# Optimization of substitutional phosphorus in n-type diamond


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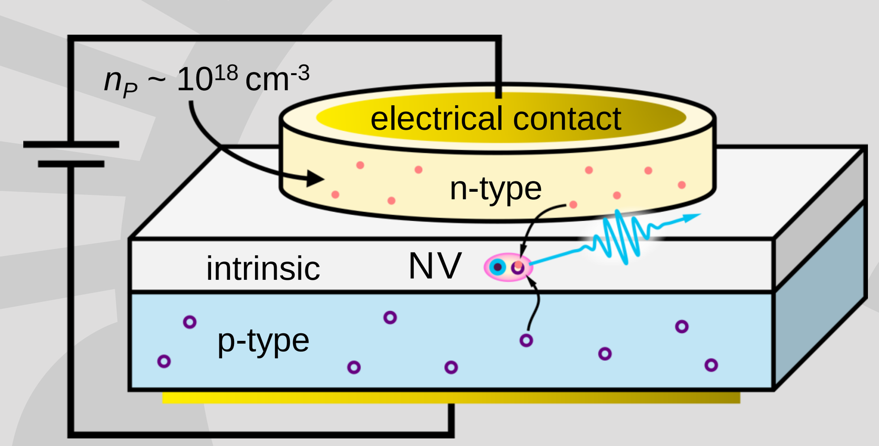
## Why Phosphorus-doped diamond?

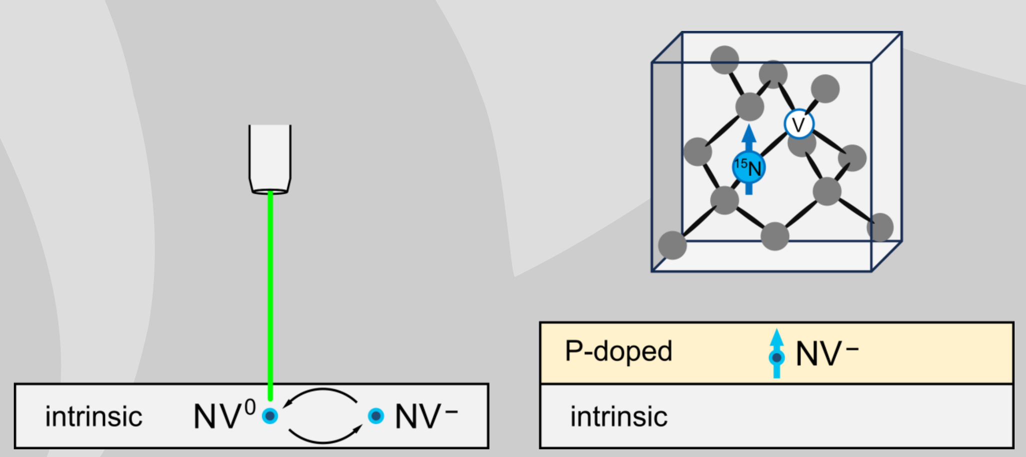
- Major potential for quantum applications.
- Much lower activation energy for P-doped diamond (0.6 eV)[1] than N-doped diamond (1.7 eV)[2], which is an insulator at room temperature.
- Longer spin-coherence times in P-doped diamond increase sensitivities of NV sensors, improve quantum fidelity, and extend quantum-memory times[3].

## Progress in the Field

- NV centers implanted within *p-i-n* junctions made of CVD diamond can be used as single-photon sources, which have applications in quantum communication, computing, and metrology[4].




- Implanting an NV center directly in P-doped diamond stabilizes the $NV^-$ state, which has major uses in quantum information processing applications, over the undesirable $NV^0$ state[5,6].




## Challenges

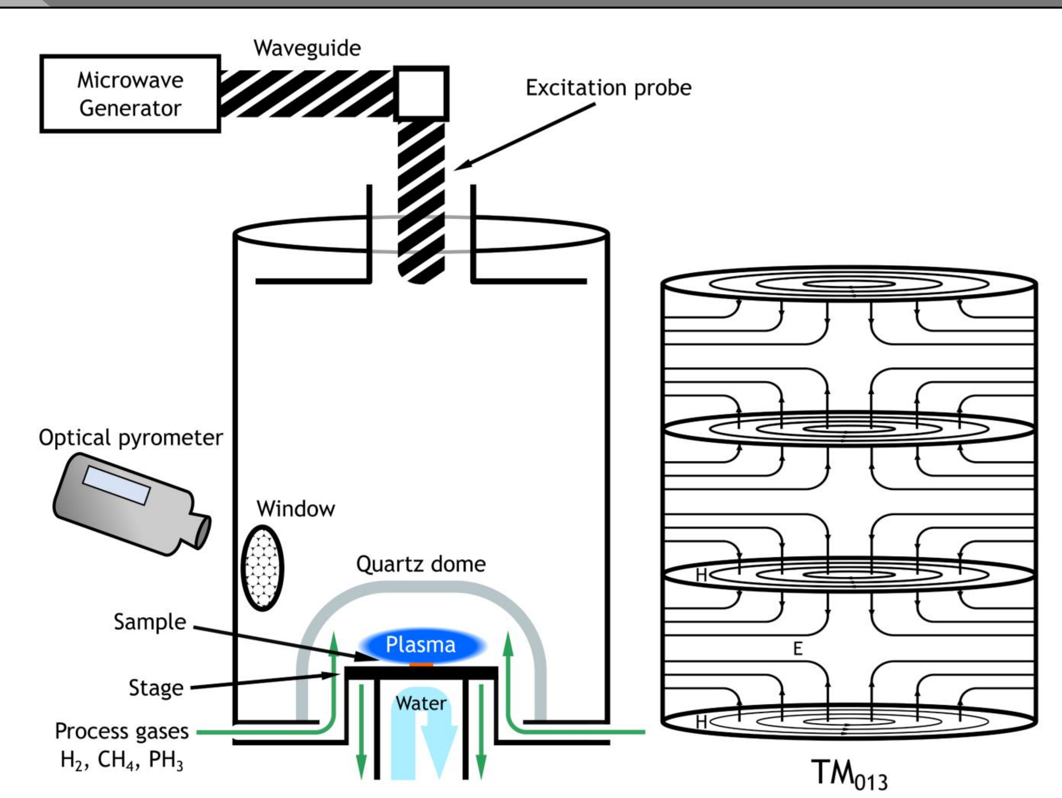
- Phosphorus's large atomic radius prevents it from incorporating into the carbon lattice as easily as boron and nitrogen.
- The conductivity of P-doped diamond is reduced when phosphorus is passivated by hydrogen atoms, impurities, and PV centers[10,11].
- Even in high-quality samples, the relatively deep donor level results in a low carrier concentration at room temperature.
- Therefore, creating useful *n*-type diamond materials requires high phosphorus concentrations and few crystalline imperfections.

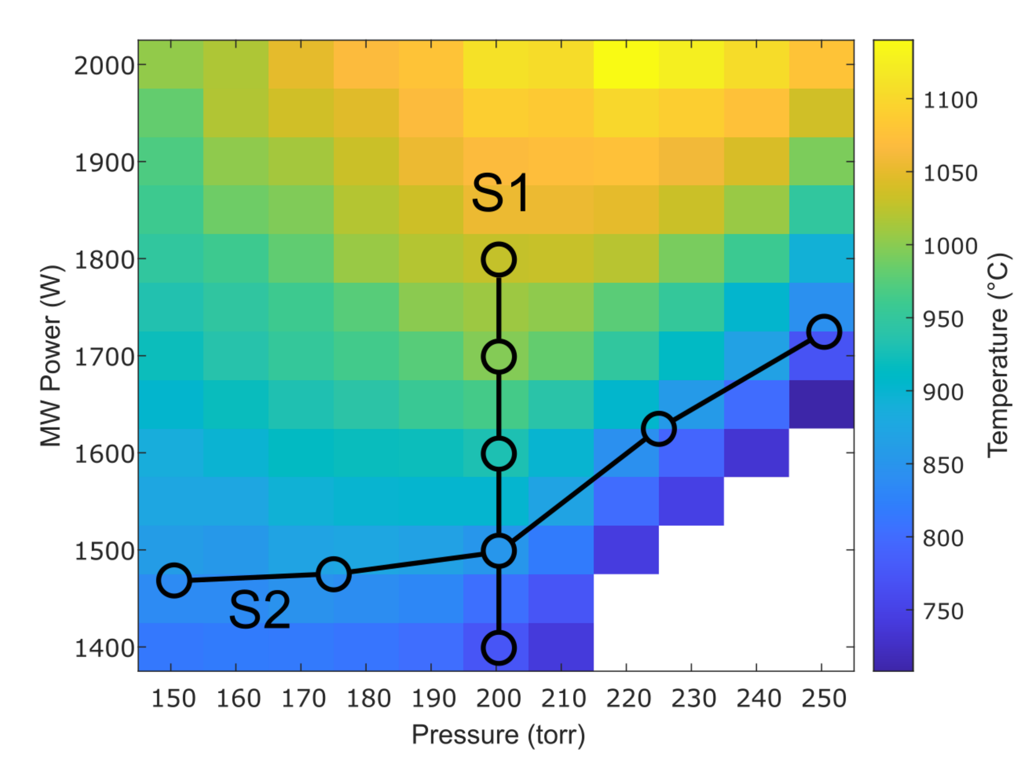
## Our Goal

To determine optimized growth conditions for *n*-type conductivity of highly-doped diamond, we will grow two series of single-crystal P-doped diamond, an isothermal series and an isobaric series, and characterize the samples' physical and electrical properties.

## Diamond Growth

Samples will be grown by Microwave-Plasma Assisted Chemical Vapor Deposition using $PH_3$ gas on (1 1 1) oriented single-crystal diamond substrates. Growth occurs within the reactor chamber where the process gasses flow through a quartz dome. The diamond reaction is sustained by a plasma that is sparked by resonant microwaves. The temperature of the sample is measured with an optical pyrometer.



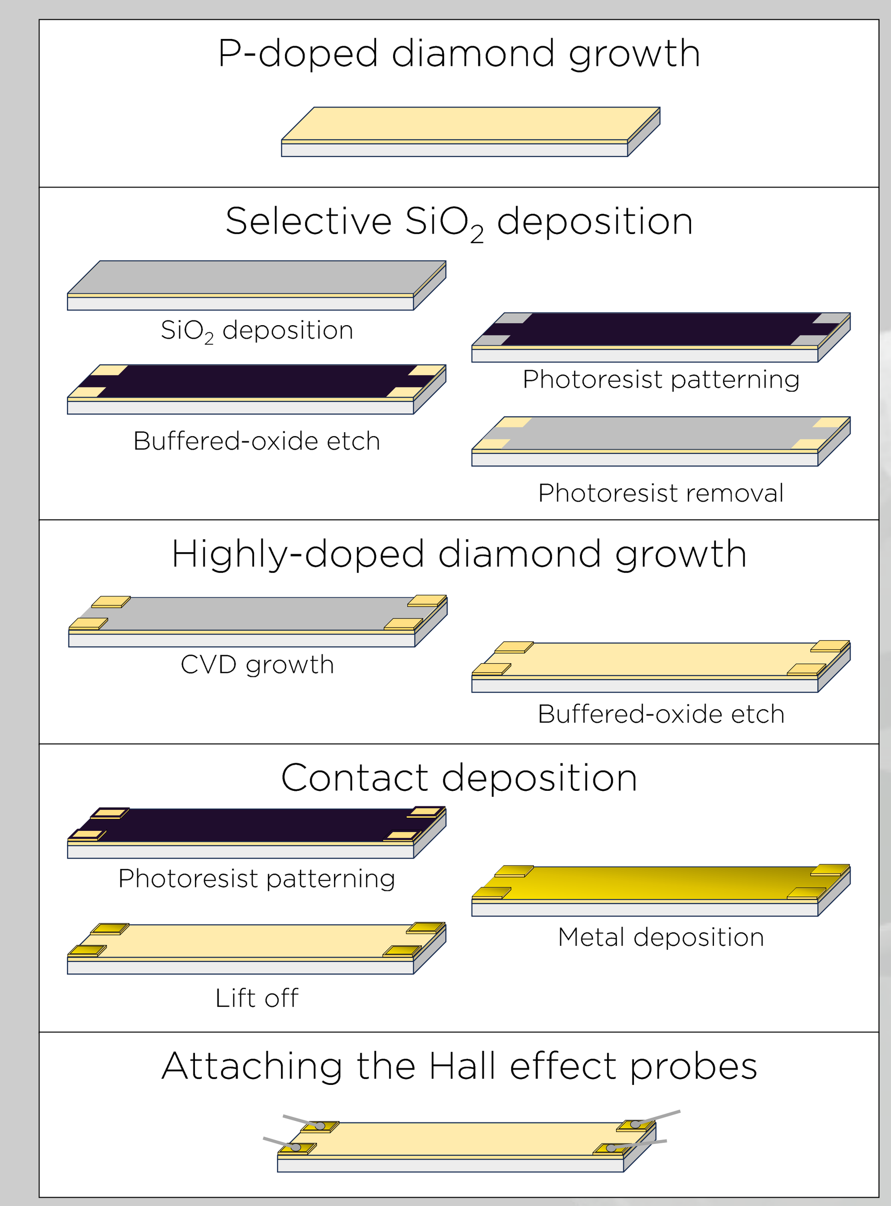



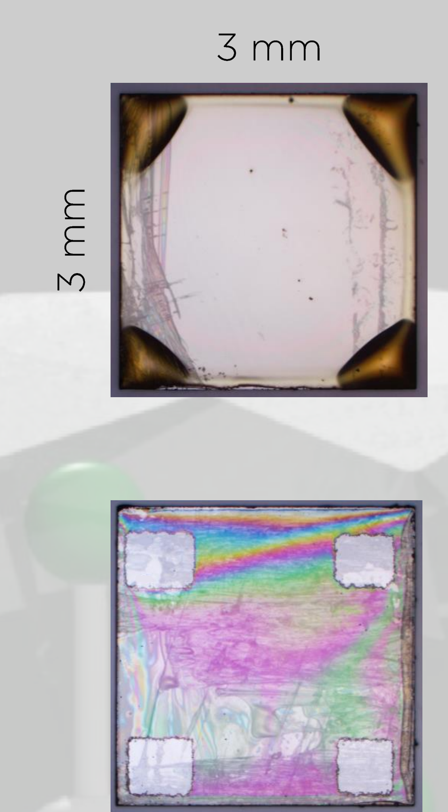

(Left) A simple schematic of the diamond reactor to be used in this study, and the resonant fields.

(Right) Two planned series of sample growths: isobaric (S1) and isothermal (S2).

## Developing the Process

Samples will be characterized by atomic force microscopy for surface analysis, x-ray diffraction determination of miscut orientation, and FTIR and UV-Vis spectroscopies. The conductivity will be determined by Hall effect measurements, which will require photolithography, oxide mask deposition, and a second diamond growth step.




A unique spin-coat procedure had to be developed to avoid beading of the photoresist on small diamond samples

## References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