# Thermal contact resistance using time-resolved EUV diffraction- a novel technique to study conduction-cooled superconducting RF cavity

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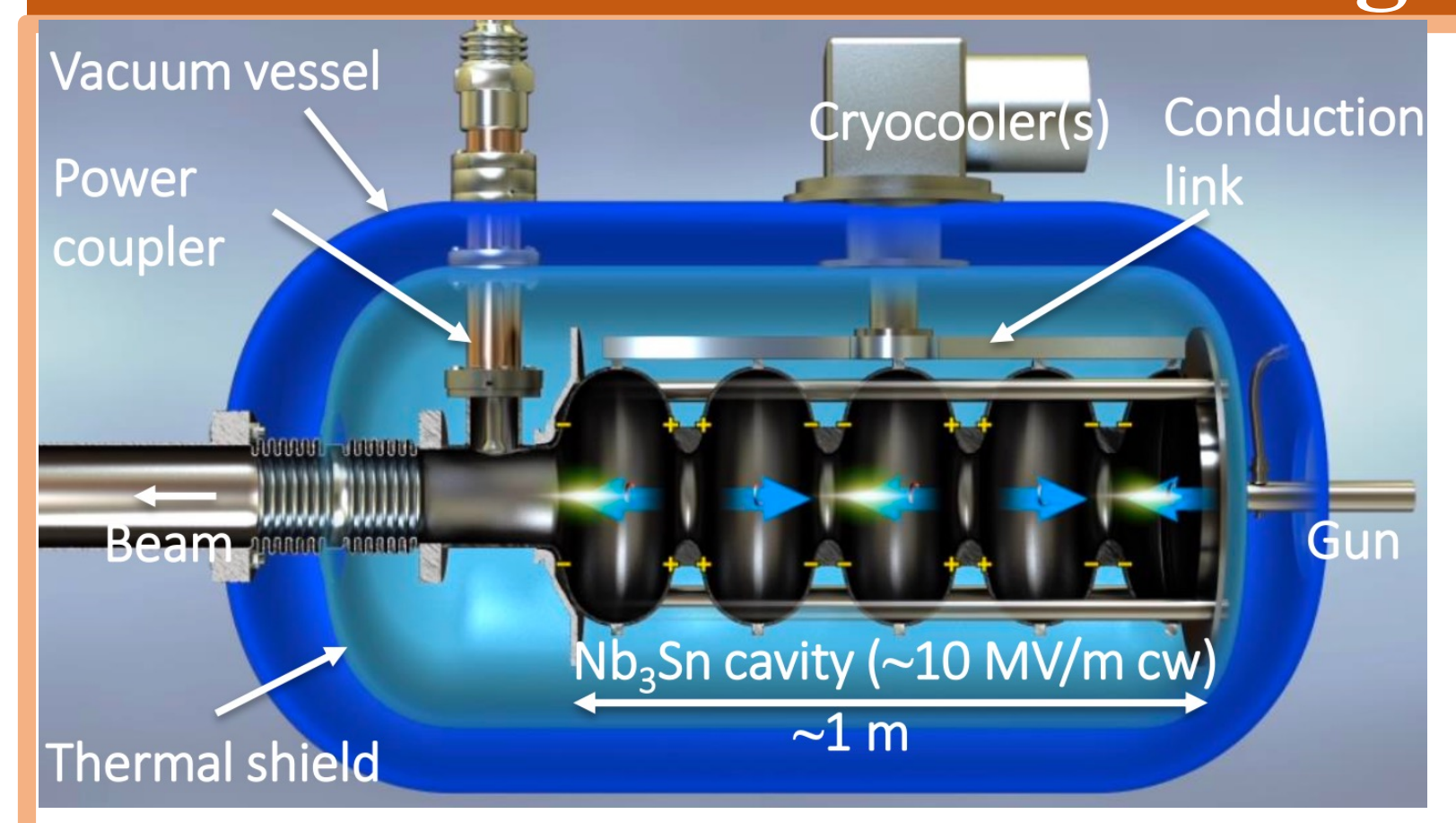
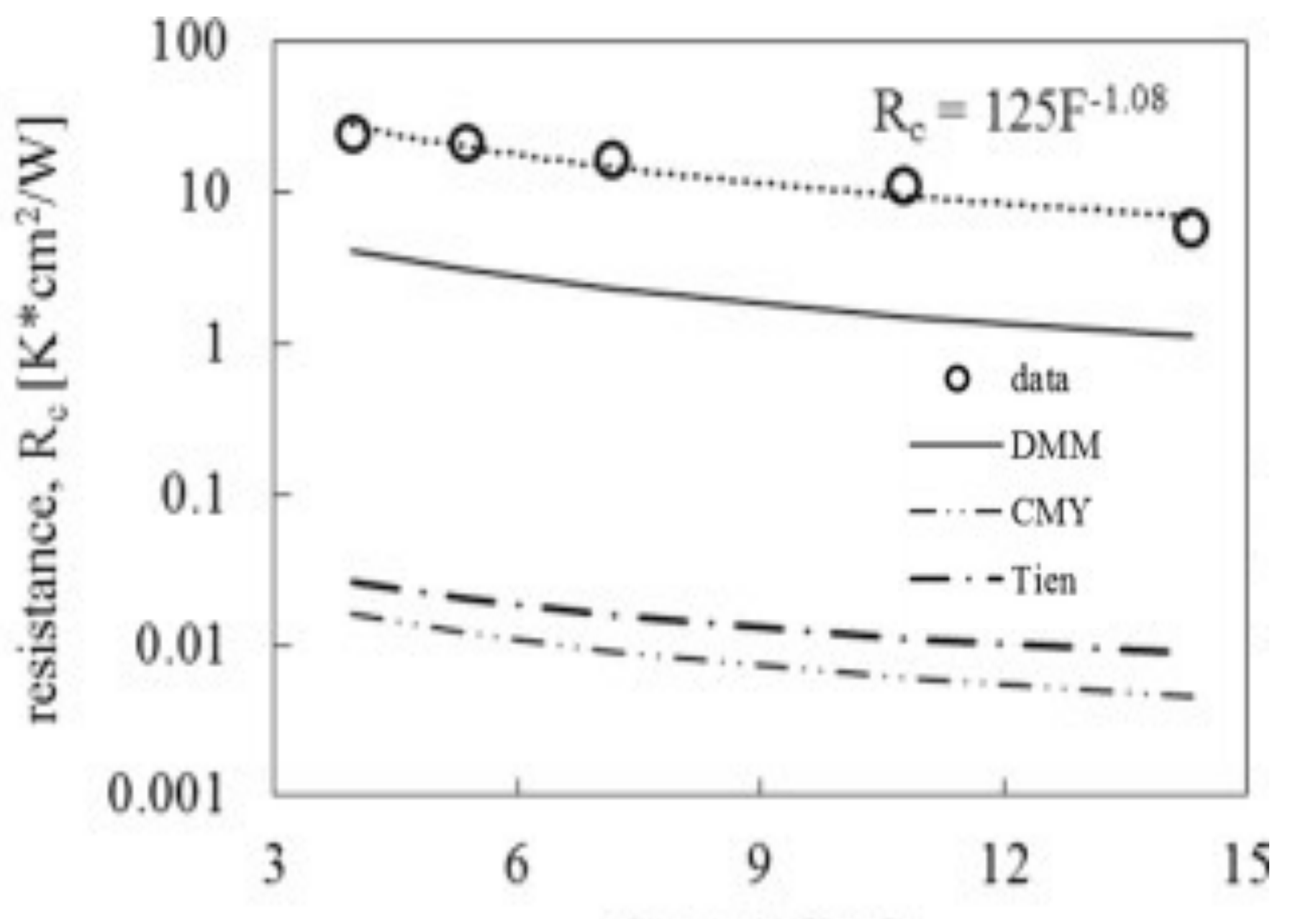
## Abstract

Cryocooler-based conduction cooling has gained traction in replacing liquid He baths for cooling in applications such as superconducting radiofrequency cavities. One of the primary governing factors in conduction cooling is thermal contact resistance ($R_c$) between two different metals, which, for example, varies from $10^{-4}$ to $10^{-3}$ m$^2$K/W near 4 K for a bolting force of 3 to 10 kN between high-purity aluminum and niobium. However, the measured $R_c$ is far from the intrinsic $R_c$ expected of metal contact, thus leading to losses at the contact. With the present study, we aim to measure the intrinsic $R_c$ between two distinct materials using time-resolved EUV diffraction measurements. The intrinsic value will serve as a benchmark for evaluating the thermal contact's effectiveness, which is currently lacking. The sensitivity of our setup is $10^{-9}$ m$^2$K/W and surpasses the existing reported values by order of magnitudes.

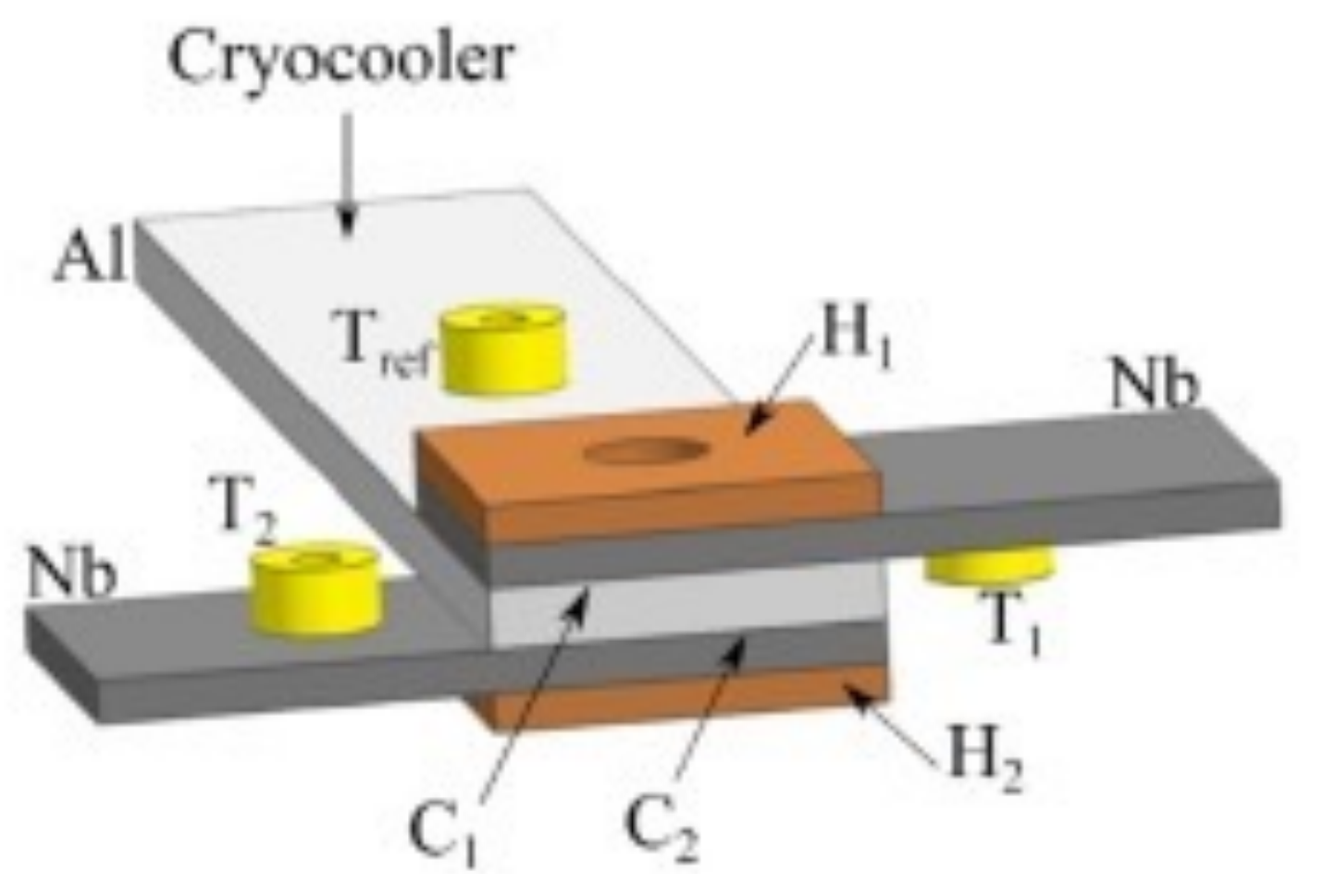
## Need for conduction cooling and why measure contact resistance



Conduction-cooled SRF accelerator [1]



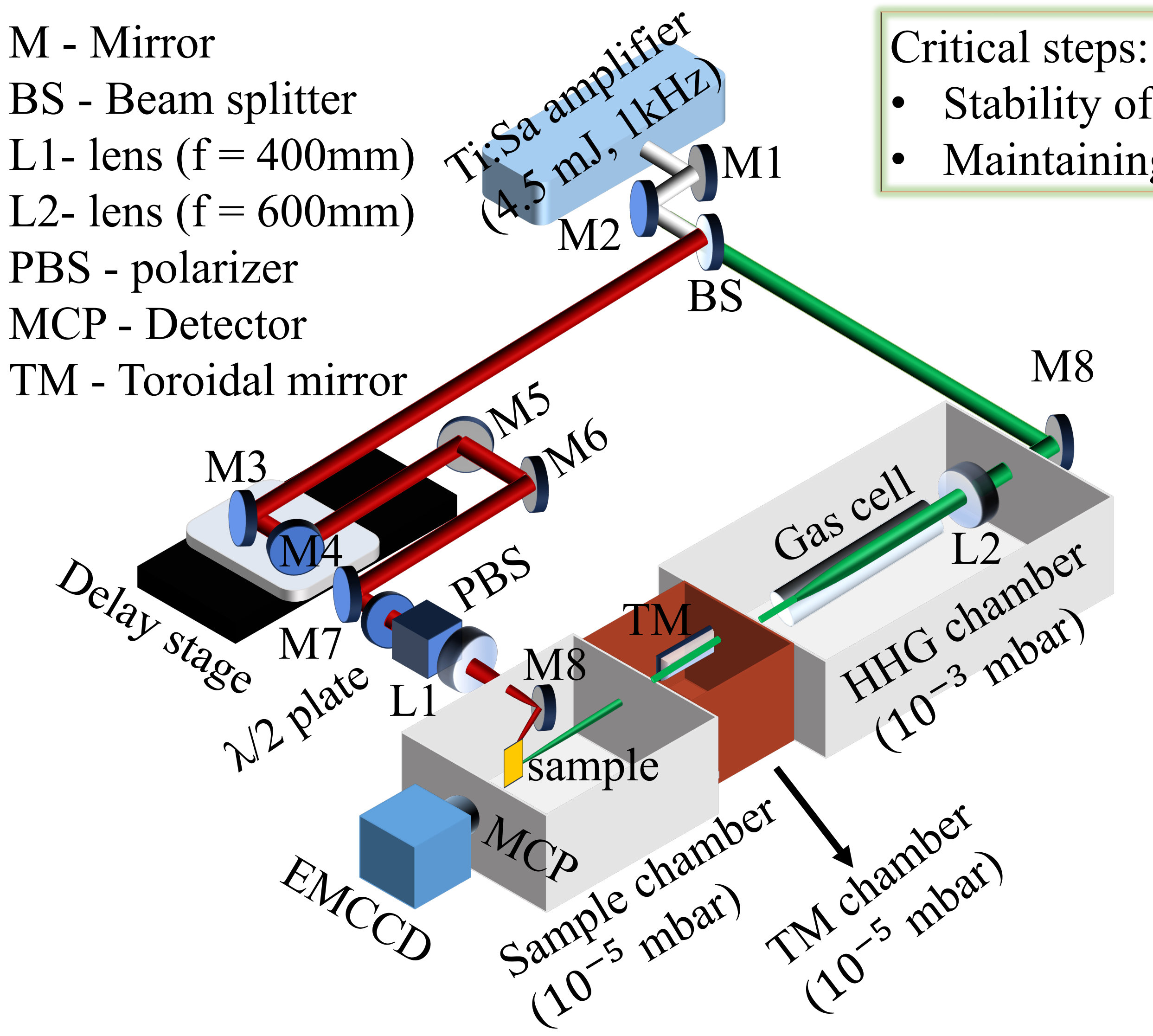
$R_c$ values between Al and Nb [2]



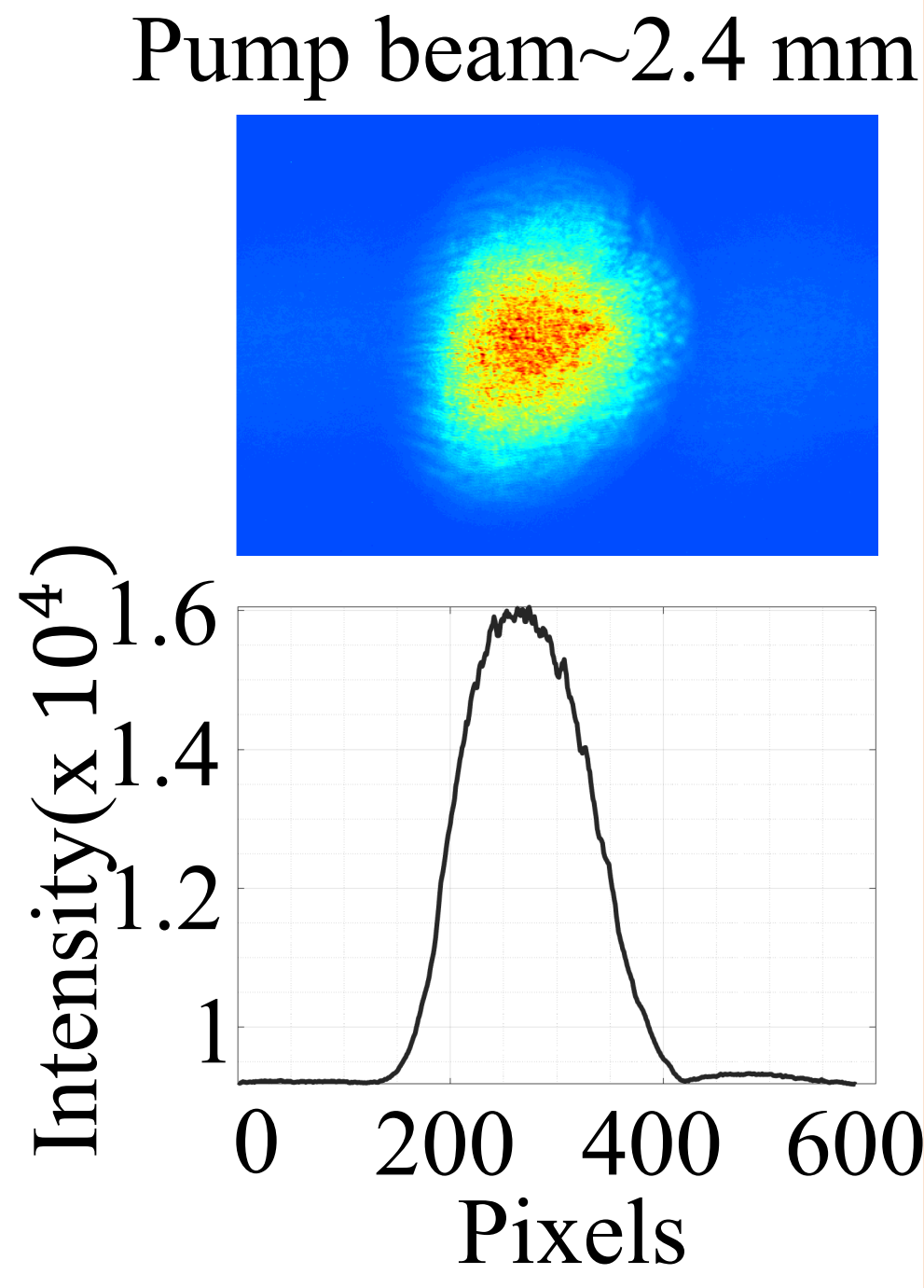
$R_c$ measurement between Al and Nb [2]

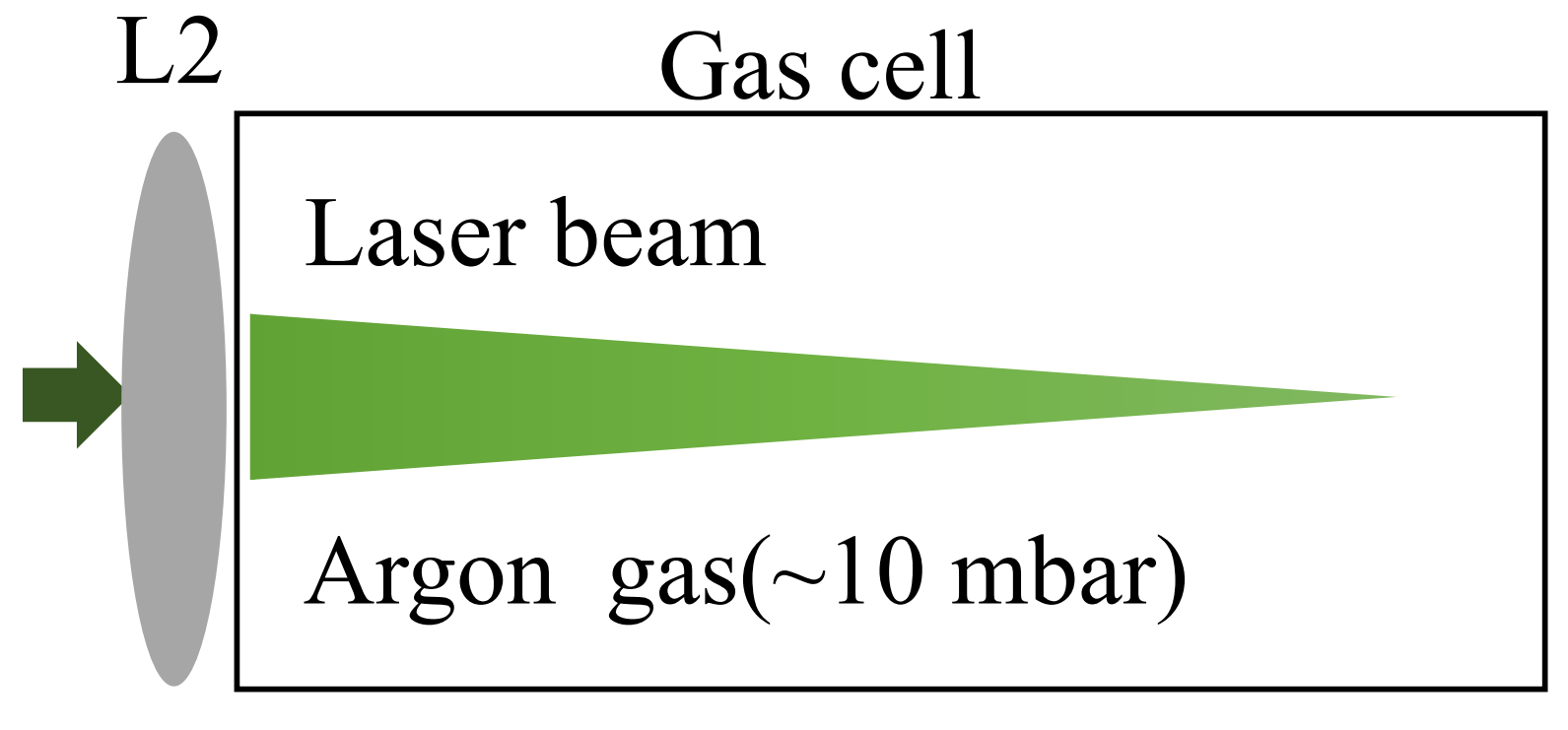
- Intrinsic $R_c$ significantly lower than measured $R_c$
- Need to determine the effectiveness of contact to identify scope of improvement

## Experimental setup: NIR pump-XUV probe

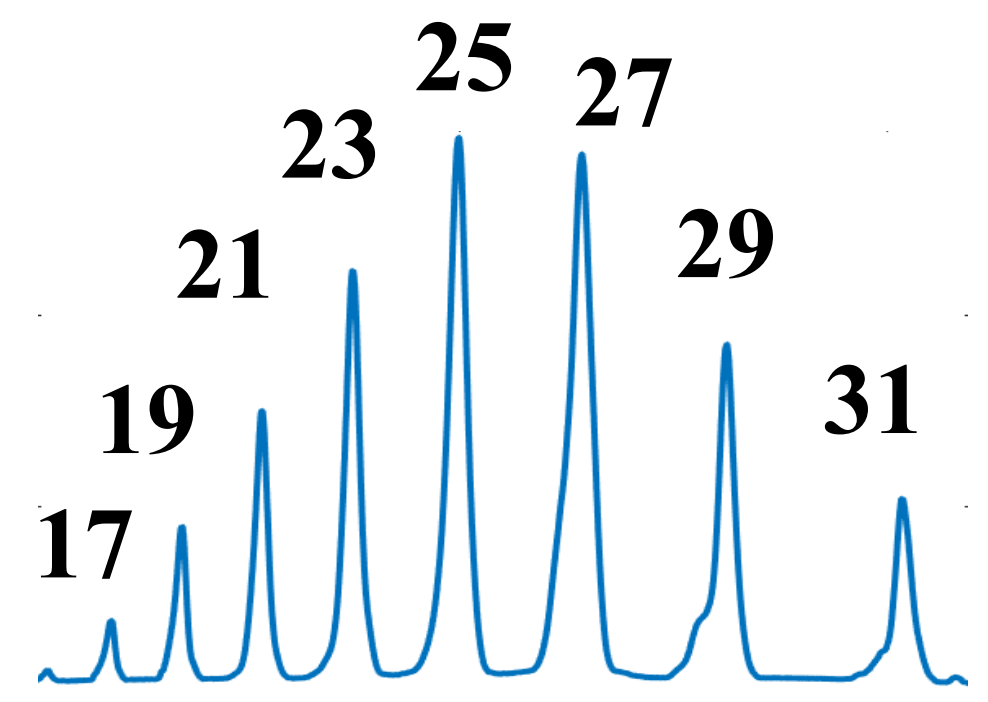

M - Mirror
BS - Beam splitter
L1- lens (f = 400mm)
L2- lens (f = 600mm)
PBS - polarizer
MCP - Detector
TM - Toroidal mirror

Critical steps:
- Stability of HHG beam
- Maintaining beam drift for hours



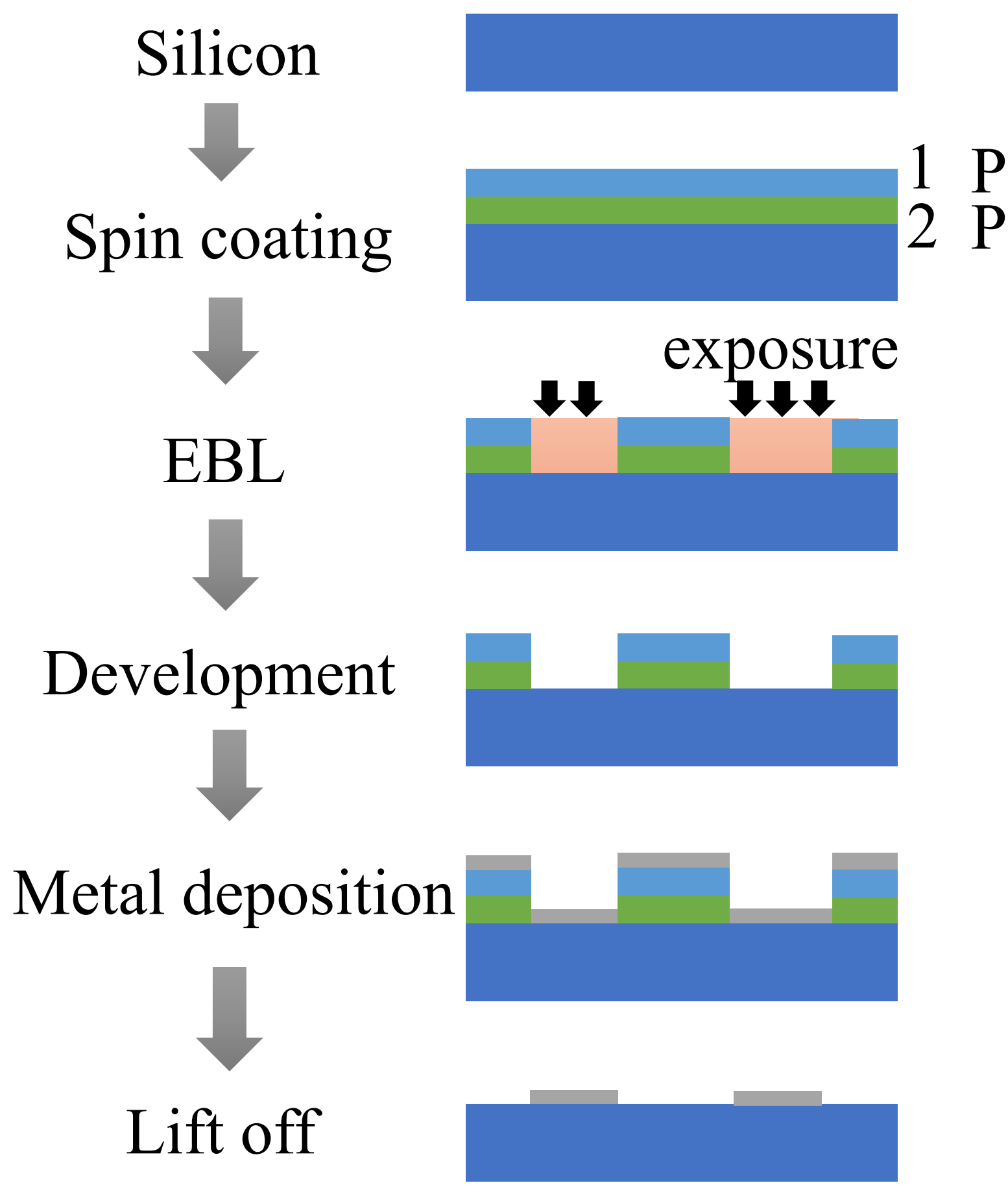


Focusing of laser beam inside HHG chamber

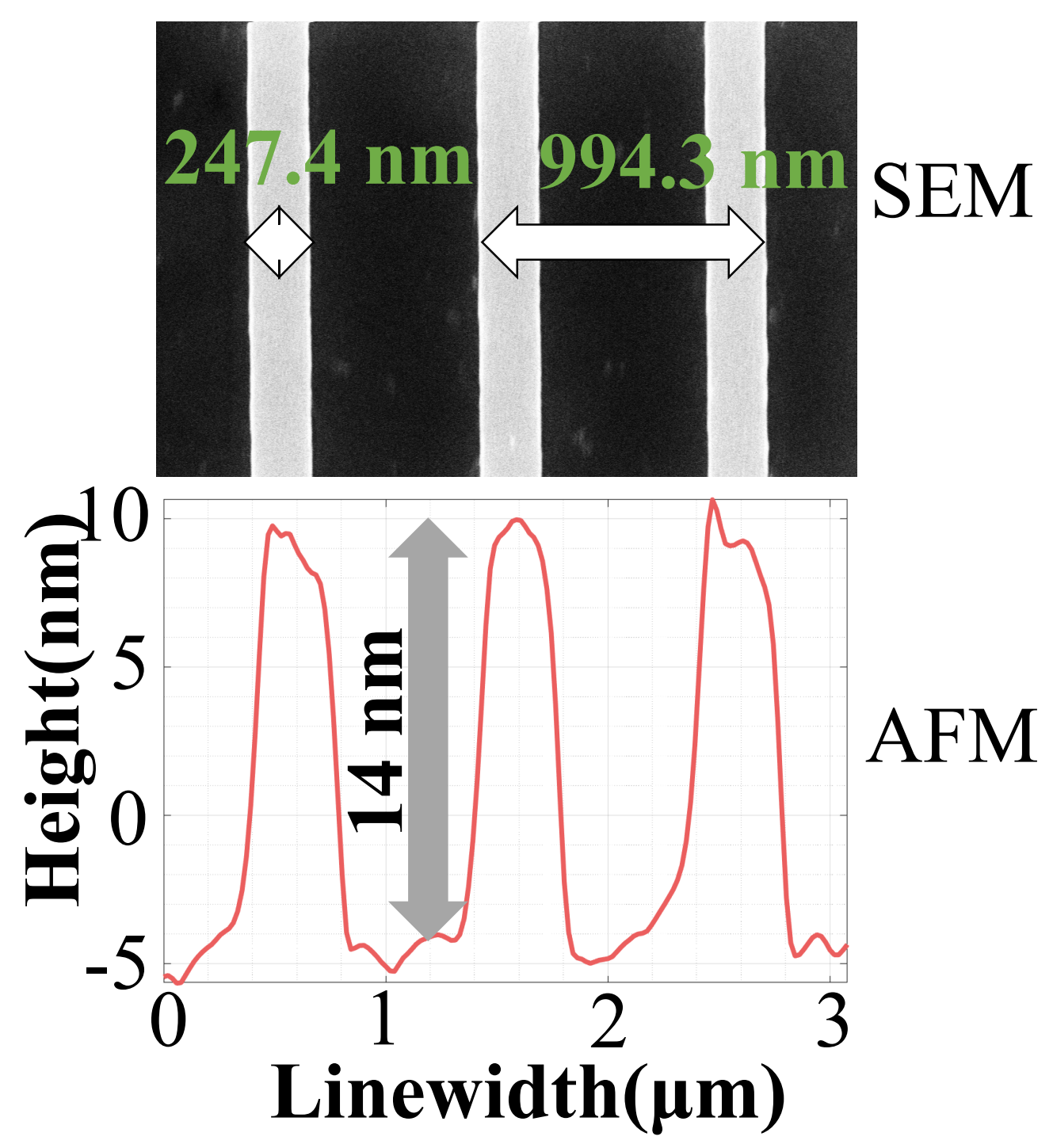


Measured HHG spectrum with less than 1% rms stability

## Sample fabrication

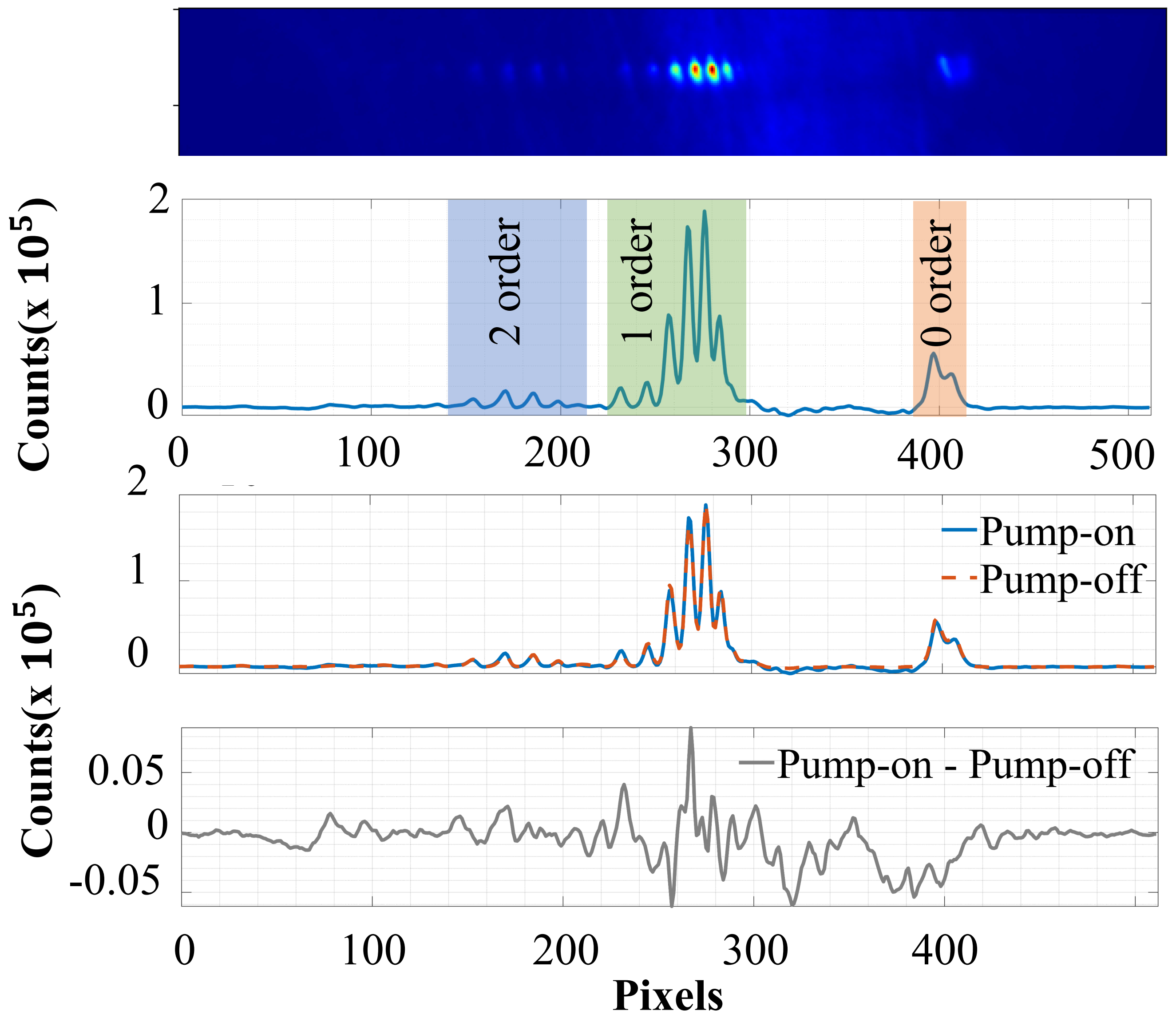


Steps for Fabrication



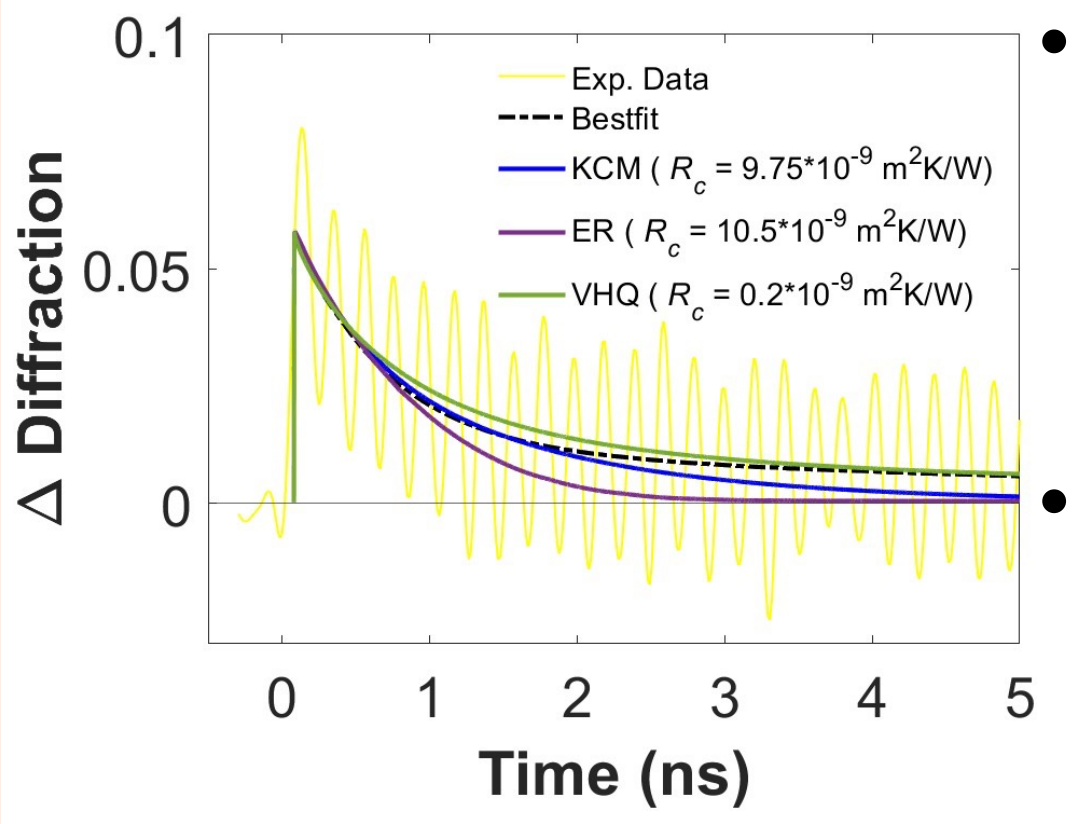
Characterization of the sample

## Raw measurements



Data extraction using MCP and EMCCD

## Conclusion

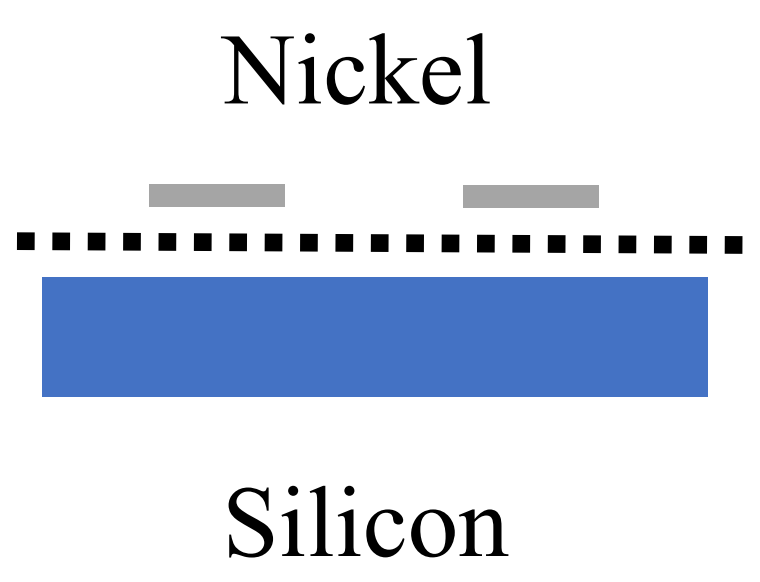


- Our experiments provide unprecedented high sensitivity in $R_c$ (~$10^{-9}$ m$^2$K/W) that can serve to classify effectiveness of contacts
- Potential strategies to decrease $R_c$ can further improve the efficiency of conduction-cooled SRF cavity

## Coupled thermo-mechanical and Fresnel diffraction modeling

$$\nabla.\left(c:\ \nabla(u-\alpha\Delta T_P)\right)=\rho\frac{\partial^2 u}{\partial t^2}$$

$$\rho C_P\frac{\partial T}{\partial t}+\rho C_P\boldsymbol{u}.\nabla T=\nabla.(K_{Ni}\nabla T)+Q$$



$$\nabla.\left(c:\ \nabla(u-\alpha\Delta T_s)\right)=\rho\frac{\partial^2 u}{\partial t^2}\quad C_s\frac{\partial T_s}{\partial t}+\rho C_s\boldsymbol{u}.\nabla T_s=\nabla.q$$

KCM [3] :

$$\tau\frac{\partial q}{\partial t}+q+k_{Si}\nabla T_s=l^2(\nabla^2 q+\alpha_1\nabla\nabla.q)$$

$$(T_p-T_s)=-R_c q.n+\frac{1}{\gamma^{Si}}(\beta\nabla.q-\nabla q:X)$$

Effective resistivity [4]: $q+k_{Si}\nabla T_s=0 \Rightarrow \frac{T_P-T_s}{R_{c,eff}}=q$

Viscous heat equations [5]:

$$C\frac{\partial T}{\partial t}+\sum_{i,j=1}^{3}W_{0j}^{1}\sqrt{\bar{T}A^jC}\frac{\partial u_d{}^j}{\partial r^i}-\sum_{i,j=1}^{3}k^{i,j}\frac{\partial^2 T}{\partial r^i\partial r^j}=0$$

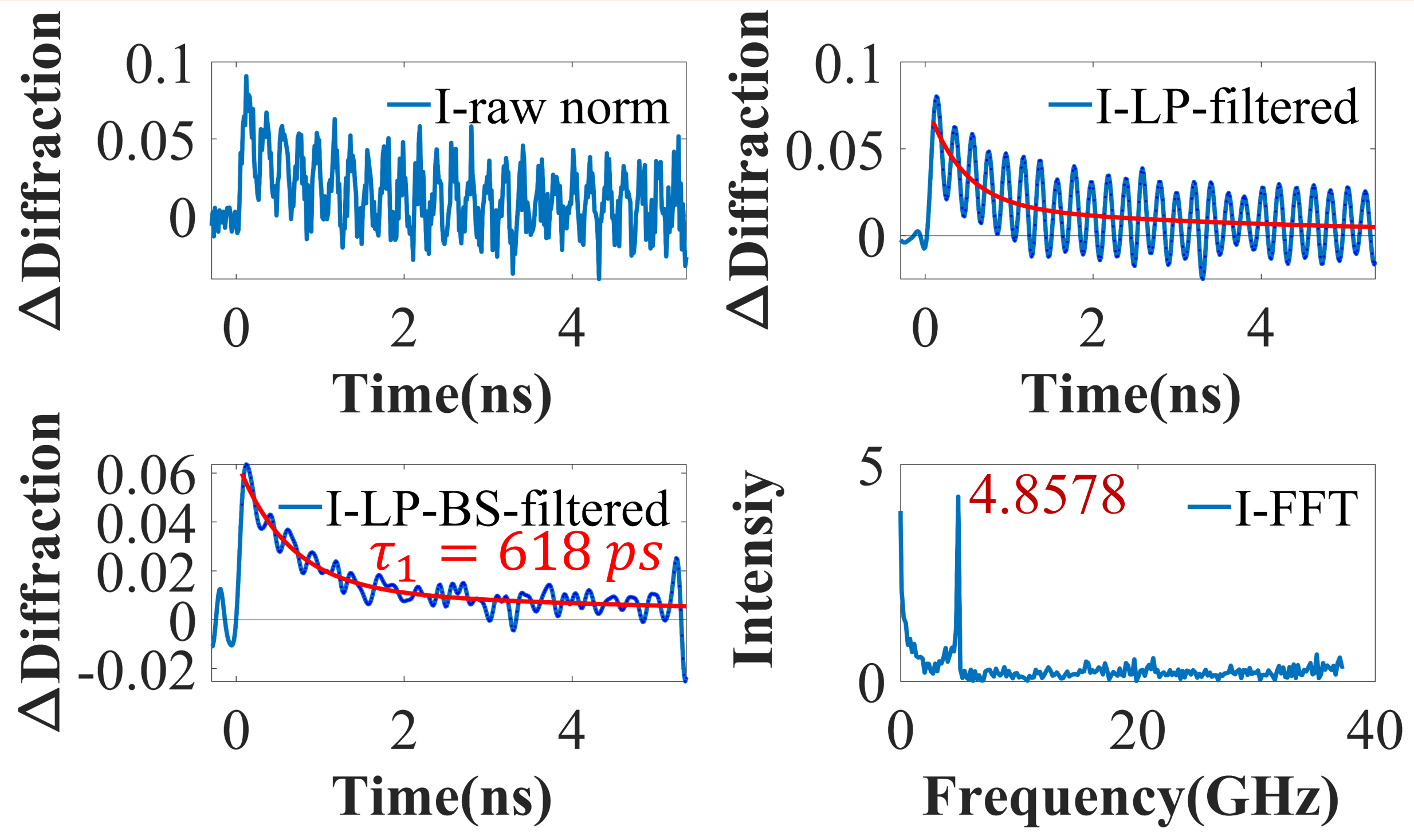
$$A^i\frac{\partial u_d{}^i}{\partial t}+\sqrt{\frac{CA^i}{\bar{T}}}\sum_{j=1}^{3}W_{i0}^{j}\frac{\partial T}{\partial r^j}-\sum_{j,k,l=1}^{3}\mu^{ijkl}\frac{\partial^2 u_d{}^k}{\partial r^j\partial r^i}=-\sum_{j=1}^{3}\sqrt{A^iA^j}D_U^{ij}u_d{}^j$$

where, $T_P, T_s, T$: phononic temperature , $u$: displacement, $c$: elasticity tensor, $k$: bulk thermal conductivity, $Q$: heat source term, $C_P$ , $C_s$ ,$C$: heat capacity, $\alpha$: thermal expansion coefficient,$\alpha_1$: constant, $\tau$: decay constant, $l$ :non-local length, $R_c$, $R_{c,eff}$: contact resistivity, $W_{0j}^1$: velocity tensor, $u_d$: drift velocity
$\bar{T}$: reference temperature, $A^j$: specific momentum,
$D_U^{ij}$: momentum dissipation rate, $\mu^{ijkl}$: thermal viscosity tensor

Fresnel diffraction

$$E(x,y,z)=\frac{e^{ikz}}{i\lambda z}\int\int_{-\infty}^{\infty}E(x',y',0)e^{\frac{ik}{2z}[(x-x')^2+(y-y')^2]}dx'dy'$$

## Data analysis and Results



Filtering and fitting of the raw data to extract decay time and $R_c$

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