Progress report: Direct injection of liquids into low-pressure plasmas

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While laboratory based plasmas are always in contact with solid surfaces (often vacuum chambers) they have historically been formed in gas environments. In more recent times, the use of plasmas has grown to include plasma contact with liquids including biological items. Inevitably the plasmas in contact with liquids had been at or near atmospheric pressures. This need not be the case.

We have developed a novel method for injecting liquids directly into low-pressure discharges. As such, this technique opens new areas of possible industrial use for plasmas. For example, we have injected inorganic nano-particles into argon plasma by suspending them in hexane (or ethanol) as a high vapor pressure liquid carrier. As a result, we believe that metals, dielectrics, superconductors, aromatics, proteins, viruses, etc. could all potentially be injected into low-pressure plasma environments using this technique. The resulting films indicate the ability to synthesize nano-structured composites.

The technique also opens new areas of plasma science research. For example we find that the plasma reacts in fascinating ways to the pressure wave induced by the injection process. This is seen in the emission from the discharge as shown Figure 1. Models of the inject liquid have also been developed. The model indicates that the time required for the droplet to fully evaporate is a function of the background pressure, initial (wall) temperature, the number of droplets inserted simultaneously and initial size. A typical evaporation time for a 50 micron diameter droplet is ~3 seconds for hexane and up to 10 seconds for ethanol without plasma. The presence of plasma can reduce these times greatly. In the first few milliseconds after insertion into the low-pressure environment, the droplet temperature plummets as the first few microns evaporate. The temperature falls to a minimum value where the heat flow in and out of the droplet balances. After the solvent has fully vaporized, the remaining solute can be heated by the plasma to as high as 700K. All this can take place within 0.5 sec. Typical droplet parameter curves are shown in Figure 2.

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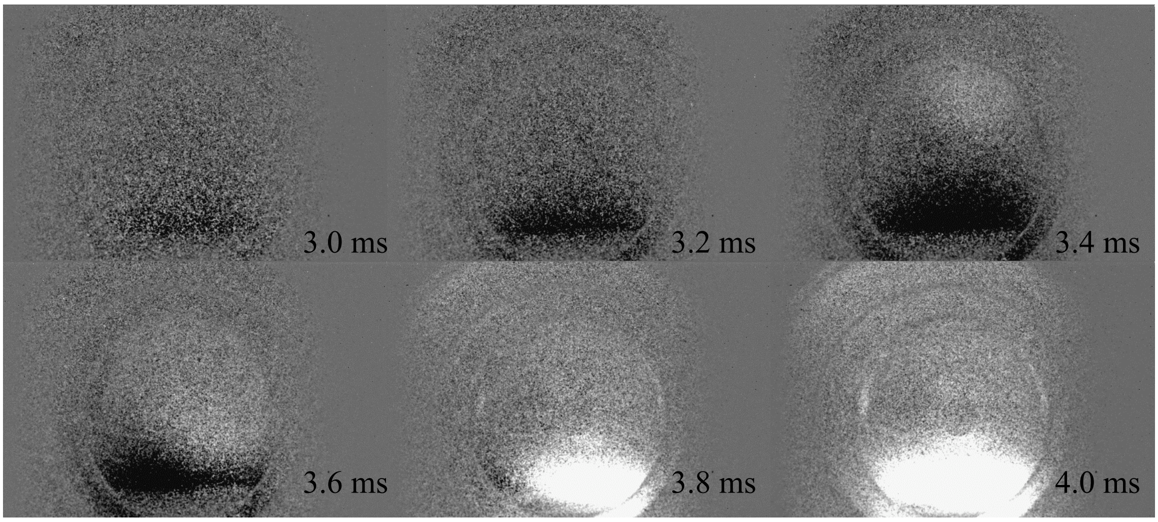

Figure 1: Time sequence of change in emission during N_2 injection into Ar plasma. Change in emission is determined via background subtraction. Here black represents a decrease in emission, white represents an increase and gray is no change. Time is given relative to initiation of injection.

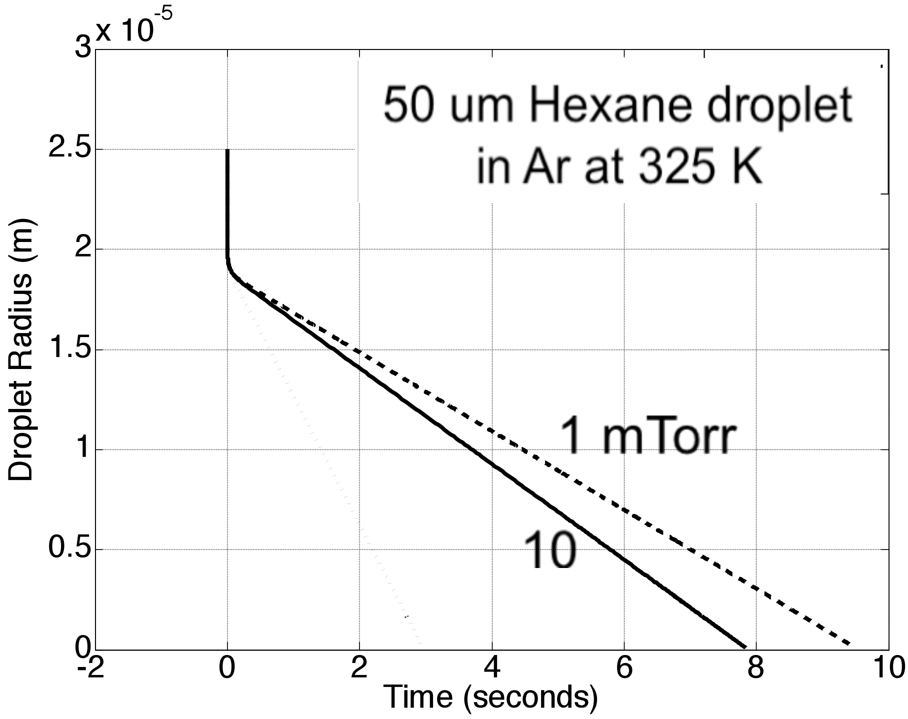

Figure 2: Time sequence of 50 μm n-hexane droplet injected into 1 a nd 10 mTorr Ar. Plasma greatly speeds this evaporation rate.