Tungsten Silicide Films for Superconducting Resonators

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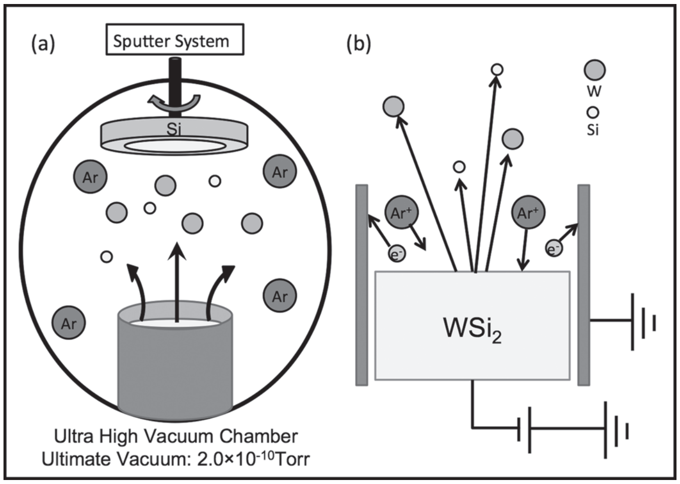

Figure 1: Schematic illustration of (a) the way to deposit WSi_2, and (b) the way to sputter WSi_2.

Abstract:

We have started to examine tungsten silicide (WSi_2) as a possible candidate for microwave kinetic inductance detectors (MKIDs). WSi_2 for MKIDs has to have a suitable critical temperature (T_c) that is uniform over the wafer and very low (about 1-2K), and the films should have low stress. We explored the parameter space of the WSi_2 sputter deposition to find the ideal condition. We used the sputter system located in the cleanroom in order to deposit WSi_2 on silicon (Si) wafers in ultra-high vacuum. We deposited WSi_2 at base pressures below 1.0×10^{-8} Torr on rotating Si wafer (30 rpm) by creating an argon (Ar) plasma above the WSi_2 target. We measured the thickness by using scanning electron microscopy (SEM), and the T_c and the room temperature resistivity of our deposited WSi_2 films.

Introduction:

MKIDs are promising for astronomy because these detectors provide highly multiplexed arrays of detectors that can be configured to operate from the sub-millimeter to the x-ray regime [1]. These detectors allow us to determine the energy and arrival time of individual photons. The applications of this technology ranges from detecting earth-like planets around nearby stars to untangling the emission mechanisms of pulsars.

In its simplest form, a MKID consists of a thin film superconductor patterned into a resonator [1]. When a photon is absorbed in the superconductor, it breaks Cooper pairs, creating an excess of non-equilibrium quasiparticles [1]. This excess of quasiparticles alters the complex surface impedance of the superconductor, raising the kinetic inductance and surface resistance, which causes the resonance feature to shift to a lower frequency and broaden [1]. MKIDs are generally operated at temperatures well below the superconducting transition in order to minimize the thermal population of quasiparticles. To achieve good sensitivity, the T_c of MKID resonator metal (WSi_2) needs to be around 1-2K. In this instance, the target value of T_c is 1-2K. It is known that T_c is different depending on the Si content of WSi_2. Therefore the T_c of sputtered thin film WSi_2 can be controlled by deposition conditions.

Experimental Procedure:

The experiment was conducted in an ultra high vacuum chamber. We sputtered a high purity WSi_2 target by creating DC plasma above the WSi_2 in Ar atmosphere. Si wafer was rotated during experiment so that we could deposit homogeneous WSi_2 over a 3-inch wafer. Varying the parameter space of the WSi_2 sputter deposition (power, Ar pressure, Ar flow, coat time) allowed to control the W:Si ratio. We measured the thickness by using SEM, and the T_c and the room temperature resistivity of our deposited WSi_2 films.

Results and Conclusions:

First, we prepared three pieces from different locations of a 3-inch wafer after deposition to measure the film thickness and T_c, so that we could verify that there are not any morphological differences of WSi_2 over a 3-inch wafer; shown in Figure 2. Position means the distance from center of the wafer. From this data, we could show that T_c did not change depending on the position of the wafer. So, we do not have to worry about the homogeneity of WSi_2.

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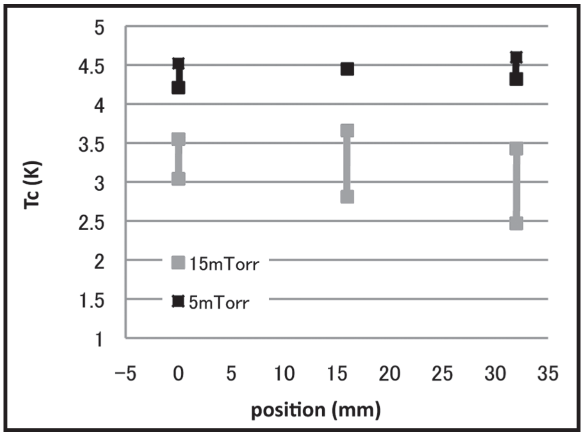

Figure 2: T_c depending on position of the wafer. (Ar flow: 20 sccm, power: 120W).

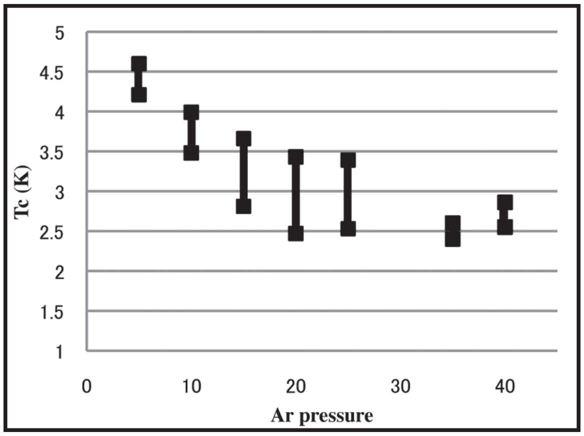

Figure 3: T_c depending on Ar pressure. (Ar flow: 20 sccm, power: 120W).

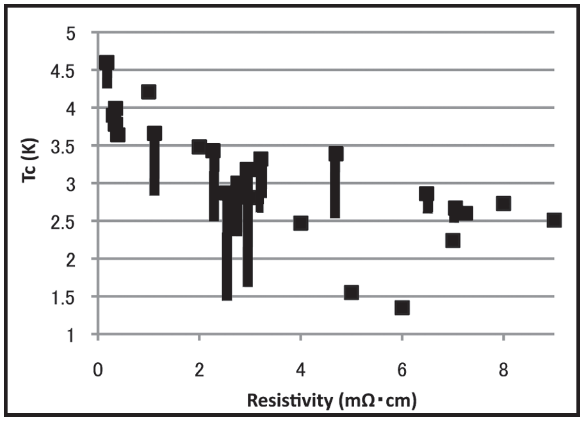

Figure 4: T_c relationship with resistivity. Resistivity was calculated with surface resistivity and thickness.

Figure 3 shows that by varying the Ar pressure T_c of WSi_2 can be minimized. It is guessed that high Ar pressure results in a low Si content in WSi_2, because Si is lighter than W and, therefore, tends to be scattered by Ar atom and ion more than W. T_c of WSi_2 depends on stoichiometry and was mapped by Kondo [2] for transition temperatures above 1.9K. For both very small and large Si concentrations, the T_c falls below 1.9K, but for Si atomic percentages ranging from ~ 7% up to ~ 60%, the T_c rapidly rises up to 5K, with a maximum T_c for Si atomic percentages between 20 and 40%. We guess that higher the Ar pressure becomes, the lower the Si content becomes, but there is a limit a parameter of Ar pressure to minimize Si content. We also got several data of T_c depending on Ar flow, power and coat time but those are not sufficient to discuss.

By measuring resistivity at room temperature, we intended to predict T_c. We wanted to do that because it takes many hours to measure T_c. From previous research, it is known that high resistivity implies low T_c. Figure 4 shows the relationship between T_c and the room temperature resistivity. From the graph, the sample has high resistivity tends to get low T_c. We guessed it is possible to predict if T_c is high or low by room temperature resistivity.

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References:

[1] T. Cecil, A. Miceli, O. Quaranta, C. Liu, D. Rosenmann, S. McHugh, and B. Mazin, Appl. Phys. Lett. 101, 032601 (2012).

[2] S. Kondo, J. Mater. Res. 7, 853-860 (1991).