Fabrication and Measurements of Vanadium Superconducting Resonators on Silicon Wafers

Yuichi Fujita
Yoshiro Urade, Yuki Hibino, Manabu Tsujimoto, Kunihiro Inomata, and Wataru Mizubayashi

National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Umezono, Tsukuba, Japan

y.fujita@aist.go.jp

Aiming to build large-scale quantum processors, low-loss material systems have been developed to improve the coherence of superconducting qubits [1]. To mitigate material loss, it is essential to verify the correlation between crystallinity of superconducting films and the losses because structurally ordered films may offer lower losses than disordered ones [1,2]. This work explores vanadium (V) as a potential material for producing well-structured films on silicon (Si) wafers. We deposited a 200-nm-thick V film on a buffered-HF-treated Si(100) wafer by using DC sputtering method with an argon gas pressure of ~0.04 Pa. Reciprocal lattice mapping (RSM) confirmed that the V film had highly (110)-oriented structure as shown in Fig.1. We microfabricated and measured the coplanar waveguide $\lambda/4$ resonators based on the V film on the Si wafer with resonance frequencies of 10-11 GHz [3]. To examine the losses at the V surface, we also prepared the resonators based on a V film with a tantalum (Ta) capping layer (5 nm). We measured the transmission coefficient (S_{21}) and obtained the internal quality factor (Q_{int}) at various averaged photon numbers ($\langle n_{ph} \rangle$) from the observed S_{21} [1,4]. Furthermore, by analyzing Q_{int} vs $\langle n_{ph} \rangle$ [1], we obtained the value of non-two-level-system (non-TLS) loss (δ_{other}) for the resonator. Figure 2 shows Q_{int} as functions of $\langle n_{ph} \rangle$, obtained from the observed S_{21}, representatively shown in the inset of Fig.2. The values of Q_{int} at $\langle n_{ph} \rangle = 1$ and δ_{other} for the resonator with (without) the Ta capping layer were obtained as 9.6×10^5 (4.8×10^5) and 0.7×10^{-6} (2.0×10^{-6}), respectively. The resonator with the Ta capping layer had a larger Q_{int} at $\langle n_{ph} \rangle = 1$ and smaller δ_{other}, suggesting that the presence of the Ta capping layer enhances Q_{int} by mitigating losses from the V surface that originate from the non-TLS loss sources. This paper was based on results obtained from a project, JPNP16007, commissioned by the New Energy and Industrial Technology Development Organization (NEDO), Japan.

References

[1] C. R. H. McRae *et al.*, Rev. Sci. Instrum. 91, 091101 (2020)

[2] R. Gao *et al.*, Phys. Rev. Materials 6, 036202 (2022)

[3] Y. Urade *et al.*, APL Mater. 12, 021132 (2024)

[4] K. S. Khalil *et al.*, J. Appl. Phys. 111, 054510 (2012)

Figures

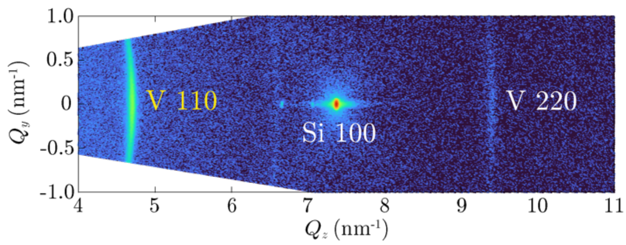

Figure 1: RSM of the Si(100)/V(200 nm) structure.

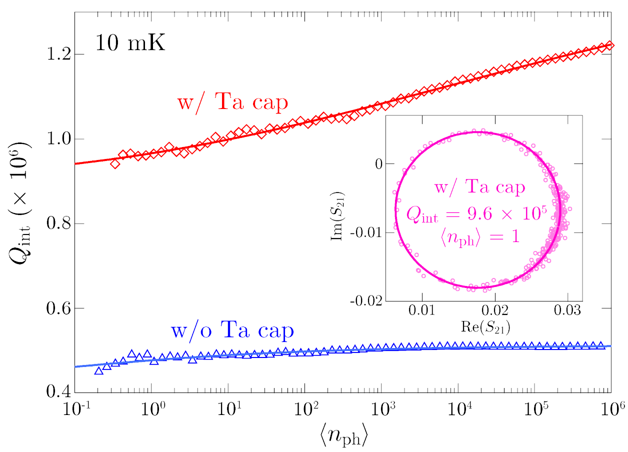

Figure 2: $\langle n_{ph} \rangle$ dependence of Q_{int}. The inset shows an observed S_{21} spectrum at $\langle n_{ph} \rangle = 1$ in the resonator with the Ta capping layer.