Experimental study on the transition from spark to arc discharge with respect to nanoparticle production

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Due to their unique properties and multiple applications in optical, magnetic, thermal, electrical, biological sensor devices, textiles, cosmetics and medicine, metal nanoparticles are beginning to be widely manufactured and used. This work is aimed to investigate the production of metal nanoparticles by atmospheric plasma synthesis, from the electrical discharge between two electrodes in an inert gas atmosphere.

The setup uses an optimized single unit (OSU) consisting of a cylindrical chamber with multiple ports through which the electrodes are inserted, the gas enters and the aerosol exits the chamber (Stein et al., 2013). The whole system is vacuum tight (<10^{-5} mbar). The electrodes lay vertically facing each other within a certain distance and the gas flows upwards coaxially around the electrodes. The consumable electrode is a copper rod and the gas is ultrapure nitrogen. The OSU is powered by a high voltage (HV) power supply (Technix) in parallel with a capacitance box (30 nF). Two HV (+10 kV) power supplies allow reaching charging currents of up to 150 mA and 1.5 A respectively. Currents of up to 200 A are delivered by a Tig welding machine (Klimag 210P) operating at low voltage (<30 V). An extensive series of experiments were conducted in order to assess the dependence of the aerosol mass flow rate and particle size distribution on the applied current (1 mA-50 A) and the gas flow rate (5-50 slm). The mass flow rate and the particle size distribution of the copper aerosols were measured online by means of TEOM and SMPS. Also, the mass output rate was determined by gravimetric analysis of aerosol samples collected onto filters; copper particles were then analyzed by SWAXS and TEM. The V-I characteristic of the discharge and the optical emission spectrum of the plasma (Cu/N_2) were measured online too.

The mass output rate is displayed as a function of the charging current in Fig. 1. Three main discharge regimes with distinct V-I characteristics and emission spectra were identified in the experiments: spark discharge, glow discharge and arc discharge. At a current of about 10 A the copper rod melts and, then, a graphite crucible is used to hold the molten copper. A mass output rate of 2 g·h^{-1} was attained by arc discharge at a current of nearly 45 A. The parameters of the particle size distribution of the copper aerosols are listed in Table 1. In general, the geometric mean diameter d_g and the particle number concentration N increase as current increases, consistently with the increase in the mass output rate. Also, d_g decreases with increasing gas flow rate. The geometric standard deviation σ_g varies between 1.4 and 1.7 with increasing current and depends weakly on gas flow rate.

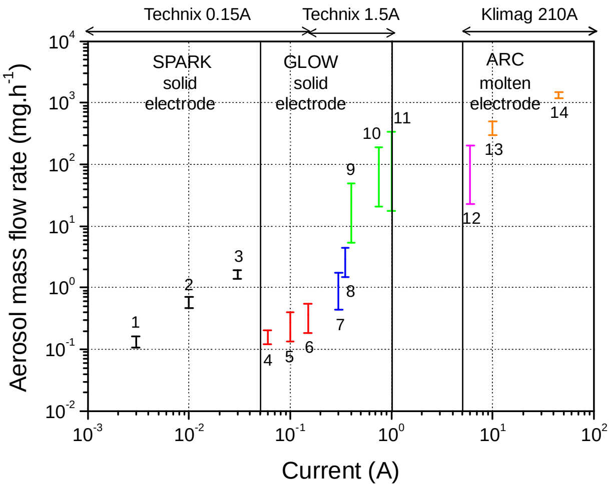

Figure 1. Mass output rate of copper nanoparticles generated by electrical discharges.

Table 1. Particle size distribution of copper nanoparticles generated by electrical discharges.

Glow discharge (solid rod)					
Fig.1	q (slm)	I (mA)	d_g (nm)	σ_g	N (cm^{-3})
4	10	60	16.7	1.35	7.0x10^6
5	10	100	17.7	1.40	1.0x10^7
6	10	150	18.2	1.35	1.2x10^7
7	10	300	20.1	1.53	3.0x10^7
8	10	350	27.4	1.53	3.9x10^7
9	20	400	41.3	1.63	6.6x10^7
10	20	750	49.0	1.67	1.4x10^8
11	20	1000	50.7	1.57	2.4x10^8
Arc discharge (solid rod)					
Fig.1	q (slm)	I (A)	d_g (nm)	σ_g	N (cm^{-3})
12	20	6	53.9	1.73	9.6x10^7
Arc discharge (molten pool)					
Fig.1	q (slm)	I (A)	d_g (nm)	σ_g	N (cm^{-3})
13	20	15	61.5	1.71	1.6x10^8
14	20	45	94.7	1.60	5.2x10^8

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