Design of Near Infrared and Visible Kinetic Inductance Detectors using MIM Capacitance

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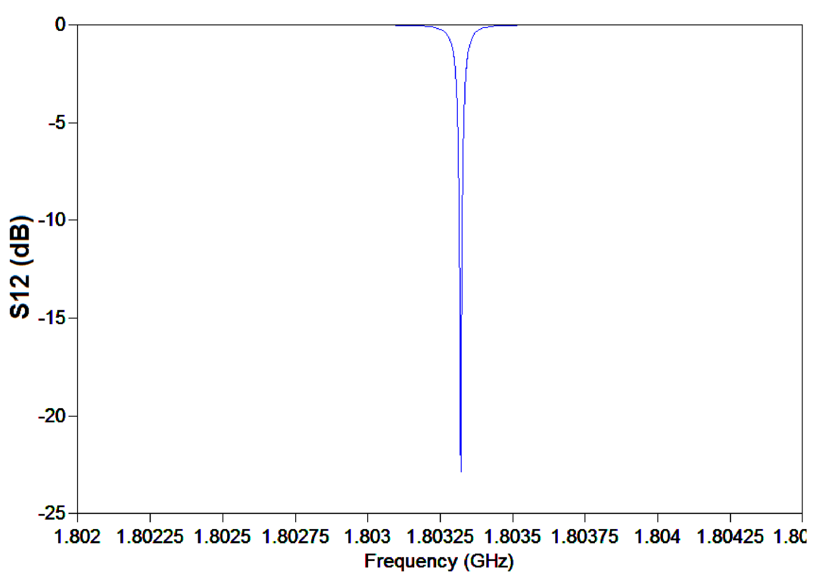
Introduction

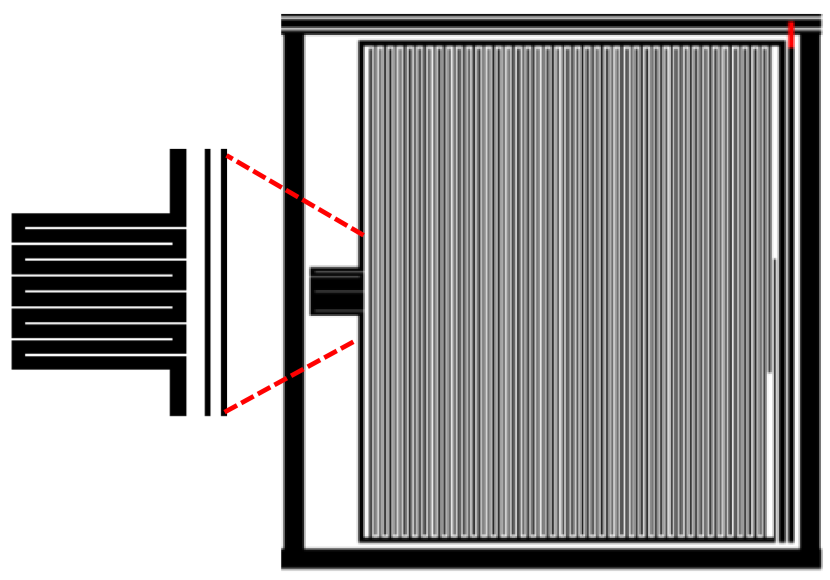
In order to efficiently meet with the requirements of some astronomical applications, the KID size should be diminished typically from hundreds to a few tens of μm. For example the optical Lumped-element KID developed by Meeker et al [1] has a size ≈130×130 μm for an operating frequency around 4 GHz. This pixel can easily reach a size of 300×300 μm for an operating frequency below 2 GHz where the interdigital capacitance take up to 90 % of the overall pixel size. We propose to replace the interdigital capacitor by a MIM (Metal-Insulator-Metal) capacitor which has the advantage of presenting a larger capacitance value within a much smaller space. The pixel will occupy a space of typically 100x85 μm which is 9 times less than a typical pixel size using the interdigital capacitor operating at the same frequency, below 2 GHz.

LEKID with an interdigital capacitance

- An interdigital capacitance-based LEKID designed to operate in near IR and visible can feature large sizes [1].
- As an example, in order to simulate a TiN-based LEKID resonating within 1-2 GHz, using typical TiN parameters of :
  - 60 nm-thick and T_c ~ 1K,
  - L_{kin}=24 pH/□,
  - ρ_n =110 μΩ cm,

the overall size of an LEKID is typically 300x300 μm where the interdigital capacitance of 260x300 μm is 1.75 pF.

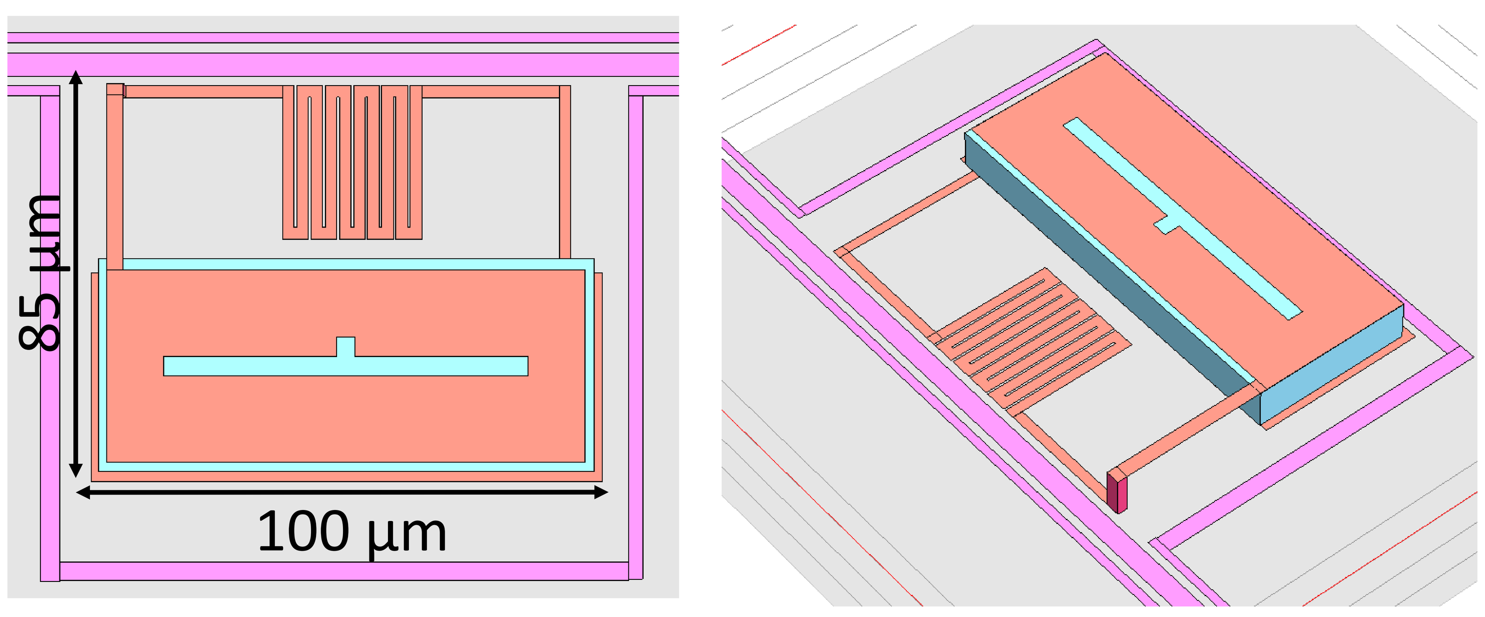




Simulated frequency response of the interdigital capacitance-based LEKID.

LEKID using a MIM capacitance

- The interdigital capacitance is replaced by a parallel plate capacitance MIM (Metal-Isolator-Metal). As an isolator, we choose the silicon (Si) and the aluminum nitride (AlN), with a thickness of $t_{dielectric}$=100 nm:



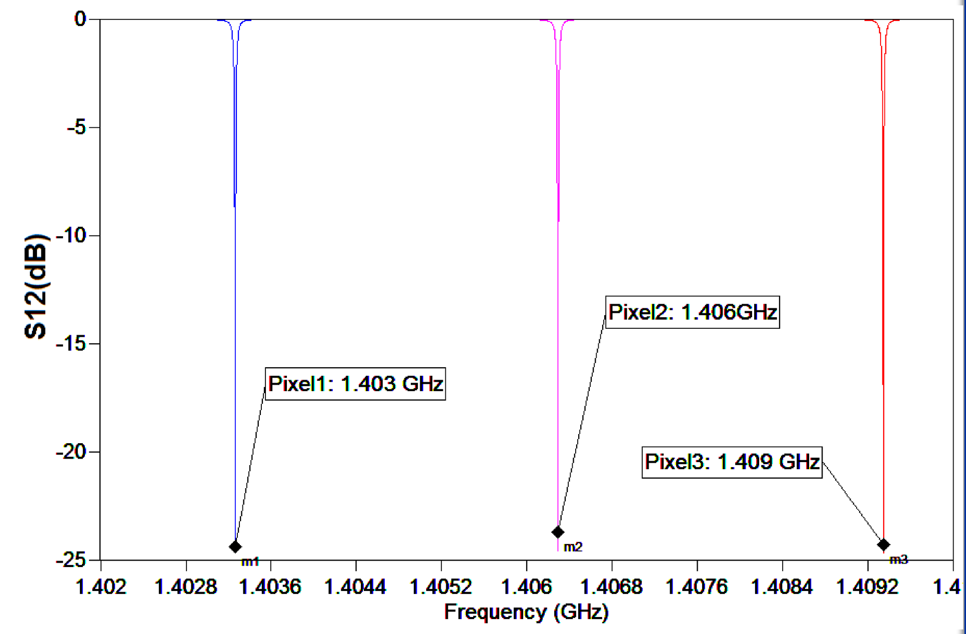
MIM-based LEKID design.

Size of the capacitance (μm)	Capacitance (pF)		
	Interdigital capacitance	MIM capacitance	
		Si ε_r =11	AlN ε_r =8.6
100 x 40	0.08	3.89	3.04
100 x 130	0.19	12.65	9.9
260 x 300	1.75	75.9	59.35

MIM capacitor allows to achieve large capacitance values and a significant gain of space compared to the interdigital capacitor-based design.

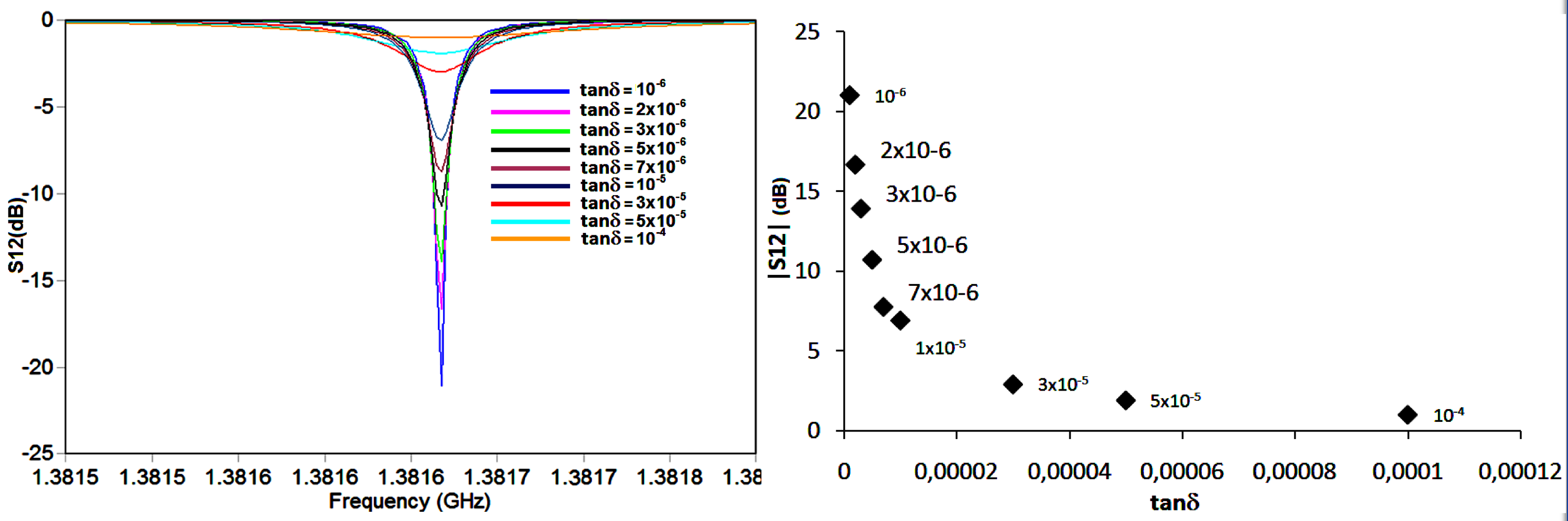
- Using 100x40 μm AlN-based MIM capacitor, we can achieve LEKIDs resonating at around f_0=1.4GHz:

The Change of MIM capacitor value from one resonator to another, is obtained by removing 4×4 μm squares from the upper electrode.



Dielectrics losses in the MIM capacitor

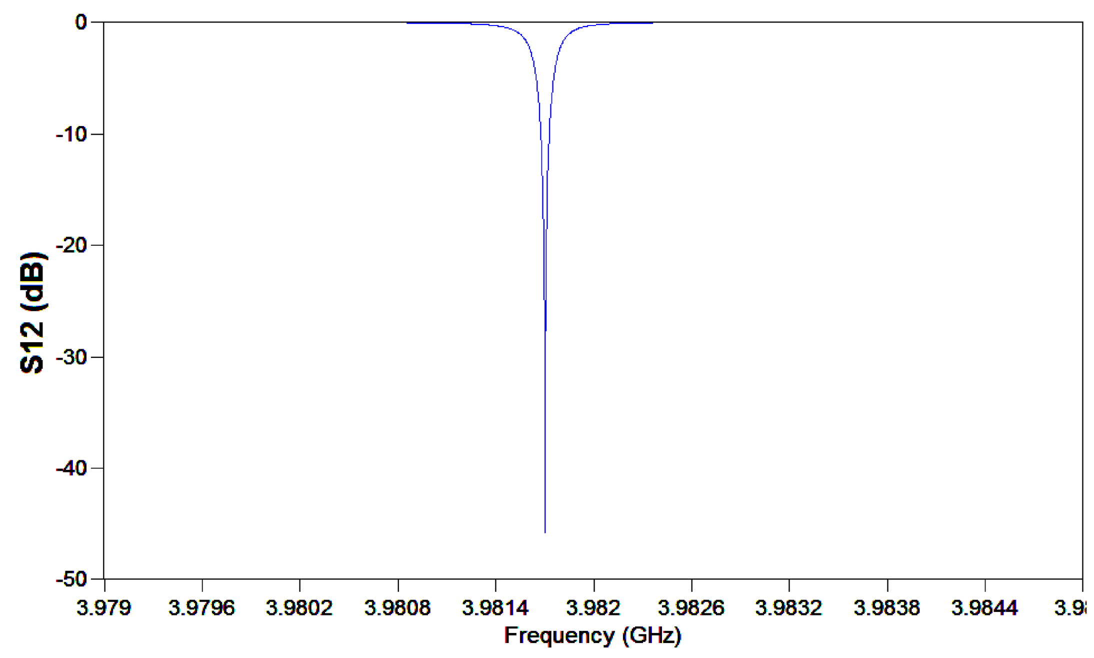
- However, silicon, especially the amorphous films, can feature high dielectric losses due to the two-level-systems (TLS). For example, as reported elsewhere [2], at 100 mK, the sputtered Si has a tanδ ≈ 5 x10^{-4}.



SONNET simulation of a MIM-based LEKID with ε_r =8.6 and t=100 nm.

- The dielectric losses must be ≤10^{-5}.
- Solution : - employ the monocrystalline silicon using a SOI wafer to define the MIM capacitance (tanδ=5 x10^{-6}) [3], or
  - replace the dielectric layer by the air [4].

SONNET simulation of the MIM-based LEKID (100 x40 μm capacitance size) with t_{air}=100 nm.



- The resonance becomes deeper and shifts to higher frequencies.

Conclusion

The LEKIDs with MIM capacitance would considerably reduce the size of the pixel by a ratio of 10. This allows to achieve a better fill factor compared to the interdigital capacitor-based LEKID. The dielectric losses which make this approach unsuitable can be solved by the use of monocrystalline silicon which can feature dielectric losses around 5X10^{-6} [3]. SOI wafers will be used to define MIM capacitors [3]. Ideally, the dielectric should be eliminated and replaced by the vacuum. However, this is very hard to implement as the gap between electrodes must be lower than 300 nm. This first step will be followed in the near future by the nano-fabrication of these detectors and by cryogenic and photometric measurements.

References

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3. S. J. Weber. et al. Appl.Phys. Lett. 98, 172510 (2011).
4. Katarina Cicak. Et al. Appl. Phys. Lett. 96, 093502 (2010).