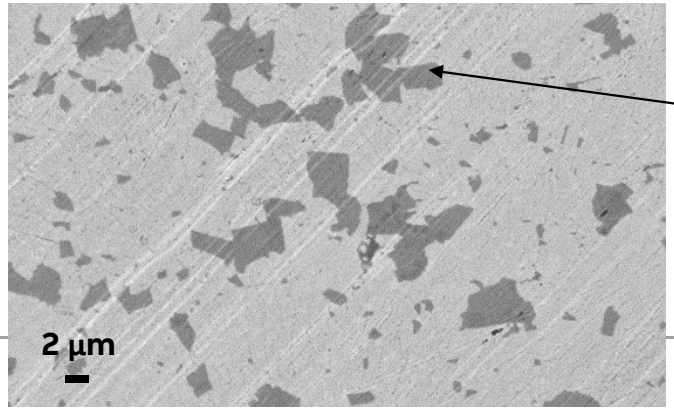




Agglomeration

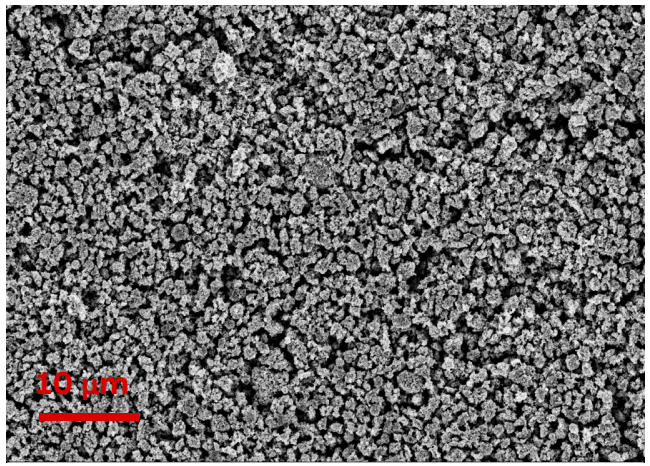
Cleaned

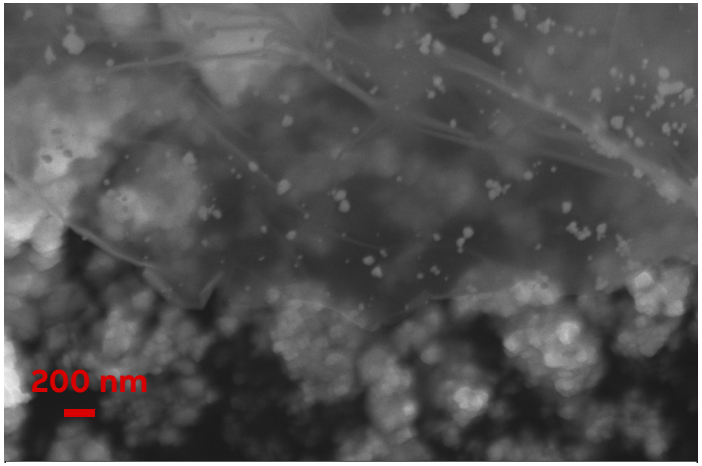


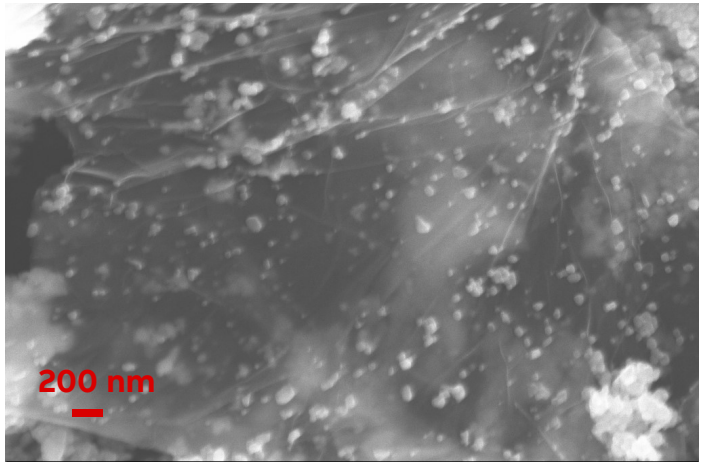


Separate, un-wrinkeled sheets
Narrower size distribution

Powder dispersion Ag:GO powder mixture



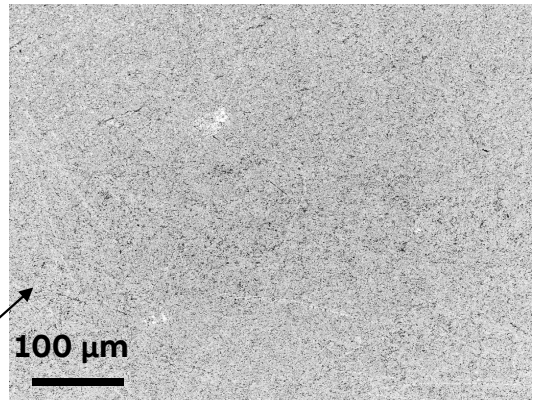


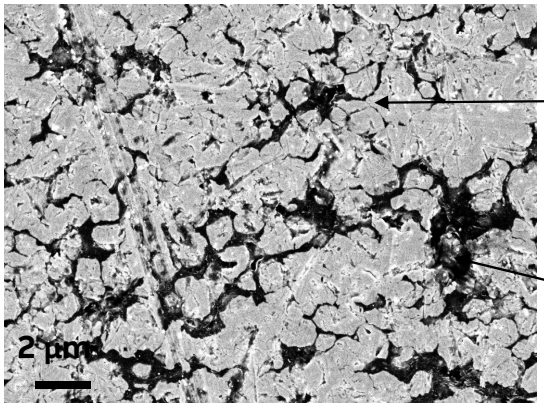


Sintering of Ag:GO composites

Sintered bodies
- cleaned GO
- wet-dispersed powder
- improved sint. parameters

GO content 0.5 wt%
Density : 90-95%



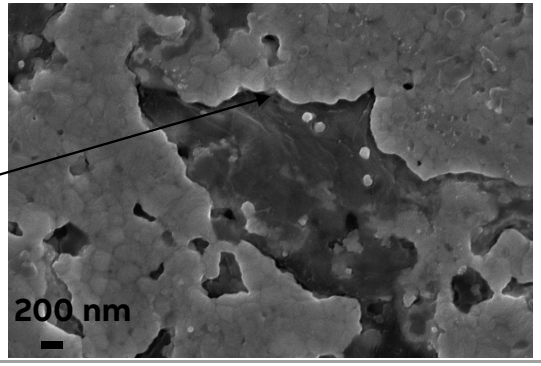


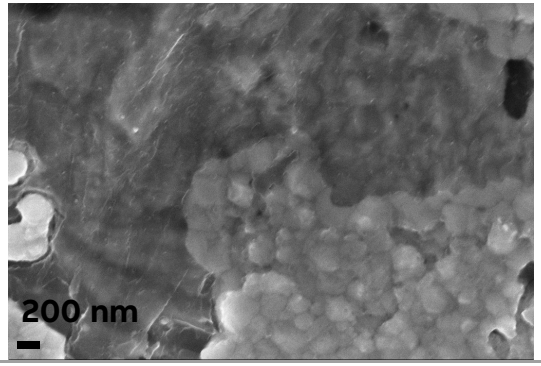
Fine GO network,
no discrete lumps

Small pores still
remaining from gas
evolutioon (GO
reduction)

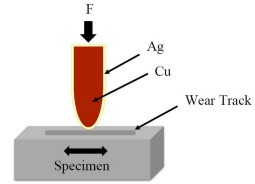
Well-dispersed
composite material

Weak interactions
between GO sheets
and Ag matrix

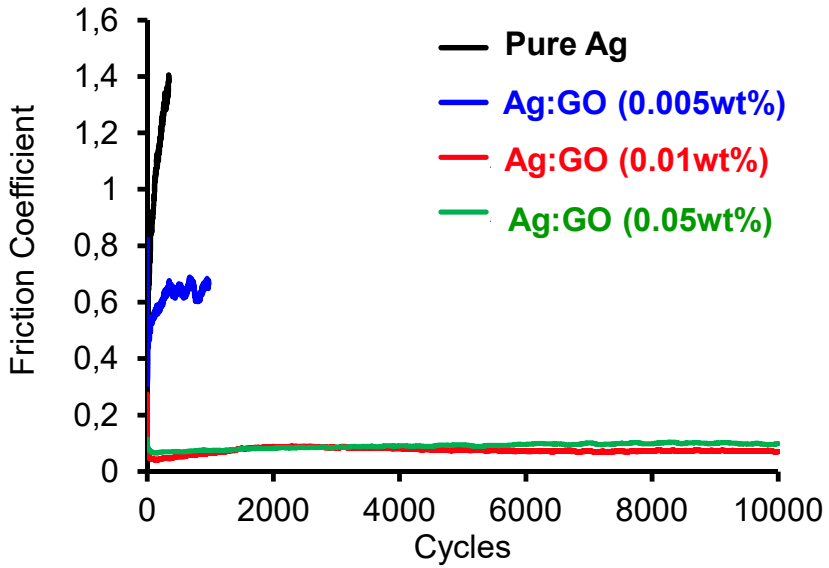


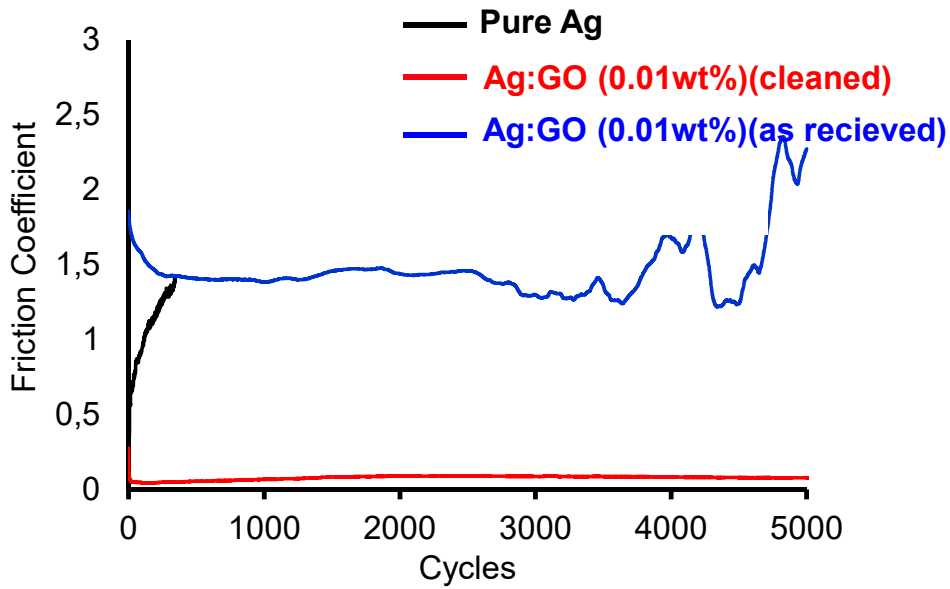


Dry friction of Ag:GO composites

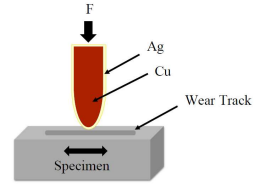


Pin-on-disc in reciprocating mode, load 5 N, speed 5 cm/s, Ag-plated Cu-pin counter (∅ 10 mm)





Wear of Ag:GO composites sintered at 400°C

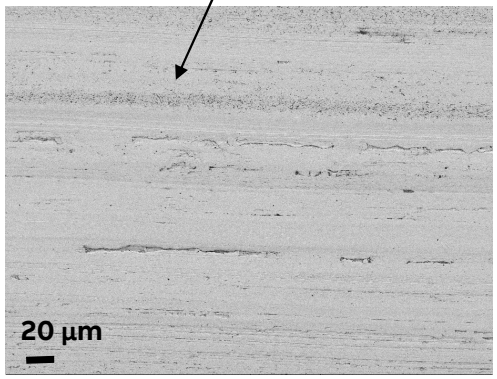


SEM/LOM analysis

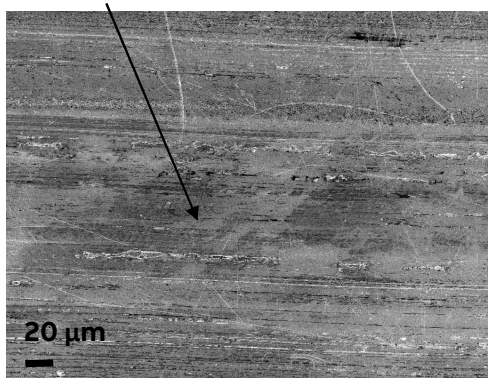
Ag:GO (0.5wt%)

Ag-plated Cu pin counter contact

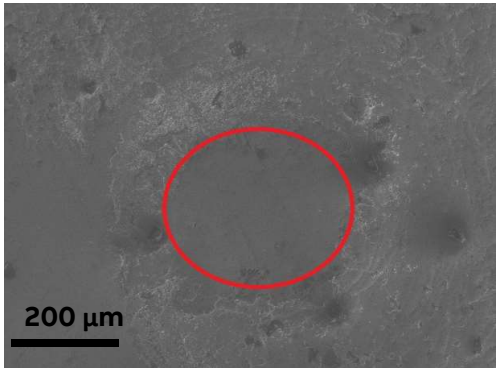
Smooth wear wear track

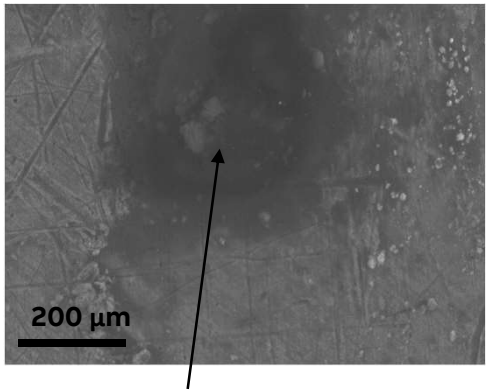


Thin GO tribofilm



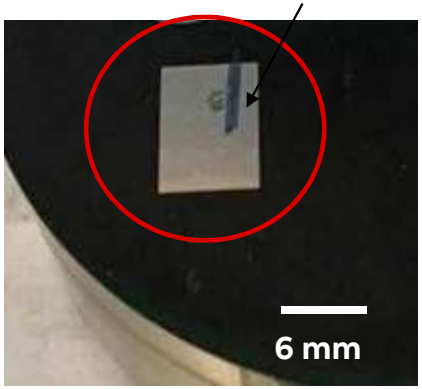
Compositional contrast images (BSE)

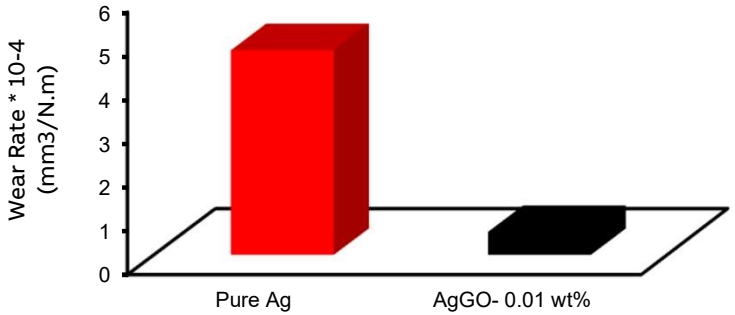




Thin GO tribofilm on counter surface

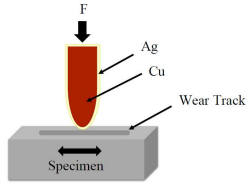
Narrow wear track, no wear debris





Substantial reduction of wear

Wear of Ag:GO composites sintered at 400°C



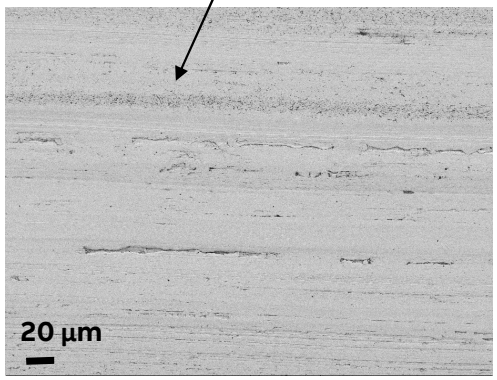
SEM/LOM analysis

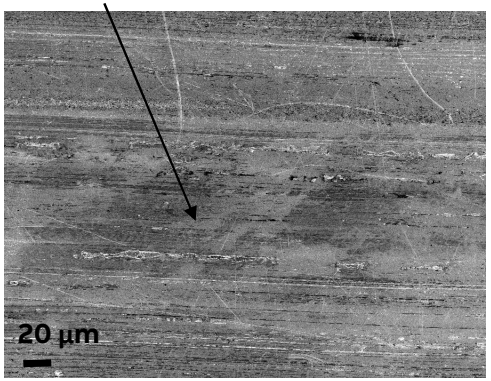
Smooth wear track

Thin GO tribofilm

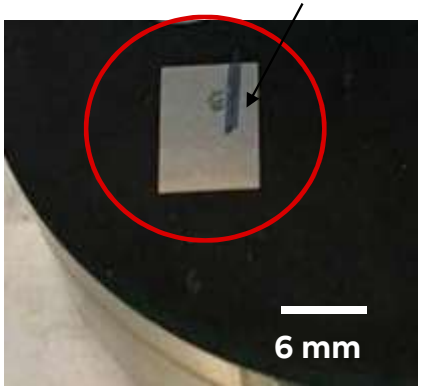
Narrow wear track, no wear debris

Good case
Ag:GO (0.5wt%)

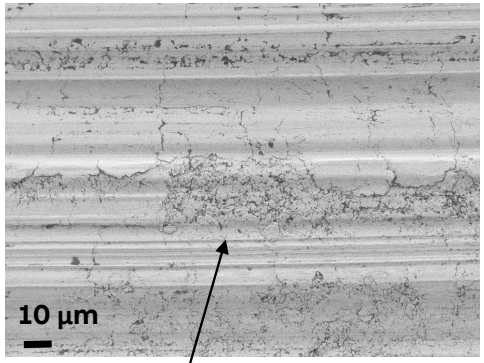


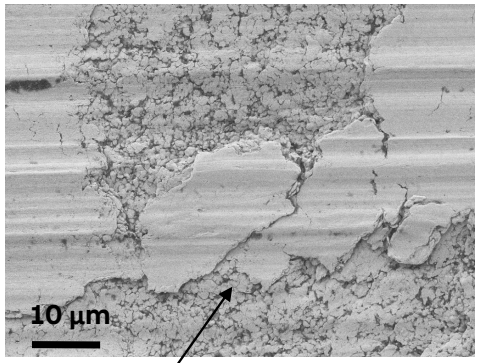


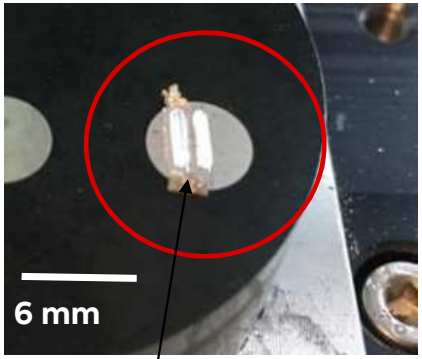
Compositional contrast image (BSE)



Bad case
Ag:GO (0.5wt%)







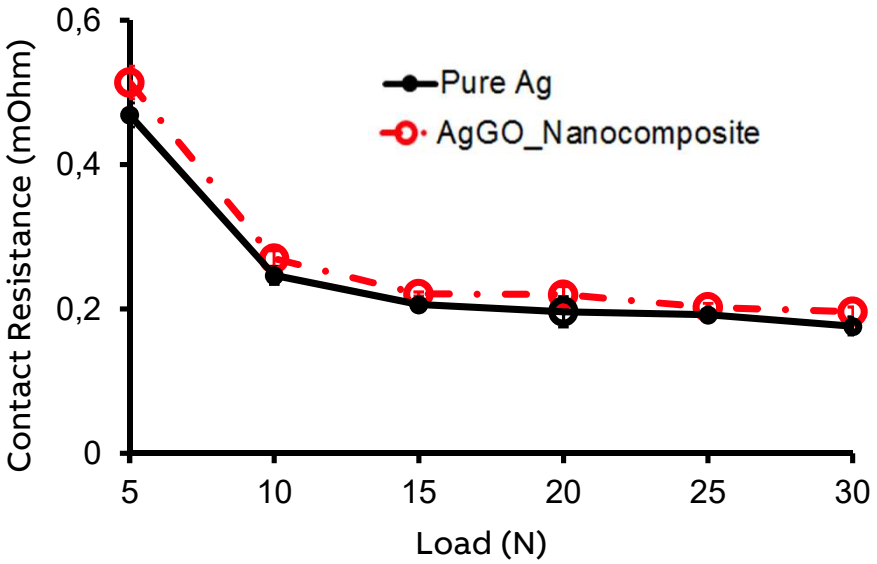
Irregular wear track

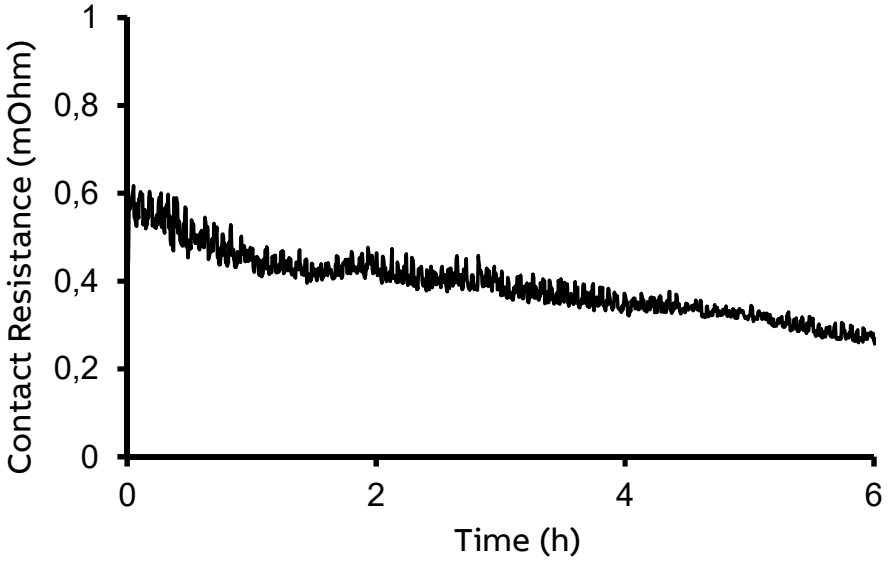
Poor cohesion

Wide wear track, wear debris

Electrical properties of Ag:GO composites

Write something?





Cost of graphene-related materials

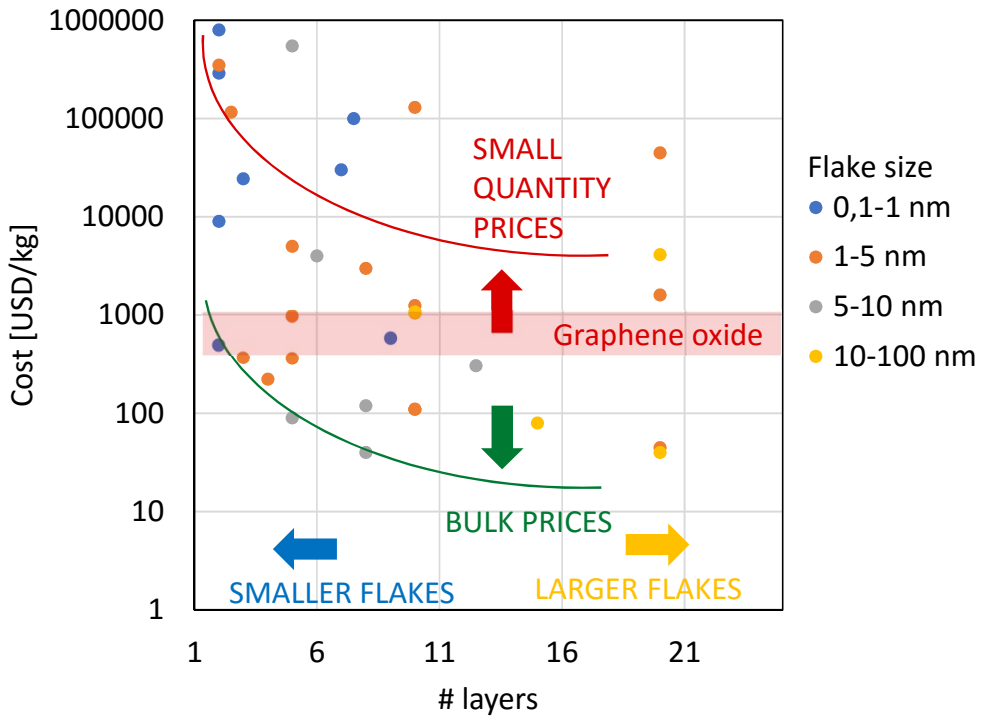
Few-layer graphene now outperforms GO on price!

Graphene/graphene oxide flakes (Jan 2018) [1]

	Size	Cost (USD/kg)
Graphene nanoplatelets (GNP)	>10 layers	20
Few layer graphene (FLG)	3-10 layers	100
Mono/bi-layer graphene	1-2 layer	20 000
Liquid-exfoliated graphene	5-50 layers	0.2-20
Graphene oxide	3-10 layers	600-1 000

Graphite (China graphite flake-194 EXW spot prices April 2018) [2]

XL flake	+50 mesh	1.85
Large flake	+80 mesh	1.175
Medium flake	+100 to -80 mesh	0.95
Small flake	-100 mesh	0.85



]1] SIO Grafen leverantörsguide 2018-1; https://siografen.se/report/leverantorsguide/
[2] http://northerngraphite.com/graphite-pricing/

Concluding remarks

Ag:GO composites show great promise as sliding electrical contact material

Purity and dispersion of GO is key to create a multifunctional material

More basic knowledge needed how composite microstructure and composition couples to tribological, electrical and mechanical properties

Product-related tests will be an important next step

THANK YOU FOR YOUR ATTENTION!