P5-03: Field electron emission from a nickel-carbon nanocomposite

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Abstract: Field-emission properties of nanocomposite films comprised by nickel 10-20 nm particles immersed in carbon matrix were investigated. The films were deposited onto silicon substrates by means of the metal-organic chemical vapor deposition (MOCVD) method. Substrate structure was controlled via the deposition process parameters. Experiments demonstrated that such composite films can efficiently emit electrons, yielding current up to 1.5 mA/cm² in electric field below 5 V/µm. Yet, good emission properties were showed only by films with low effective thickness, where nickel grains did not form a solid layer but left some part of substrate area exposed to the action of electric field. This phenomenon can be naturally explained in terms of two-barrier emission model.

1. Object of investigation:

Nickel-carbon composite films fabricated by the Metal-Organic CVD method at Si substrates at 350..650°C. (see more detail in the poster P5-31).

2. Background & motivation:

-- Many types of heterogeneous sp^2/sp^3 nanocarbon films demonstrate good FEE parameters (threshold field below 1 kV/mm). → What if we replace the graphitic phase with a metal?

-- The phenomenon of low-field emission from low-aspect ratio $sp2/sp3$ carbons can be explained by the two-barrier (or hot-electron) model -- see more in the adjacent poster P5-2.

In this model, emission properties of a structure are determined mostly by properties of conductive grains' size and interfaces, but not by their electron properties. → Emission via Ni nanoparticles may also be efficient.

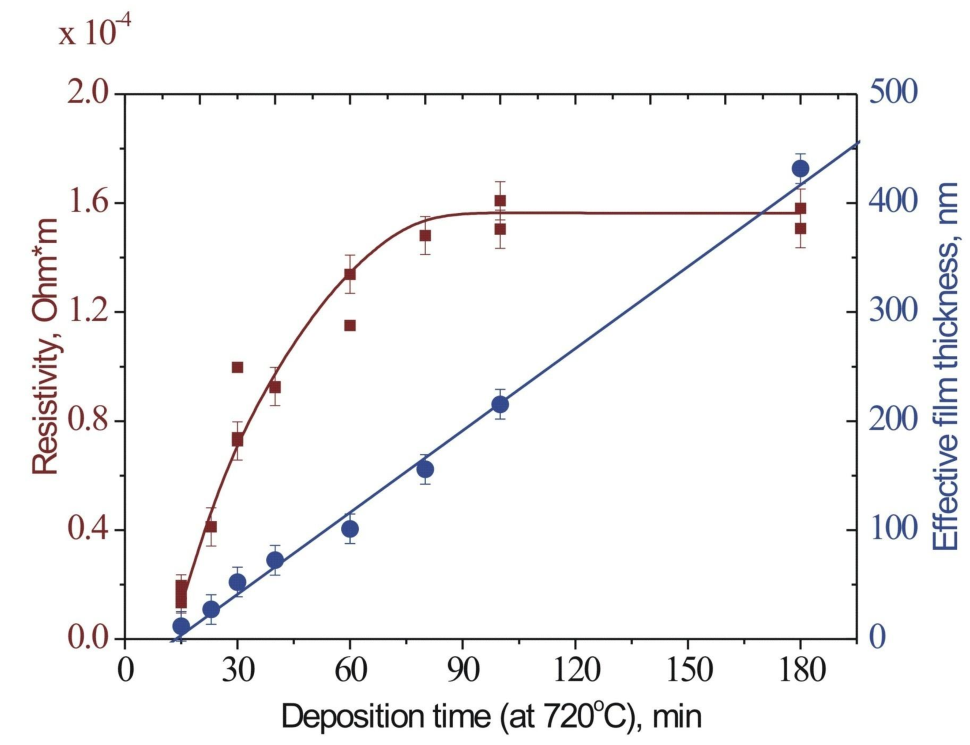
-- More complex structure of Ni-C composite (in comparison with pure-carbon films) provides additional flexibility to fabrication process. → More accurate tailoring of emitter structure may be possible.

3. Film structure & properties

The deposited films included:

Nickel component:
nanograins with aver. size 30 nm or less.
At early stages of deposition process – separate particles. Then, form a solid layer. Deposition rate grows with substrate temperature.

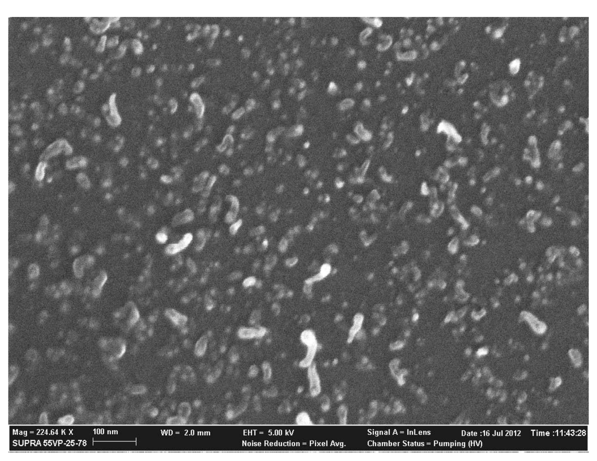
Carbon component
is present in different forms:
1)amorphous sp^3-bonded matrix;
2)graphitic phase (appears in samples deposited at higher temperatures);
3)"nanocones" growing from Ni particles;
4) ??



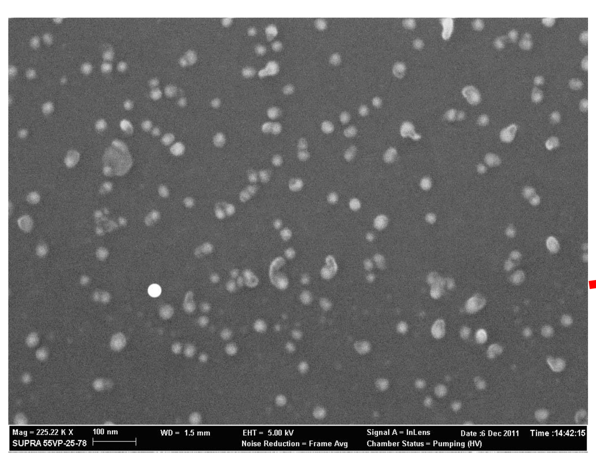
Nickel carbide shells of Ni particles, with thickness presumably increasing with deposition time and substrate temperature, which leads to increase of surface resistivity with film thickness (see in the plot above).

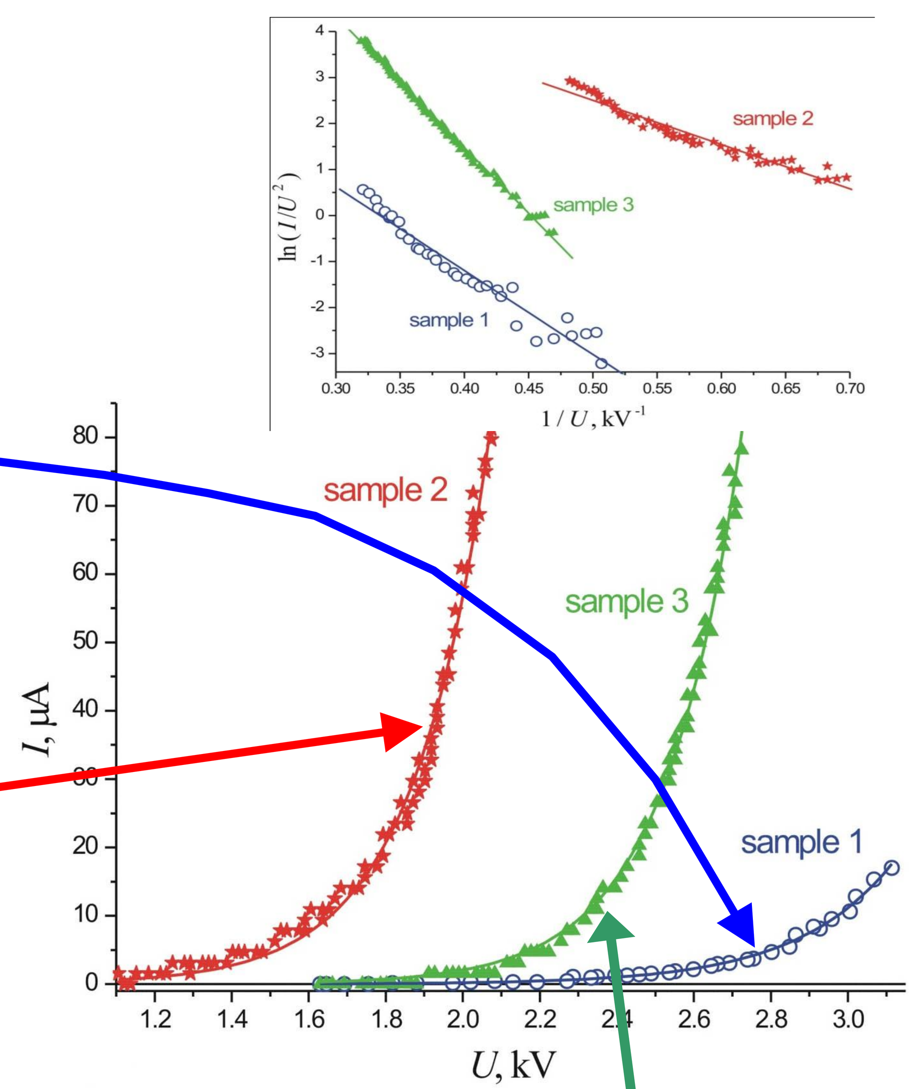
4. Film samples & emission characteristics

Sample 1:
Deposition process: 390°C, 60 min;
$(EtCp)_2Ni/H_2/Ar$ 75/210/555 Pa (for all samples).
Isolated Ni particles, average size 11 nm.
Good emission properties.

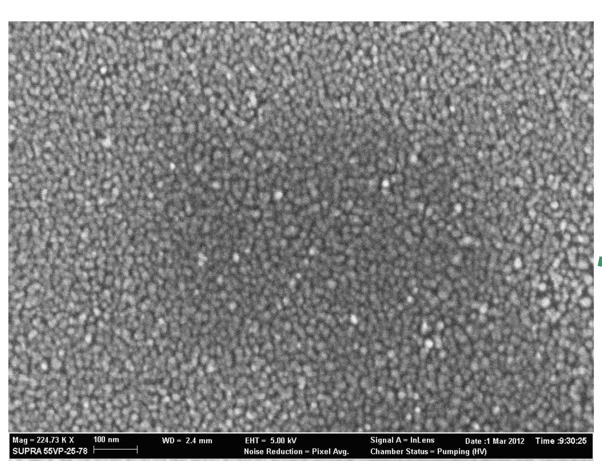


Sample 2:
Deposition process: 410°C, 60 min;
Isolated Ni particles, average size 20 nm.
The best emission properties, threshold field <2 V/µm.

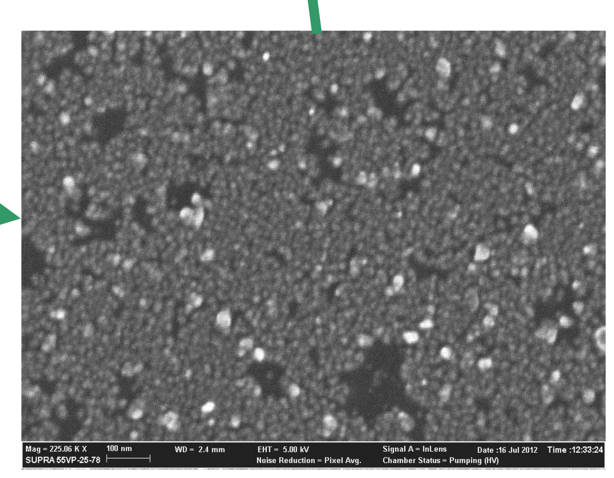




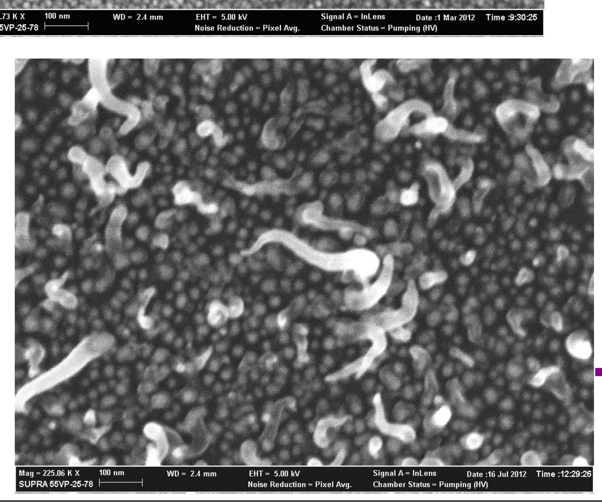
Sample 3:
Deposition process: 570°C, 5 min;
Full monolayer of 10-20 nm Ni particles.
Good emission properties after activation treatment (heating+extraction of current)



The film was damaged during activation treatment, only then it yielded emission current



Sample 4:
Deposition process: 450°C, 60 min;
Full monolayer of 15-30 nm Ni particles + carbon nanocones.



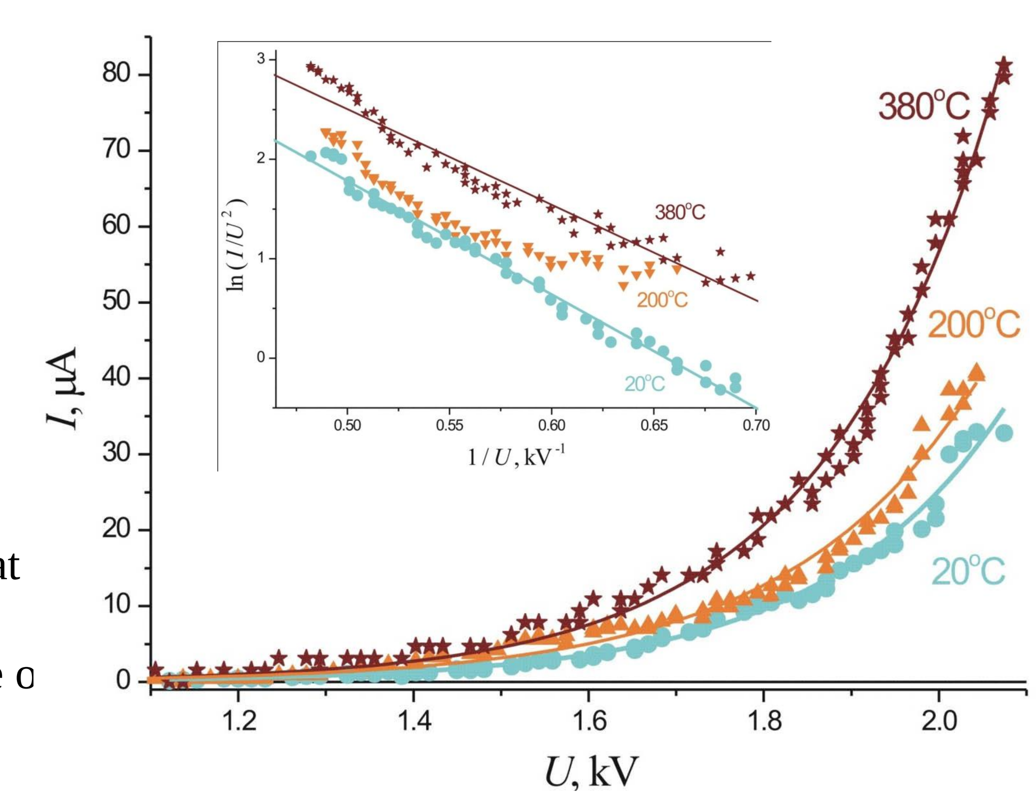
No emission up to 10 kV/µm

5. Temperature dependencies

A typical temperature dependency of emission I-V plots (sample 2) →

The dependency is relatively slow. Plots for all temperatures are approximately linear in Fouler-Nordheim coordinates.

The effect can be explained either by increased substrate conductivity at higher temperatures (if resistance of the low-doped substrate actually limits the emission current) or by activation of the sample in the course o the experiment.



6. Conclusions

The experiments performed in the presented work demonstrated that:

- Ni-C nanocomposite films can be fabricated by the MOCVD method from nickel $(EtCp)_2Ni/H_2$. The composite has the general form of 10-20 nm Ni particles in carbonic matrix. Physical characteristics of the composite can be controlled parameters of deposition process;
- the composite films can serve as efficient cold electron emitters producing current with mean density at least up to 1.5 mA/cm² in electric field below 5 V/µm;
- electron emission was observed only for the films with relatively low effective thickness, with at least a part of substrate surface open for the action of the applied field. This observation can be naturally explained in the hot-electron emission model if we assume that hot electrons can be injected in nanoparticles only from the substrate and not from other nanoparticles. Surface conductivity of the film (measured as approximately 10^4 S/m) is too high to allow field penetration in the material, which is necessary for generation of hot electrons.

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