3D-impaction printing of porous layers

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3D-impaction printing of porous layers

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Porous layers composed of nanoparticles (NPs) have a wide range of applications including catalysts and (chemical) sensors. In addition, such layers are strong candidates for thermoelectric materials. In electronics, porous metal layers can be used as resistive elements or, in a strongly sintered/coalesced form, as electrical connections. All these application domains will profit strongly from a NP printing process which is flexible with respect to i) the composition of the NPs and ii) the possibility of composing arbitrary mixtures of different NPs (external mixtures).

The 3D NP printer we report on provides this versatility. It is a combination of the VSPARTICLE G1 spark ablation NP generator (Boeije et al., 2020) with an impactor equipped with an xyz stage. The G1 provides unagglomerated metal or semiconductor NPs of an adjustable size between 0.5 and 10 nm. Any alloy can be produced by using alloyed electrodes or electrodes of different materials in the G1. A spatial resolution of a few tens of microns would be feasible by applying focused impaction (Girshick, 2008). Our impactor is usually operated in the domain of hypersonic impaction, where a gas stream at P_1 = 1 bar is accelerated into a vacuum of about P_0 = 0.3 mbar through a cylindrical nozzle (d = 0.1 mm) in a 0.3 mm thick plate and reaches values above Mach 5. The substrate is placed at a distance L from the nozzle upstream of the Mach disk (distance L_{Mach}) to ensure a high particle velocity.

$$L_{\mathrm{Mach}} = 0.67d\sqrt{\frac{P_0}{P_1}}$$

This allows particles as small as 5 nm to be deposited in the case of silver (Huang, 2007). The final particle velocity can be calculated numerically as a function of L. It easily reaches 200 m/s and determines the impaction energy. If high enough, it induces sintering in the direction of deposition, which gives the porous layer some stability.

Fig. 1 shows the result of laser profiling of the line cross sections for different distances and 5 nm (geometric mean) gold particles, which quite exactly coincide with Gaussian curves.

Regarding applications of this 3D-printer set-up, the capability of (external) mixtures sets no limit to development of arbitrary co-catalysts, e.g. for microreactors and of chemical sensors. Detection of single (bio-)molecules is, in principle, possible by SERS, and our versatility with respect to material and morphology has already enabled production of SERS substrates at VSPARTICLE, which are significantly superior to the state of the art. An example of printing

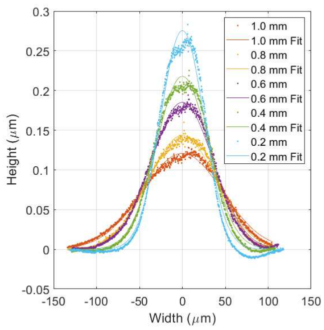

Figure 1: Deposition profiles at different distances

on a contact lens is shown in Fig. 2 (Rennen et al., 2020). The golden color indicates strong impaction sintering/coalescence, since an unsintered Au powder layer would appear black. The heating caused by the collisions is so local that the polymer stays intact.

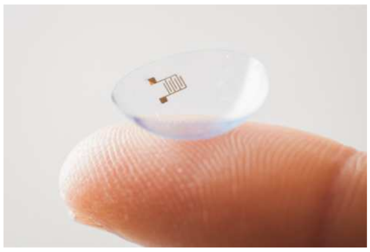

Figure 2. Au Pattern printed onto a contact lens

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